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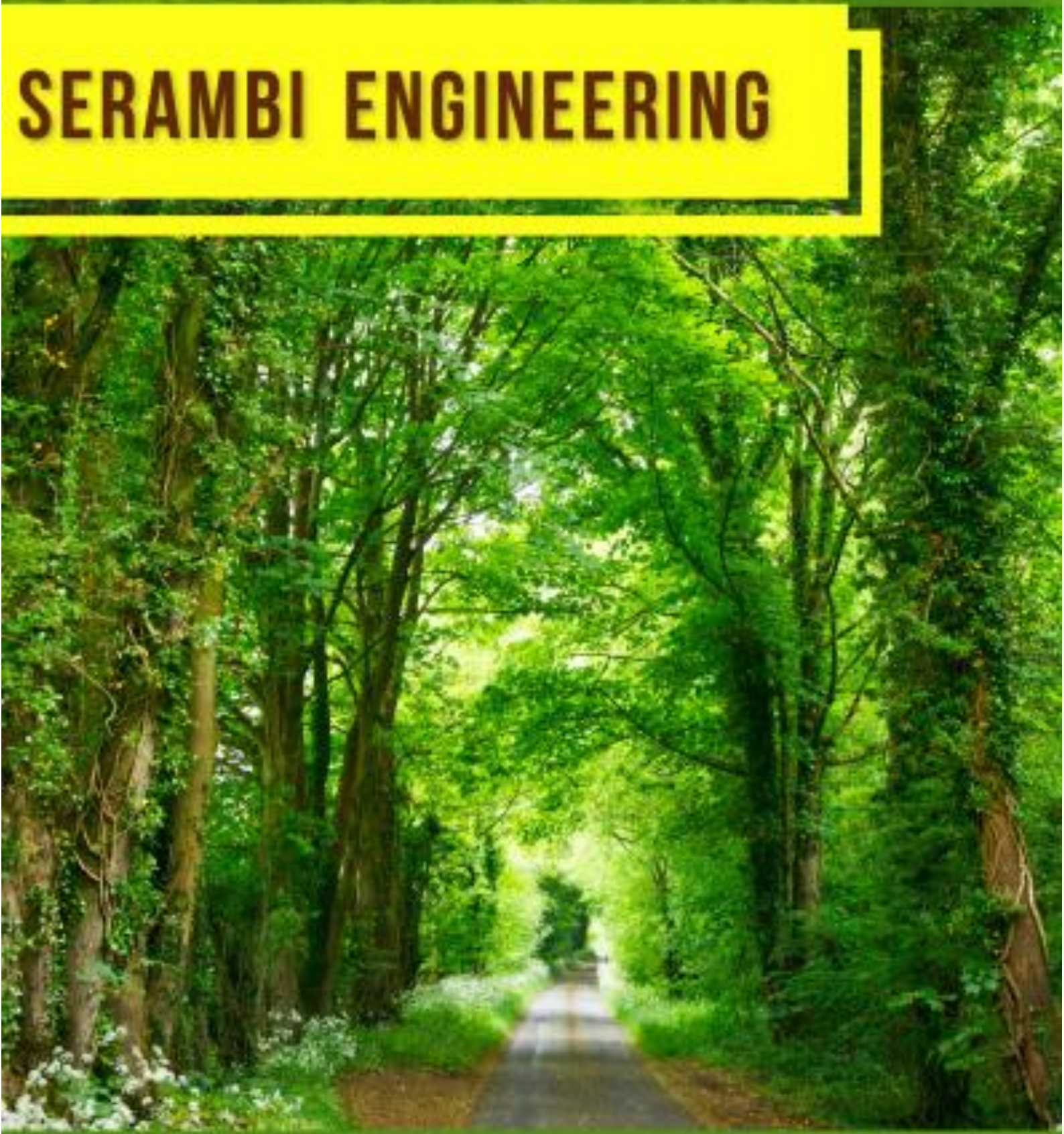

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Waste Management of COVID-19 Personal Protective Equipment in Indonesia and the Potential for Globally Oriented Development

