

Article

Disposal of Personal Protective Equipment during the COVID-19 Pandemic Is a Challenge for Waste Collection Companies and Society: A Case Study in Poland

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Abstract: One of the social measures applied during the COVID-19 pandemic has been the use of personal protective equipment (PPE)—face masks and gloves. As a result, this waste category has expanded enormously. This study investigates waste management issues from multiple perspectives, including local governments, waste collection companies, and individual citizens in Poland using a telephone survey for institutions and an online questionnaire for individuals. The results of this study show that approximately 80% of local governments in the Silesian region have applied special measures for handling and collection of waste PPE. Only 13% of waste collection companies have applied special collection schedules for the waste generated at quarantine collection points due to the high costs of changing collection schedules, providing additional vehicles, and paying for more labor. The information campaigns focusing on new methods of PPE waste collection have been difficult to introduce on a large scale, and citizens need better information regarding how to handle and dispose of waste PPE. Results indicated the most helpful method in supporting waste PPE collection would be automatic PPE dispensers with waste PPE collection options and waste bags of a designated color. The respondents identified waste PPE pollution of the environment as an issue and the necessity for proper recovery of this waste stream.

Keywords: personal protective equipment; disposal of face masks and gloves; COVID-19; waste collection; medical waste

1. Introduction

In March 2020, the World Health Organization announced that the outbreak of COVID-19, caused by the SARS-CoV-2 virus, had reached pandemic status [1]. Governments worldwide have faced a situation unprecedented in the recent history of civilization. There has been increased uncertainty and concern for public health around the world as governments have introduced special measures to prevent the spread of the disease. The regulations of health authorities have become the most important guidelines by imposing various restrictions on our daily activities [2]. Regardless of the cause of the appearance of the virus and other aspects of its epidemiology, one of the events following the declaration of the pandemic state was the introduction of potentially effective methods to limit the spread of the virus by individuals in a population [3]. In numerous countries worldwide, the use of personal protective equipment (PPE), face-covering masks and gloves in particular [4], has been required in public. New products have appeared for common and everyday use, which were previously used

to a very limited extent in specific locations, such as public health facilities, hospitals, clinics, nursing homes, and in specific industries (i.e., electronic equipment manufacturing or food processing) [5,6].

The new PPE products are considered disposable after brief use. As a consequence, a new waste category has appeared. The mandatory use of PPE has been extended to many locations such as public transport, shops, supermarkets, or medical centers. In many countries, this requirement has also been applied to open spaces. This use has resulted in a significantly growing volume of disposed PPE items. In the European Union (EU), waste PPE can be classified as medical, separated, or mixed waste depending on the source of its generation [7]. Due to concerns of possible virus transmission from the surfaces of face masks or gloves and the increasingly common use of PPE in society, management of PPE waste has emerged as a challenging task that includes legal, business, and social aspects [8,9]. Management should combine methods of storage, collection, transport, and treatment of PPE. Also, all resources containing various raw materials are subject to further recovery, including for energy generation or recycling. The natural consequence of the introduction of the common and broad use of PPE is the need to implement a system and methods of collecting this waste, which requires cooperation between local governments, waste collection companies, local institutions, and each individual in society. Proper disposal also requires additional tasks, including preparation of waste collection schedules and adequate handling of waste from households and quarantined locations, including from persons with positive SARS-CoV-2 results and medical centers [10,11].

In Poland, infection protection measures have been similar to that of other EU countries. It is necessary to fulfill public health officials' requirements, including using PPE to protect against SARS-CoV-2. After a single use, PPE becomes waste generated in households, workplaces, public transportation networks and hubs, shops, and supermarkets. Waste masks or gloves from the above sources should be disposed of in waste bins for mixed municipal waste, and different measures for the treatment of PPE are applied for the quarantined locations. Such places include locations inhabited by residents who had contact with persons infected by SARS-CoV-2, persons with COVID-19, or asymptomatic carriers of the virus [10,12]. Waste generated from these places should be qualified for municipal waste collection but considered possibly contaminated, and the PPE waste should undergo special handling and storage. Taking into consideration that the waste is originating from the sources where infected or potentially infected people reside, it is necessary to take precautions during the collection and transportation of such waste [13]. The waste management tasks for local governments include coordination of activities for monitoring persons required to isolate or in quarantine. The most important recommended elements of the waste management system for waste PPE collections in Poland are [14,15]:

- providing bags assigned with a "C" label or of a designated color,
- collecting waste at least every seven days,
- providing direct transportation from collection points to the incineration plant or treatment facility for proper treatment of the waste, and
- disinfecting the containers or waste bins.

Guidelines for healthy people and activities in public transport, shopping locations, and other social places to minimize the spread of SARS-CoV-2 include the collection of PPE in a separate box and then disposal into municipal waste containers. Additional proper collection measures include allocating specific times for waste collection and filling the bags to not more than 75% of their capacity, without compacting. Each activity associated with handling the waste requires using protective gloves.

The temporary storage of the waste PPE should be provided in the same containers as for the scheduled municipal waste collection. The requirements for the waste collection and treatment companies mandate that the COVID-19-related household waste complies with European Commission guidelines, in that it does not present a threat after nine days [11]. Residents improperly handling the waste (e.g., not entirely closing the waste bags) are required to be instructed by the waste collection company employees. The treatment of waste in the designated bags mentioned above

should be provided on automated lines in the treatment facilities. If such installations are available, the waste stream should be directed for incineration. The collection companies should prioritize waste (including PPE) pick-up from infected households. Each person handling and touching the waste should wear masks and goggles.

To investigate the key players' roles in the reverse supply chain, we have selected three target groups: local governments, waste collection companies, and regular citizens. The subject and the scope guiding this study is presented in Figure 1.

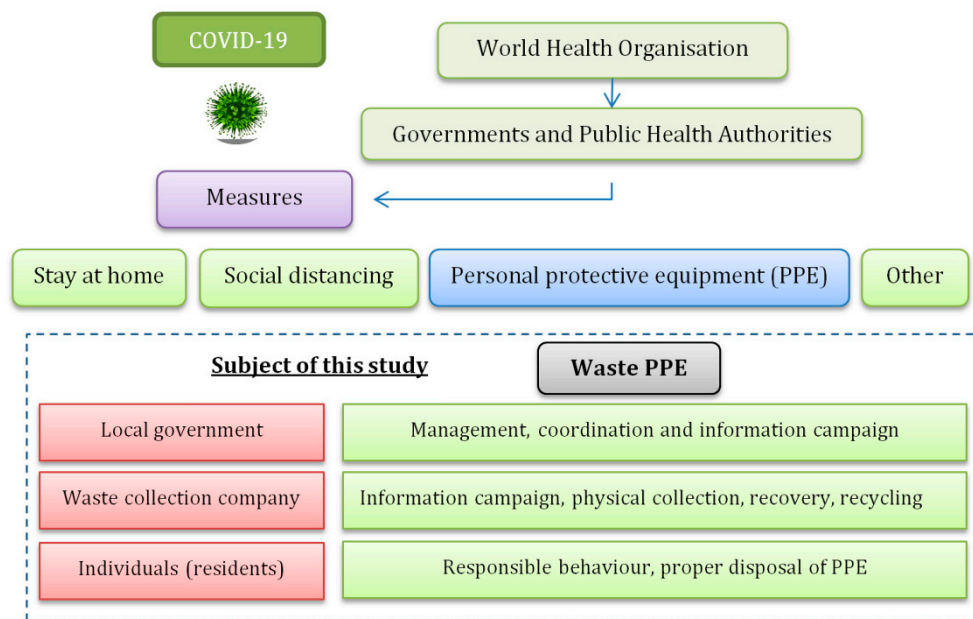


Figure 1. COVID-19 pandemic related measures and key elements of this study.

The main goal of this study is to determine how the new waste stream generated from households and other places including supermarkets, institutions, and medical centers, has affected each participant of the reverse supply chain. Employing exploratory research, the purpose is to gain an understanding of the methods, opinions, and motivations of policymakers, waste collection companies, and individuals. An investigation of the operational capability of the waste collection system is conducted to provide insight into the challenge of a new category of household waste. The results of the survey will help in working out a framework for further analysis.