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Abstract
The use of Personal Protective Equipment (PPE) can protect against exposure to the COVID-19 virus, but on the other hand it causes an increase in the generation of plastic waste. The amount of COVID-19 PPE waste is estimated at 1.6 million tons per day with masks or face shields worth 3.4 billion per day. The urgency of handling PPE waste is not only due to the volume of waste, but also the nature of the virus that survives on solid surfaces. This publication aims to provide a systematic review of PPE waste management in Indonesia, both from health facilities and households. Good practices from abroad are explored to see the potential for developing PPE waste management in Indonesia. The search results provide 38 articles, namely 21 national articles and 17 international articles. PPE waste management in Indonesia and abroad in general is separation, disinfection, collection/temporary storage, transportation, and final disposal (incineration/sterilization/landfill). 3R practice improvement (reuse, reduce, recycle) can create sustainable PPE waste management, for example, the use of environmentally friendly materials, reuse PPE after sterilization to increase lifetime or conversion of PPE waste into raw materials.
Keywords: *Personal Protective Equipment (PPE) Waste, COVID-19, waste management, waste treatment, hospitals, households*

Abstrak
Pemakaian Alat Pelindung Diri (APD) dapat melindungi dari paparan virus COVID-19, tetapi di sisi lain menyebabkan meningkatnya timbulan limbah plastik. Jumlah limbah APD COVID-19 diperkirakan mencapai 1,6 juta ton per hari dengan masker atau pelindung wajah senilai 3,4 miliar per hari. Urgensi penanganan limbah APD tidak hanya disebabkan volume limbah, tetapi juga sifat virus yang bertahan pada permukaan padatan. Publikasi ini bertujuan untuk memberikan tinjauan sistematis mengenai pengelolaan limbah APD di Indonesia, baik yang bersumber dari fasilitas kesehatan maupun dari rumah tangga. Praktik baik dari mancanegara ditelusuri untuk melihat potensi pengembangan pengelolaan limbah APD di Indonesia. Hasil penelusuran memberikan 38 artikel, yaitu 21 artikel nasional dan 17 artikel internasional. Pengelolaan limbah APD di Indonesia dan mancanegara secara umum adalah pemisahan, disinfeksi, pengumpulan/penyimpanan sementara, transportasi, dan pembuangan akhir (insinerasi/sterilisasi/*landfill*). Peningkatan praktik 3R (*reuse, reduce, recycle*) dapat menciptakan pengelolaan limbah APD yang berkelanjutan, misalnya penggunaan material ramah lingkungan, *reuse* APD setelah sterilisasi untuk meningkatkan *lifetime*, atau konversi limbah APD menjadi bahan baku.
Kata Kunci: *Limbah Alat Pelindung Diri (APD), COVID-19, pengelolaan limbah, pengolahan limbah, rumah sakit, rumah tangga*

1. Introduction

The phenomenon of COVID-19 has had various physical [1], [2], psychological [3], even environmental [4] impacts. One example is the impact of the use of Personal Protective Equipment (PPE), both in hospitals and households, which has resulted in people's lifestyles changing [5] and unconsciously causing an ever-increasing amount of PPE waste [4]. The use of masks, which have become a primary need for the community, for example, is now contributing to the increase in PPE waste for the environment today. The mask consists of three layers made of waterproof polymer so that mask waste is included in plastic biomedical waste. The increasing volume of waste due to the use of disposable masks is certainly contrary to the government's efforts to reduce single-use plastic. Therefore, planning for the handling of COVID-19 PPE waste needs to be thought out and implemented properly and with commitment.

Much research has been done on handling PPE waste in Indonesia since the first year the COVID-19 case was found in Indonesia. One of them is research from Wulansari et al [6] which recommends that

the COVID-19 PPE waste in the Bantul Health Center area be internally sterilized first before being handed over to a third party. The government has also issued special regulations regarding how the household level needs to manage PPE waste resulting from the self-quarantine of COVID-19 patients, and stated in the Minister of Environment and Forestry Circular Letter (SE MENLHK) Number SE. 2/MENLHK/PSLB3/PLB. 3/3/2020 [7]. These efforts were made to prevent the environmental impact caused by the COVID-19 PPE waste.

Handling of COVID-19 PPE waste is also carried out not only in Indonesia. The amount of COVID-19 PPE waste is estimated at 1.6 million tons per day with the use of masks or face shields worth 3.4 billion per day [8]. The fantastic volume of waste generation and the pandemic conditions experienced by almost all parts of the world have encouraged each country to handle COVID-19 PPE waste in their own ways and strategies. In Wuhan, the place where the outbreak of COVID-19 started, handling COVID-19 medical waste by providing temporary waste storage, which is then transferred to a temporary waste treatment center and then forwarded to the final waste disposal center [9]. These waste collectors, if they are not careful, actually become the distributors of existing virus contamination [10]. In contrast to China, which is also a producer of various PPE, Ireland implements a policy of reusing face protective equipment, such as masks, for household use [11]. The strategy for treating PPE waste in the world in general needs to really pay attention, because how the processing is carried out will have an impact on the surrounding environment and the state of the world. In addition, the strategies implemented abroad can be used as a reference for waste treatment in Indonesia, taking into account the suitability of regional conditions and health facilities in Indonesia.