2. Materials and Methods

Commonly used PPE is mainly composed of polymers, textiles, latex, or natural products such as cotton. The materials used in face masks can be woven fabric, textiles, cotton with rubber stripes, or with a textile band for fastening onto the face. The most commonly used gloves can be manufactured from latex or polyethylene foil. The materials used in manufacturing are relatively easy to recycle, but considering PPE is relatively small and lightweight, it can be easily mixed with other waste. Another possible method of waste PPE treatment is energy recovery by incineration. The calorific value of medical waste ranges from 19–24 MJ/kg, and polymers, including plastics, is 35–44 MJ/kg [16]. The commonly used surgical type face cover weighs approximately 3 g, and the mass of other types of masks with filters and strengthened edges is up to 16 g. Lightweight polyethylene glove mass is 0.8 g, and latex or nitrile gloves are within the range of 5–14 g depending on thickness and size. The incineration and waste-to-energy process should be considered a priority for waste PPE, knowing the potential medical hazards (collection from quarantined households or medical centers) and the high calorific value of the materials [17]. Another issue that has emerged in handling PPE waste is environmental pollution by plastics and micro-plastics via the disposal of waste masks and gloves in all

locations [18,19]. This waste can pollute green areas such as parks, forests, or beaches, and is a serious issue in Asia [18–20]. A properly designed framework for waste management contributes to a positive response by individuals. The hierarchy of waste management regulations in emergency mode was adapted by individual EU members. The guidelines published by the EU [10] proposed a general approach for household management of people with coronavirus disease. In Poland, these guidelines were included in the legislation creating a framework of the necessary measures for public health protection [12,14]. Local government is responsible for supporting necessary information for waste collection companies and the residents. Each member of the EU has selected appropriate measures depending on WHO and EU guidelines and taking into consideration national Public Health officials.

We prepared a survey for local administration (i.e., the departments of local governments responsible) for waste management policy and waste collection companies. The study was conducted in the Upper Silesian region of Poland. The population in the Silesian region is approximately 4.5 million inhabitants, and the majority live in cities and towns [21]. There are 12 cities with more than 100,000 inhabitants, including the capital city Katowice with approximately 300,000 people. The region consists of industrial municipalities in a large conurbation and some rural satellite municipalities (Figure 2) [22]. By the end of August, a total of 66,900 cases of COVID-19 were reported in Poland, including 2040 deaths. In the Upper Silesian region, it was 20,300 positive cases and 478 coronavirus related deaths.

The research was divided into two separate surveys. The first part of the research included a telephone survey for the local government environmental departments responsible for waste management policy and control and waste collection companies for several municipalities in the Silesian region.

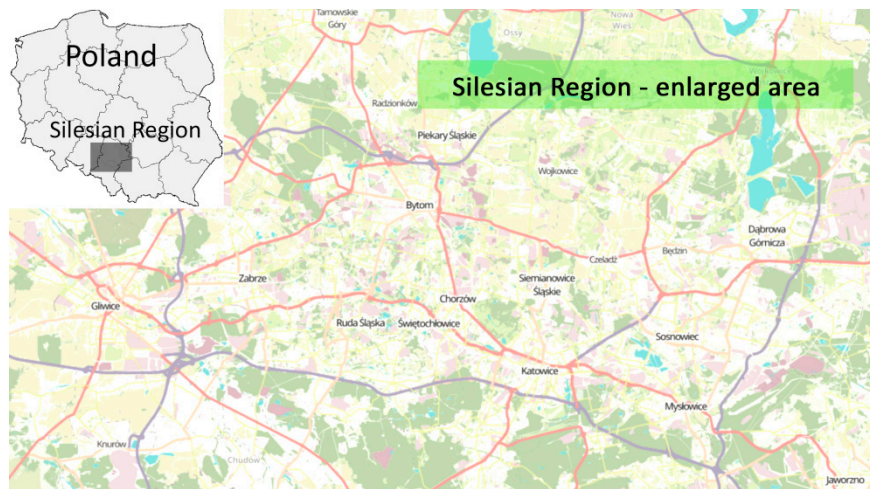


Figure 2. Location of the Upper Silesian Region included in the survey (map—[openstreetmap.org](https://www.openstreetmap.org)).

The main questions for local administration and waste collection companies focused on the three key activities in the practical approach of waste management: collection, transportation, and treatment of waste. The goal of each set of questions was to investigate the impact of a pandemic on the generation, handling, and collection of PPE. The local government representatives and managers of waste management companies were asked about differences between collection from quarantined locations and ordinary collection locations. The study examined the impact of special procedures and requirements from the public health authorities on PPE collection. The respondents were also encouraged to supply additional information and opinions concerning the practice of PPE collection. Data were collected from 11 local government offices covering an area with a population of over 800,000, including Katowice and 16 waste collection companies operating within an area with 1.3 million residents. The list of municipalities participated in the survey is shown in Table 1.

Table 1. List of municipalities participated in the survey.

Local Government Office		Waste Collection Company	
Municipality	Population	Municipality	Population
Kalety	8600	Bełżnica	1000
Lubliniec	23,000	Mszana	3600
Pszczyna	26,000	Chybie	4000
Zawiercie	50,000	Marklowice	5000
Będzin	53,000	Godów	14,000
Piekary Śląskie	55,000	Pawłowice	18,000
Tarnowskie Góry	60,000	Myszków	32,000
Zory	62,000	Jastrzebie-Zdrój	48,000
Mysłowice	73,000	Racibórz	55,000
Bytom	160,000	Siemianowice Śląskie	65,000
Katowice	300,000	Wodzisław Śląski	90,000
		Rybnik	138,000
		Zabrze	170,000
		Gliwice	180,000
		Częstochowa	220,000
		Katowice	300,000

The number of respondents was a result of acceptance for participation in the survey. The difficulties with data collection from a larger number of municipalities occurred due to disruptions of regular working schedules and unavailability of employees from government offices and waste collection companies. The sequence of questions required answers from a representative of a local government office or waste collection company for the two scenarios: waste collection from quarantine and regularly scheduled waste collections. The other portion of the survey was an online questionnaire prepared for the residents and presented by student research group members from the Silesian University of Technology using social media (Facebook and WhatsApp). Example of the online questionnaire screenshots is presented in Figure 3.

Ankieta dotycząca zbiórki środków ochrony osobistej w czasie pandemii Covid-19

Jesteśmy członkami Studenckiego Koła Naukowego Logistyków "LogisticAD" działającego na Politechnice Śląskiej Wydziału Transportu i Inżynierii Lotniczej. W wyniku programu Inicjatywa Doskonałości – Uczelnia Badawcza realizujemy projekt mający na celu poprawę efektywności zbiórki środków ochrony osobistej głównie maseczek i rękawiczek. Zależy nam na wypracowaniu metody, która pozwoli na efektywną zbiórkę i będzie wygodna dla mieszkańców.

DANE MAJĄ W PEŁNI CHARAKTER ANONIMOWY. W razie jakiegokolwiek pytań lub wątpliwości jesteśmy do Waszej dyspozycji. Możecie się z nami kontaktować mailowo w każdej chwili: sknl.logisticad@gmail.com

Z góry dziękujemy za wypełnienie ankiety :)

***Wymagane**

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! Bierzemy udział w projekcie Inicjatywa Doskonałości - Uczelnia Badawcza 🎉👏👏 w składzie: Sandra Kuśnierz, Patrycja Sosna, Dawid Maj, Kuba Mauer. Opiekunem projektu jest dr hab. inż. Piotr Nowakowski profesor PŚ. Nasz projekt to "Opracowanie nowych sposobów zbiórki i zagospodarowania odpadów środków ochrony osobistej (maseczki 🧴, rękawiczki 🧤) w czasie trwania pandemii związanej z wirusem Covid-19". 🙏👏👏👏👏. Prosimy o wypełnienie ankiety 🙏, gdyż pomoże nam to w realizacji projektu 🙏👏👏. Z góry dziękujemy za poświęcony czas 🙏👏👏

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DOCS.GOOGLE.COM
Ankieta dotycząca zbiórki środków ochrony osobistej w czasie pandemii...
Jesteśmy członkami Studenckiego Koła Naukowego Logistyków "LogisticAD" działającego na Politechnice Śląskiej Wydziału...

Czy wiesz jak powinno się postępować ze zużytymi środkami ochrony osobistej w czasie pandemii Covid-19 (maseczki, rękawiczki)? *

Tak

Nie

Co robisz ze zużytymi środkami ochrony osobistej ?

Wyrzucam z ogólnymi odpadami

Wyrzucam z selektywnie zbieranymi (np. plastik)

Zbieram lub usuwam do specjalnych pojemników/worków

Wyrzucam gdziekolwiek

Czy zaobserwowałeś niewłaściwe sposoby postępowania ze zużytymi środkami ochrony osobistej? *

Tak

Nie

Jeśli tak, to jakie?