These various methods of processing COVID-19 waste can be a reference for carrying out a similar process if a pandemic occurs again in the future. Different ways of handling, according to environmental conditions in Indonesia, have given rise to various methods of treating COVID-19 PPE waste, both in the form of household solid waste as well as hospitals and other health facilities. Besides that, insight from abroad regarding this activity also needs to be abstracted so that it can be used as a reference in improving the handling of COVID-19 PPE waste. However, as far as the author's tracing, there has not been a single document containing strategies for processing PPE COVID-19 waste in Indonesia, which also provides processing information from abroad, during the COVID-19 pandemic. Therefore, this literature study aims to broadly examine how the handling of COVID-19 PPE waste has been carried out in Indonesia, as well as comparisons with those that have been implemented abroad. In addition, this review will also provide a proposal for the development of ways to treat PPE COVID-19 waste in Indonesia.

2. Methodology

A systematic review was done to achieve the above research objectives carried out [10], [12]–[16]. This approach is carried out by taking inventory of various research results related to the processing of COVID-19 PPE waste. The literature that is inventoried comes from research that has been conducted from 2020 to 2022. The total literature that has been reviewed is 60 titles. Of the 60 papers, 38 papers (21 national and 17 international) passed through the sorting process. The sorting process until the final literature is selected can be illustrated using **Figure 1**.

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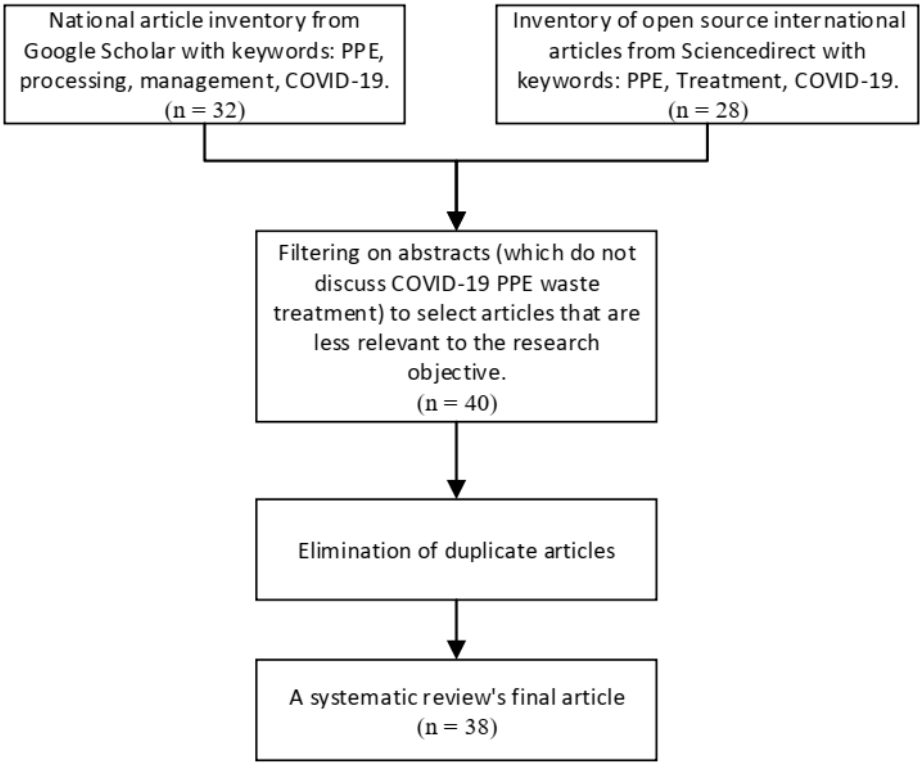

Figure 1. Process flowchart of systematic review

3. Results and Discussion

Management of COVID-19 PPE Waste in Hospitals in Indonesia

Ministry of Environment and Forestry (KLHK) based on press release No. SP.204/HUMAS/PP/HMS.3/5/2020 states that there has been a 30% increase in medical waste due to COVID-19. Since January 2020 there has been an increase in the amount of hospital medical waste in Indonesia, for example in one hospital in West Sumatra there has been an increase of nearly 18 tons of medical B3 waste within 6 months in 2020 [17].

Most of the COVID-19 PPE waste in hospitals is mixed with other solid waste such as vaccine vials, syringes, gauze, and even patient food/beverage packages [18]–[20]. Therefore, it is necessary to do the sorting first. This sorting is done by separating PPE waste from other solid waste, with one of them carrying out a labeling or container process using a different color [21][22]. The yellow color, for example, is used to accommodate PPE waste that has the potential to cause contamination biohazard [18], [23][24].

In general, from the literature study conducted, it was found that the management of COVID-19 PPE waste in hospitals can be carried out by first reducing or sorting it [21][23]–[27] for existing waste, namely separating PPE waste from other domestic waste. This process is then continued with the container step using a special label, which can be with a sticker label or also a container color label [24], as mentioned earlier, yellow for waste that has biohazard.

The third step is the process of transporting it to a temporary disposal site [19]–[21], [23]–[26]. PPE waste originating from isolation places is specially transported using garbage collection motorbikes [24]. In contrast to PPE waste at households, PPE waste from hospitals needs to use special protocols and tools such as incinerators, for the destruction process [17], [22]. However, most regional hospitals in Indonesia do not yet have permission to use these devices [22], [24]. Therefore, for hospitals that do not yet have a permit, continue the process of handling waste by handing over the waste to a third party who has a permit for destruction [18]–[21], [23], [24], [26], [27]. The process of managing COVID-19 PPE waste from this hospital can be briefly described through the flowchart in **Table 1.**

Meanwhile, the sources of the results of the literature search are summarized in **Figure 2.**

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Table 1. List of literature on waste management of COVID-19 PPE in hospitals in Indonesia

No.	Publication Year	Writer	Waste Type	Method
1.	2020	Yolarita and Kusuma	Masks, gloves.	Incinerator
2.	2020	Tri Nurwahyuni, Niki Fitria, Laila Umboh, Olce Katiandagho, Dismo	Masks, gloves, bandages, tissues, PPE clothes.	Incinerator
3.	2021	Shalihah, Enny Sholihah, Enny Mar'atus Sjaaf, Amal Chalik Djanawan, Ahmad	Hazmat, masks, gloves.	Sorting, transporting, weighing, temporary storage, and delivery of waste to third parties
4.	2021	Salman, Nurcholis Arianti, Dini Taqwa, Fadhila Muhammad Libasut	Masks, gloves.	Sorting, transfer, distribution to third parties, destruction.
5.	2021	Marwah, Marwah Hasan, Muhammad Saleh, Muh.	Masks, used tissues, and other PPE.	Collection, transportation, weighing, temporary storage, and delivery of waste to third party
6.	2021	Maharani, Shinta Enggar	Ordinary masks, surgical masks.	Segregation, transportation, weighing, temporary storage, and delivery of waste to third parties.
7.	2022	Sukmawati, Sukmawati Dahlan, Maarifah	Masks, gloves, bandages.	Identification, separation, labeling, transportation, storage, disposal, destruction or distribution to third parties
8.	2022	Himmatul'Ulya, Meila Authority, Eram Tunggul	Masks, gloves.	Separation, storage, labeling, disposal, and distribution to third parties.
9.	2022	Anwar, Andi Awaliya Rochka, Mega Marindrawati	Masks, gloves, boots, and aprons	Storage, sorting, transportation to TPS, and distribution to third parties.
10.	2022	Mapau, Zrimurti Chairani, Miftah Akbar, Fajar	Face mask	Storage, sorting, transportation, distribution to third parties, destruction.
11.	2022	Kasdjono, Erika Agustina Bakhtiar, Adang Octamianti, Puput Sipahutar, Esna	Face mask, *face shield*, hazmat, medical suits, gloves.	Reduction, storage, collection, transportation, utilization, processing, and/or hoarding.

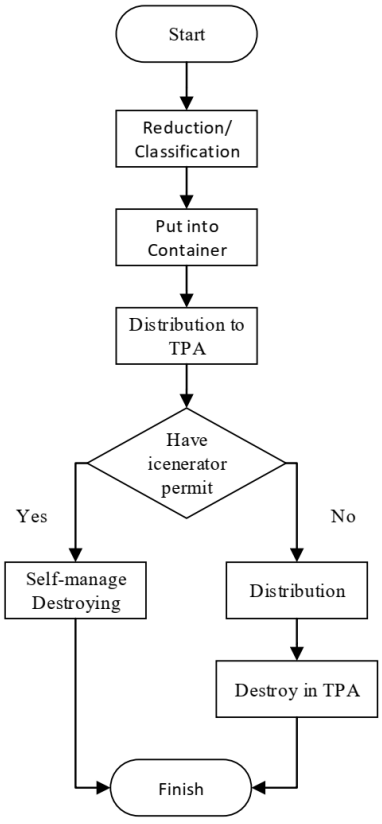

Figure 2. The flow of COVID-19 PPE waste management in hospitals in Indonesia

Management of COVID-19 PPE Waste in Households in Indonesia

Household waste generated by Indonesian citizens is quite diverse. Most of the waste is generated from used masks and gloves [28]–[34]. This consumable PPE is used every day by every member of the family, and it only lasts for a maximum of 1-2 days. In addition to masks and gloves, some researchers also classify protective clothing, tissues, gauze, cotton, pads, diapers, and face shields or face shield, as part of household COVID-19 PPE waste.