Twoja odpowiedź

Który z naszych pomysłów na rozwiązanie problemu ze zbiórką odpadów podoba Ci się najbardziej? *

Wydzielenie specjalnych miejsc do oddawania maseczek oraz rękawiczek

Zapewnienie mieszkańcom specjalnych kolorów worków na maseczki i rękawiczki

Aplikacja mobilna ułatwiająca zbieranie odpadów z kwarantanny

Automaty przyjmujące zużyte środki ochrony osobistej i wydające nowe

Figure 3. Screenshots of the online questionnaire (in Polish)—Introduction and request for participation in the survey and samples of questions with answers.

The framework of the questionnaire was created using Google forms. It was conducted between the 6 and 24 of June 2020. The purpose of surveying residents was to identify awareness of individuals regarding handling, storage, and improper behavior with disposal waste PPE (Table 2). The online survey was chosen as a convenient method for accessing individuals. The set of questions explored the critical issues considering the generation of waste PPE in the reverse supply chain.

Table 2. Details of the questionnaire for residents.

Question	Answers
Do you know what is correct method for disposal of waste personal protective equipment (PPE)?	Yes/No
How do you dispose of PPE—face masks or gloves?	Collection together with mixed waste Collection in other separated bags Collection separately (together with plastics) Disposal of wherever available
Which method is correct for the disposal of waste PPE?	They can be disposed wherever possible They should be placed in a separated waste They should be placed in mixed waste Special bags or containers should be provided Not sure
Have you noticed any improper methods of waste PPE disposal?	Yes/No
Are there any improper methods of PPE disposal?	Disposal of wherever available Wrong category of waste selection Not sure
Have you any idea how to support waste PPE collection?	Automatic dispensers for PPE with an option to collect used PPE Special colors for bags for waste PPE for residents Preparation of special collection points for waste PPE Mobile application to facilitate collection of waste from quarantine

The intent was to determine Polish society's response to the management, handling, and disposal of PPE. The research mainly focused on whether the residents had difficulties with waste PPE disposal, if the local government or waste management companies provided information about proper handling of used PPE, and what kind of behavioral issues are the main concerns for residents. Finally, residents were asked what kind of support in the collection of waste PPE is the most preferable. Table 3 includes details of the participants of the online survey.

Table 3. Online survey participants data.

Factor	Value	Number of Responses
Gender	Male	99
	Female	51
Age	18–25	84
	26–35	39
	36–45	11
	46–55	11
	>55	5
Type of habitation	Urban	87
	Rural	63
Population of municipality	<5000	54
	5000–50,000	24
	50,000–200,000	27
	>200,000	45

Both parts of the survey were intended to summarize the effects of the pandemic and management of a new category of household waste (PPE) from the perspective of policymakers, the companies collecting, handling, and transporting the waste, and behavior and response from individual citizens.

The results should highlight weak points in waste PPE management including business to customer relations in the reverse supply chain.

3. Results

The results from the first part of the survey, which was directed to local government environmental departments and waste collection companies, indicated a significant difference in approach between these two groups of entities. The survey included two separate groups of questions for ordinary waste collection points (residential or institutional) and places with quarantined persons, social welfare homes for older adults, and other locations. Although PPE is distinguished as a separate category with the potential hazard of spreading a virus, the requirements for the collection of this kind of product were not intended to introduce very strict measures for waste handling. The approach of waste collection companies would include the preparation of additional routes, vehicles, or changes in the schedules; as those measures incur additional operational costs, these companies were reluctant to apply changes. The results from the survey regarding the collection points with a positive or potentially positive SARS-CoV-2 test result, called quarantine points, are presented in Table 4. For clarity of results, the differences are separated for the two scenarios into no or minor measures and major or significant measures taken in management, collection, transportation, and treatment of PPE waste.

Table 4. The results of the survey of local government and waste collection companies.