Research that has been conducted in Indonesia shows that the processing of COVID-19 PPE waste is carried out in various ways. Most of the results found, the researchers recommended a waste treatment method that refers to hospital waste treatment, simply. Communities can start by separating [28], [29], [31], [33], [35] PPE waste from other household waste. Separation can be followed up by collecting PPE in a separate container and then labeling the container [28]–[31], [33], [35]–[37].

This separation process is not the final step, because the collected waste needs to undergo a disinfection process [28], [29], [33], [37], to reduce the potential for transmission of COVID-19 to staff work that carries the waste. Even Monica [37] adds that PPE that will be disposed of needs to be damaged first or changed in shape (deformation), so that there is no potential for it to be reused or misused by other people.

Especially in the final process, some researchers suggest that it can be handed over to the officers, to then be taken to the final disposal site or TPA, so that the officers at the TPA can process it further in a professional manner [36], [37]. To support the PPE waste distribution process, Rahmalia [34] built one platform to facilitate the collection of this waste, by using an application called Smart Infectious Waste Bank (SIWAB). Meanwhile, Islamiyah [31] and Isykapurnama [32] recommend that the destruction process be carried out at the household level, one of which is using a simple pyrolysis process. This management process needs to be carried out by considering local wisdom [33], so that the tools, technology, and procedures applied are feasible according to each area.

Through a systematic literature search on the management of COVID-19 PPE waste, it can be seen that the management process is carried out by separating it through container and labeling, disinfection, and deformation, and then it can be destroyed or distributed to TPA, which has more qualified destruction facilities. The management process is carried out by considering the principle of local wisdom. This process can be simply illustrated through the chart presented in **Figure 3**. Meanwhile, the results of a literature search to explore methods for managing COVID-19 PPE waste in households in Indonesia can be seen in **Table 2.**

Table 2. List of literature on managing COVID-19 PPE waste in households in Indonesia

No.	Publication Year	Writer	Waste Type	Method
1.	2020	Amalia, Vina Hadisantoso, Eko Prabowo Wahyuni, Ira Ryski Supriatna, Adi Mulyana	Masks, disposable tissues, handkerchiefs, gloves, and disposable wipes.	Sorting, container, disinfection, labeling
2.	2021	Hardi, Rachmat Taufick Akbar, Randy	Mask, gloves, face shield.	Storage, collection, distribution and processing separated from other waste.
3.	2021	Isykapurnama, S., Sarastri, D., & Mahardika, H. A.	Mask and gloves.	Pyrolysis
4.	2021	Pudjiastuti, D., Rahmatiar, Y., & Guntara, D.	Masks, gloves, protective clothing.	Sorting, container, disinfection, labeling with local wisdom orientation.
5.	2022	Intan Rahmalia, Namira Yostya Oktiviani, Fifik Samhun Kahalnashiri, Nova Ulhasanah, I Wayan Koko Suryawan	Masks, gloves, clothes decontamination, face shield.	Development of a special infectious waste bank for PPE COVID-19
6.	2022	Islamiyah, N.Q.A.	Masks, gloves.	Collection, storage, separation, destruction.
7.	2022	Batari, A.U.	Masks, gloves.	Sorting, collection, container, disinfection, labeling.
8.	2022	Kurniawaty, Y.	Face mask.	Separation, container.
9.	2022	Monica Djaja Saputera, A. Joko Purwoko, Edward Kurnia Sanusi	Face mask.	Disinfection, deformation, housing, disposal.
10.	2022	Dwi Utami Farkhati, Surahma Asti Mulasari	Masks, tissues, gauze, cotton, pads, diapers.	Container, labeling, disposal to landfill.

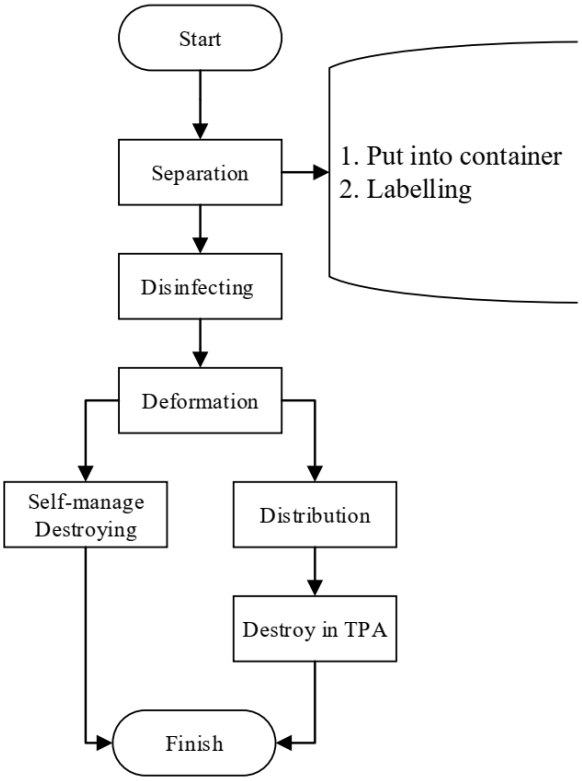

Figure 3. Flow for COVID-19 PPE waste management in households in Indonesia

Management of COVID-19 PPE Waste in Other Countries

The international literature search did not explicitly separate the management of PPE waste from household waste and health facility waste. Management of collection and management of PPE waste is not much different from that in Indonesia, although there are some slightly different practices.

Countries in Asia, for example, Thailand, China, and India provide separate bins for the disposal of masks. Some countries do not separate mask waste from general waste, but there are additional procedures, in which masks are folded or rolled up and then put in plastic before being disposed of. India even disinfects mask waste from households doing quarantine using a 1% solution of bleach or sodium hypochlorite.

Treatment of discarded mask waste in India, China, Bangladesh, Japan, Malaysia, Nepal, and Thailand is generally done by incineration [38]. Tripathi et al [12] proposed a sustainable solid waste management method involving all parties, starting from municipal waste service providers, the community, and waste recycling companies. The management chart for handling PPE COVID-19 waste in foreign countries can be seen in **Figure 4**.

The management of COVID-19 PPE waste in developing countries is experiencing greater challenges than in developed countries. In Ethiopia, for example, waste segregation is limited so mixed medical waste is collected and transported in open plastic containers, then incinerated or buried in open areas [39].

The same thing was found in the study by Adusei-Gyamfi et al [40] who stated that urban waste management in Africa before COVID-19 was already experiencing challenges before the pandemic hit, both from environmental, social and economic aspects. The pandemic conditions pose more challenges with the volume of PPE waste, especially masks, with an estimated 10.5 billion units per month.

It is recommended that PPE waste processing for COVID-19 use recovery energy considering that PPE waste is included in the category of non-organic waste. To support this, waste segregation is a must so that waste can be treated according to its characteristics while maintaining ongoing organic waste processing. Research shows that mask waste that is treated with organic waste can reduce the performance of High Solids Anaerobic Digestion (HSAD) in waste treatment facilities by reducing methane production, which is renewable energy or biogas [41].

Research abroad does not only focus on handling waste at the end-of-pipe but also to reduce waste generation at the source as well as other strategies to utilize COVID-19 PPE waste as raw material. **Table 3** shows a summary of the literature on managing COVID-19 PPE waste abroad. Opportunities to reduce the consumption of PPE use are shown by the research of Wang et al [42] who soaked masks that had been used in hot water at temperatures >56℃ for 30 minutes according to the method issued by the National Health Commission of the People's Republic of China, followed by drying using a tumble dryer to recharge the masks. This method is called hot water decontamination and charge regeneration. The study was conducted for three types of masks (disposable masks, surgical masks, and KN95 masks) and obtained mask filtering efficiency, both Bacterial Filtration Efficiency and Particle Filtration Efficiency, is maintained and meets the standard. This method was even applied by the company to employees and there was a decrease in the use of masks from 1 mask per day to 1 mask per three days per person with a total reduction of 122,500 mask consumption in the period 20 February-30 March 2020.