Entity	Measures Taken	Number of Municipalities/Number of Inhabitants in Municipalities	Process Type Waste Collection from Quarantine Points	Process Type Waste Transportation and Processing from Quarantine Points
Local government environmental department	None or minor	2/100,000	The collection is in accordance with the regular schedule, with the same timeline	No additional vehicles or routes required, processing is conducted with separated or mixed waste
	Major or significant	9/700,000	The residents are required to use additional bags for PPE; the collection is postponed up to nine days; in some cases, local administration delivers special bags or containers	The local authorities require additional routes or use of special vehicles for medical waste. If the routing is conducted on an ordinary schedule, the quarantine points must be the last visited
Waste collection company	None or minor	14/950,000	The collection is in accordance with the previously assigned schedule, the same containers, waste bins or bags used	The same collection vehicles and processing as for normal operation—the employees in the waste processing plants are equipped with protective gloves and glasses
	Major or significant	2/365,000	Additional bags provided to quarantine points; if available red color of bag required, the bags remain quarantined additional 48 h in the waste collection company warehouse.	Transportation by additional vehicles, if available—vehicles for medical waste are used, the waste after collection is directed to incineration plant

The results presented in Table 4 indicate various approaches towards management of waste PPE by local government offices and waste collection companies. Two scenarios of waste management show significant differences for the collection, transportation, and treatment of waste PPE. The primary guidelines from the Public Health Office included requirements for special treatment of waste PPE from households and strict safety requirements from quarantined locations. The local government offices followed the Ministry of Health and Head of Public Sanitary Office decrees regarding the collection, identification, and transportation of PPE waste and prepared information campaigns for waste collection companies. However, it was difficult to introduce special methods for the collection of PPE by waste collection companies waste due to various reasons. The most important was the additional cost factor for an additional category of waste collection. At the same time, the schedules of the waste collection had to be changed. The results show the requirement of financial support by the government for the increased cost of waste collection by the companies. The collection company

managers indicated that the employees used protective gloves and masks while collecting waste from households.

Another portion of the survey focused on residents as a target group. Figure 4 shows the survey results for methods of disposal of face-covering masks and gloves. The majority of respondents indicated that the used PPE was disposed of together with mixed household waste.

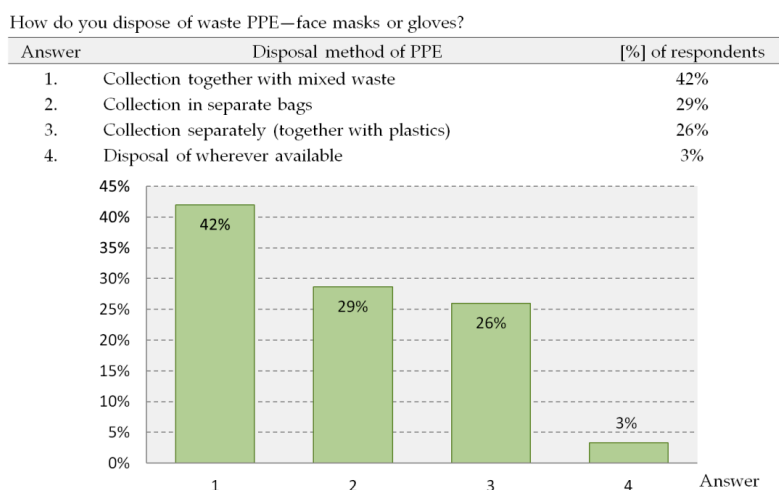


Figure 4. Methods of disposal of waste PPE in households.

Another question in the questionnaire concerned PPE disposal methods; specifically, which method is correct for the disposal of waste PPE. Almost 73% of respondents were not sure or did not know, 12% knew they should be collected separately, 8.5% thought they could be placed in the mixed waste container, and 5% knew they were collected in special bags. The respondents were asked if they noticed any improper methods of waste PPE disposal, and out of 150 respondents, 75% answered positively. The next question asked respondents what kind (if any) method for disposal had they observed. More than 60% of respondents answered that disposal in random places is the main issue, 32% had not noticed any significant issues, and 7% indicated wrong segregation of PPE.

Finally, the respondents were asked about proposals for the improvement of PPE waste collection. The results in Figure 5 indicate the overwhelming willingness of individuals to support the novel design of automatic dispensers with an option to collect waste PPE and use of bags with different colors to existing waste collection containers.