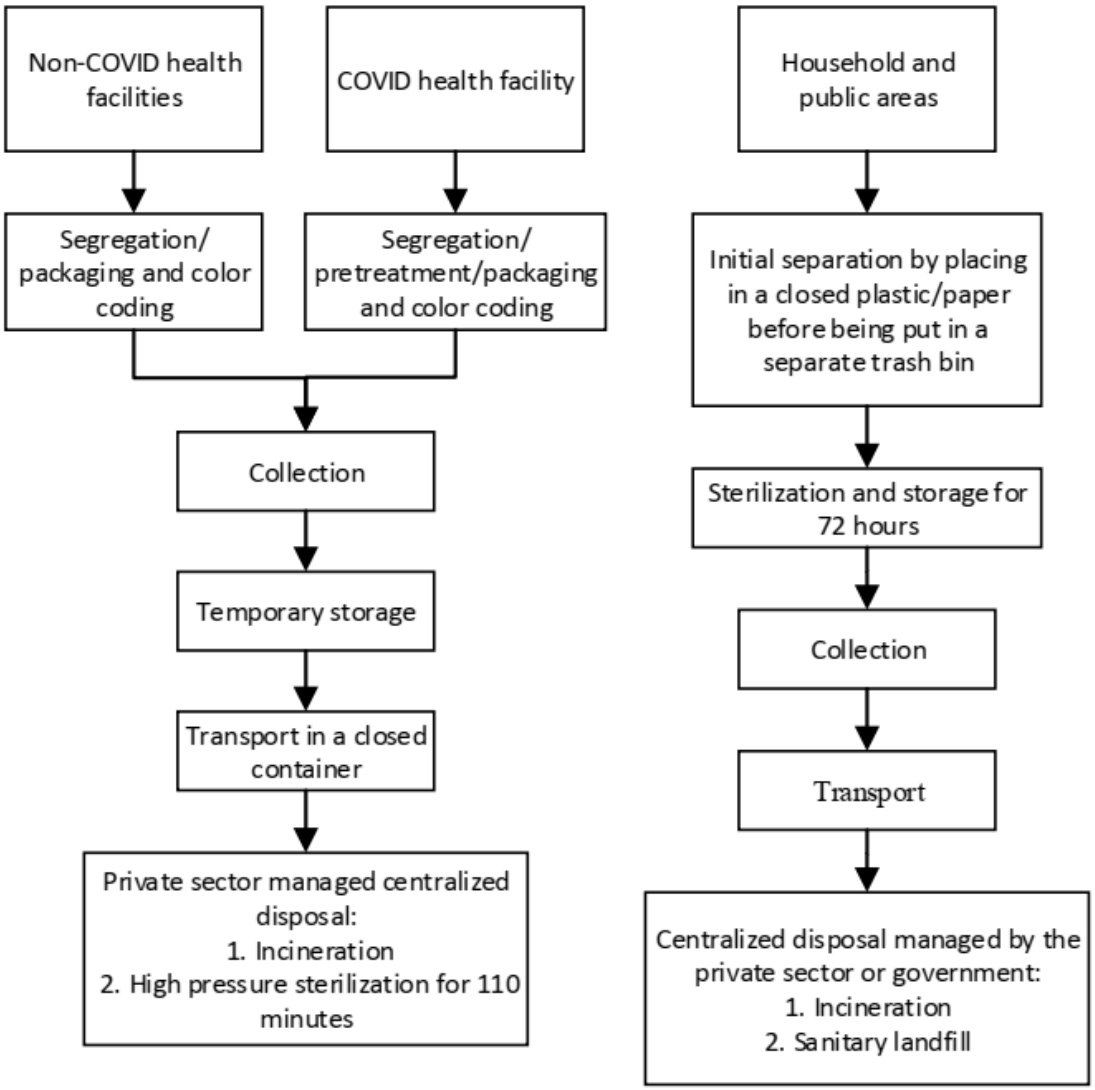

Figure 4. Flow of the COVID-19 PPE waste management process in other countries

Table 3. Literature list of COVID-19 PPE waste management in other countries

No.	Publication Year	Writer	Country	Waste	Summary
I. PPE Waste Collection and Disposal					
1.	2020	Tripathi et al. al.	World (developing and developed countries)	Face mask	The challenge of solid waste management related to the increased use of PPE during the COVID-19 period considers the stability of the virus on solid surfaces. Converting PPE waste into energy is recommended to reduce plastic waste generation
2.	202	Sangkham	Asia (Thailand, China, India, Singapore, South Korea, Malaysia, Taiwan)	Face mask	PPE disposal policies from households and health facilities in Asian countries, Japan, Malaysia, Nepal, and Thailand are generally carried out by incineration.
3.	2021	Give you in the.	Philippines, Jordan, China, United States	Biomedical waste	Examples of hospital waste management and development strategies in several countries during COVID-19.
4.	2021	Chand et. para.	India	Biomedical waste	PPE waste is classified as biomedical waste with a yellow color code which will be processed by plasma pyrolysis, incineration, or burial.
5.	2022	Adusei-Gyamfi, et al. al.	Africa	Face mask	Estimating the generation of mask waste on the African continent and seeing the potential for improving urban waste management in Africa after COVID-19.
6.	2022	Lema, et. al.	Ethiopia	Face mask	Calculating the rate of medical waste generation, including PPE, and evaluating medical waste management
7.	2022	Chalermsinsuwan, et. al.	Thailand	Face mask	Optimizing the PPE waste gasification process
8.	2022	Miao, and. para.	China	Infectious waste	Processing with *Mobile Emergency Incinerator*
II. Reduce, reuse, and recycle (3R)					
9.	2020	Wang et. eel.	China	Face mask	Approach to mask decontamination for repeated use during COVID-19 with hot water decontamination and load regeneration.
10.	2021	Selvaranja et al. al.	World (developing and developed countries)	Face mask	The potential for soil and ocean pollution from PPE waste and the potential for increased use of plant fibers in the manufacture of masks and the use of PPE waste as raw material for construction materials
11.	2021	Bumajdad & Khan		Face mask	Utilization of mask waste as a nitrogen source in the manufacture of carbon adsorbents.
12.	2022	Zhipeng, et. al.		Face mask	The mask waste is then chopped as a mixture of portland cement paste
13.	2022	Emenike et al. to the.		Face mask	Recycle PPE waste by co-carbonization method with biomass waste improves the quality of biochar and can be an alternative treatment for PPE waste that is environmentally friendly
14.	2022	Wang et. eel.		Face mask	Opportunity to recycle PPE waste, especially masks, to reduce the viscosity of crude oil.
15.	2022	Santos-Rosales, et. to the.		Face mask	Sterilization-based supercritical CO_2 to replace conventional methods using heat or radiation. Sterilization-based supercritical CO_2 can maintain the function of the mask up to 10 times the sterilization cycle.
16.	2022	Hou, et al. al.		Face mask	Production of the reusable mask using natural ingredients from fish scale waste
17.	2022	Srenscek-Nazzal, et al. al.		Face mask	Mask waste is processed into carbon-based electrodes that can be used in supercapacitors

Sterilization using supercritical CO2 has proven able to maintain mask efficiency for up to 10 cycles of use [43]. PPE waste for COVID-19 belongs to plastic waste which can be used as a mixed material for construction [44], [45], manufacture of adsorbents [46], production of biochar using the co-carbonation method [47], reducing the viscosity of crude oil [48], and making supercapacitor [49]. Another option for reducing pollution due to COVID-19 PPE waste is the use of environmentally friendly raw materials, replacing polymers that have been used as PPE raw materials [50].

Proposed Strategy for Management of COVID-19 PPE Waste in Indonesia

A systematic review of national and international publications shows that the handling of COVID-19 PPE waste in Indonesia, especially in households and public places, can be improved by considering several things:

- Provision of special trash bins in public places for disposal of masks or other PPE waste

- Standardization of PPE waste disposal procedures, for example masks need to be folded inward or rolled up before being disposed of
- Strengthening regulations not to throw masks anywhere
- Education to the public regarding the impact of PPE waste on health and the environment, as well as standard procedures for disposing of PPE waste
- Separation of waste must be carried out for handling COVID-19 PPE waste.

In addition, learning from good practices in foreign countries, research, and implementation of research results regarding the use of reusable masks to reduce the consumption of PPE, it is necessary to reduce the volume of PPE waste for COVID-19. The utilization of COVID-19 PPE waste as raw material for construction materials is an opportunity to convert waste into resources and support a circular economy. Recovery energy from COVID-19 PPE waste needs further research to be implemented as an alternative energy option

4. Conclusion

The use of PPE can protect against exposure to the COVID-19 virus, but on the other hand, it causes an increase in the generation of plastic waste. PPE waste for COVID-19 can be categorized as biomedical waste considering the retention of the COVID-19 virus on solid surfaces. Management of COVID-19 PPE waste needs serious attention because of the nature of the waste and the volume of waste generated. Both the management of COVID-19 PPE waste in hospitals and households need to start with the separation or segregation of waste. Disinfection and collection in closed containers, followed by processing with incineration are common options in Indonesia and abroad. It is important to standardize procedures in the community. Using the end-of-pipe approach is not enough to create sustainable COVID-19 PPE waste management. Therefore, efforts need to be made to reduce waste generation by reuse PPE after sterilization, use of environmentally friendly materials, and recycle PPE waste for COVID-19 is a material that has added value

5. Acknowledgment

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