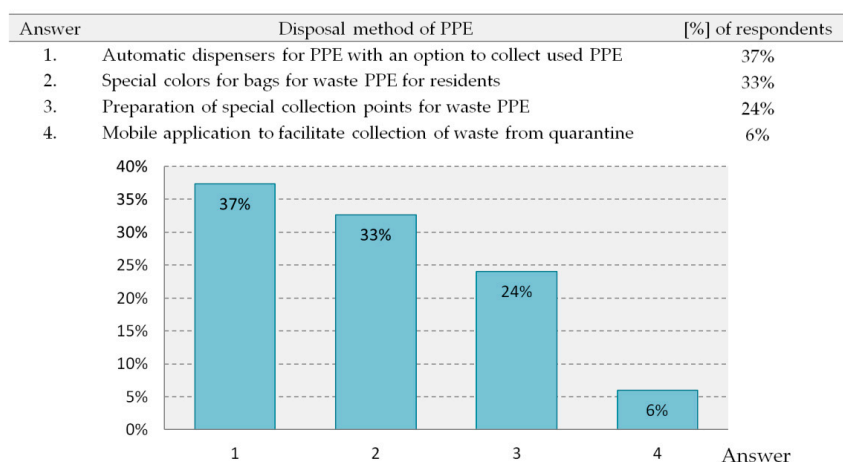


Figure 5. The residents’ proposed methods for improving the collection of waste PPE.

The waste stream of PPE generated from the households includes both face masks and gloves. Assuming daily activity of 20% of the population in the Silesian Region, it can generate 7.2 tons of waste face masks, and 12.6 tons of disposable waste gloves can be generated per day. The total calorific value ranges from 500,000 to 700,000 MJ per day.

4. Discussion

The majority of PPE products are intended for one-time use, introducing a new category of waste. Various management and environmental issues have emerged with widespread PPE use [23], including waste management decisions on the collection, transport, and treatment of waste, and the issues with social behavior in PPE waste disposal [24]. As indicated in the results of this study, waste management approaches differ between local governments and waste collection companies. From the local government point of view, it was relatively easy to prepare the requirements for all participants of the reverse supply chain following the guidelines of Public Health Service officials. The regulations included separating waste from ordinary collection points from that within quarantined locations, including quarantined households [11]. The results of the survey show more difficulties encountered by waste collection companies because of additional costs in changing collection methods or schedules. Even in some cases, it was necessary to modify waste collection vehicle routing or collect waste by special medical waste vehicles. The survey's results indicated only a low number of waste collection companies were capable of fulfilling all requirements imposed by officials considering the collection, transportation, and treatment of PPE waste.

The major issue with the introduction of the changes for the waste collection planning was dynamically changing the location of quarantine collection points that are usually assigned for two consecutive weeks. A recent study by Kargar et al. discusses modeling and optimizing of the waste collection and transportation during an epidemic [9]. Following the difficulties with waste collection planning and additional costs, the companies preferred to conduct waste collection and transportation as it was previously planned but with additional protective equipment and rules for the employees, mainly also by using PPE.

The results show that the residents were not sure how and where they should dispose of PPE. This issue can be attributed to disturbances in the information flow between local government, waste collection companies, and the residents in emergencies. Under normal circumstances, schedules and waste collection plans for an individual waste stream are known in advance. However, when the pandemic began, it was difficult to predict that waste PPE products would emerge as an additional category of household waste. Also, there was no knowledge about the use of another type of bag or bin or associated labels. Broader information campaigns concerning new methods of waste collection were unlikely to be the topics of news headlines, especially as most of society was concerned about health issues and the geographic range of the pandemic. The results of this study also show that when a high number of individuals utilize single-use products, such as face-covering masks or gloves, it creates a large stream of resources with potential for recycling or energy recovery. Klemeš et al. indicated that during a pandemic we observe a significant surge in the volume of plastic waste. Therefore, potential short-term and long-term changes in plastic waste management practices are necessary [25]. In the Silesian region, PPE use can generate approximately 20 tons of waste per day. Proper management and handling of this waste stream require consideration of emissions and environmental burdens associated with waste products containing polymers [26]. We found among our respondents that improper disposal of PPE is an environmental pollution problem, which was consistent with the results of Kalina and Tilley [20]. Additional results indicated that individuals are eager to support new methods for the collection of waste PPE. Reverse logistics modeling that included medical waste transportation optimization methods was presented in a case study in Wuhan, China [27]. There are complex dependencies between government regulations, waste collection companies, and society. A top priority is the identification of interactions between key players as indicated in an example of interpretive structural modeling [28]. It includes the general framework of the collection schemes,

new or modified bags or bins, schedules, and collection plans that can change dynamically, especially in urban areas. Future work can focus on the efficiency of the PPE collection including research in treatment plants and waste stream contents from mixed and separated fractions.

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