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Municipal infectious waste during COVID-19 pandemic: trends, impacts, and management

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ABSTRACT

The coronavirus disease 2019 (COVID-19) shifts the characteristics of municipal waste. This paper aims to provide an overview of trends, impacts, and management during the COVID-19 pandemic globally. The increase in the generation of plastic waste and infectious waste is a new challenge during the COVID-19 pandemic. It was found that the emergence of plastic waste due to the consumption of food delivery becomes an issue in several countries. Despite the increment of plastic waste generation, the mass layoffs contributed to the decrease in the total urban waste generation in general. In addition to plastic waste, a surge of infectious waste from health facilities and household waste originating from residents infected with the SARS-COV-2 virus was observed. This infectious wastewater potentially leads to environmental disturbances to the rivers and oceans. To tackle global environmental concerns, sustainable waste management is required especially in the development of biodegradable personal protective equipment.

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1. INTRODUCTION

Economic development zone officials claimed that they collected around 240 tons of pharmaceutical trash every day in Wuhan alone, a city considered the epicentre of the virus [1], [2]. Particular bins in the city area are even damaged due to overload mask disposal in residential areas, streets, and other public areas, although it is difficult to obtain an exact figure on the number of masks discarded. However, the environment and health authority estimate that the volume of medical waste in Wuhan as a whole has increased four times by more than 200 tons a day [3]. Various environmental problems can occur due to infectious waste management from personal protective equipment during the coronavirus disease 2019 (COVID-19) virus outbreak. An initial strategic study and the latest issues, especially changes in waste generation and characteristics, are needed. Currently, after radiation waste, health waste is considered the second most hazardous waste globally. For example, the waste includes various forms of waste, both harmless and hazardous, such as sharp objects, human body parts, blood, chemical waste, pharmaceutical waste, and medical devices [4].

The coronavirus disease 2019 (COVID-19) outbreak was first reported in Wuhan, China in December, 2019. The outbreak emerged from the SARS-CoV-2 virus that causes acute respiratory illness [5]. The number of patients infected with COVID-19 and the highly contagious nature of the disease led to such a high number of hospitalizations that the pandemic continues to pose a significant public health threat worldwide. Thus, the generation of health care solid waste has also increased rapidly. In addition, the increase in the number of personal protective equipment (PPE) compared to normal conditions used during the COVID-19 pandemic has increased waste in health services [6].

Worldwide, at least 5.2 million people, including 4 million children, die each year from diseases originating from unmanaged medical waste. Biomedical waste in excessive quantities has now become a new major threat to public health as well as the environment during this pandemic. Solid waste generated from waiting areas of health facilities must be sealed prior to transfer, and properly disposed of by waste management personnel. This waste is considered as non-hazardous waste and stored in designated bags or containers. Alternative technologies have been used to manage health care solid waste in a sustainable manner, namely autoclaves and incinerators with high-temperature burners [7].

The composition of healthcare solid waste is of great importance as observed during normal circumstances. This will determine its ability to be recycled and managed sustainably, which is especially important during the current pandemic [8]. PPE, namely masks, goggles, boots, long-sleeved gowns, heavy-duty gloves, and face shields are also considered infectious waste, and including the waste generated from these materials has increased considerably during the COVID-19 pandemic. Therefore, it has become a tremendous challenge in managing this type of waste during the pandemic [9]. The longer lifespan of the COVID-19 virus increases the risk of transmission to society and the environment. The survival period of the COVID-19 virus after aerosolization on materials containing plastic, copper, cardboard, and stainless steel were 24 hours, three hours, four hours, and 2-3 days, respectively . In addition, other researchers have also reported that the virus can survive on the surface of inanimate objects, such as glass, plastic or metal for a period of nine days [10]. This study aims to analysis the environmental impacts caused by this personal protective equipment and to determine sustainable and safe waste management for the environment and health.

2. RESEARCH METHOD

This paper presents review regarding the characteristics of waste and some of the issues caused by the generation of infectious waste from COVID-19. Reviews are taken from news sources during the COVID-19 pandemic, along with scientific articles from both journals as well as proceedings that highlight the problem of infectious waste COVID-19. Comparison of literature and policies and regulations issued by governments was discussed.

3. RESULTS AND DISCUSSION

3.1. Characteristics of municipal solid waste

China, in the beginning of the spread of the COVID-19 virus, produced 6,066.8 tons/day of medical waste [11]. With such a large generation and inadequate medical waste disposal during COVID-19, the use of municipal solid waste incinerators to treat medical waste collectively might be a key toemergency disposal method [12]. The trend of increasing the amount of medical waste generation occurs in all countries in the world. During the COVID-19 outbreak in Hubei Province, China, there was a six times increase in the generation of ordinary medical waste, from 40 to 240 tons/day. Asian development bank (ADB) predicts DKI Jakarta alone will produce 212 tons of medical waste/day.

Goods or materials left over from activities that are not reused that have the potential to be contaminated by infectious substances or in contact with patients and/or staff at health facilities (health care facilities) who handle COVID-19 patients, including used masks, used gloves, used bandages, used tissue, used plastic for drinks and food, used paper for food and beverages, used syringes, used infusion sets, used personal protective equipment (PPE), patient food scraps and others, originating from service activities in the emergency unit (ER), isolation rooms, intensive care unit (ICU) rooms, treatment rooms, and other service rooms are solid medical B3 waste. The calculation of the generation of medical waste generated during the occurrence of the COVID-19 pandemic is 25 tons/day from 10,000 COVID-19 patients, with a generation rate of 2.5 kg/bed. Therefore, it can be concluded that infectious waste generated from COVID-19 patients has the highest percentage in contributing to the percentage of the amount of hazardouse waste.

When the pandemic hit the United States in mid-March, the number of online purchases increased across all ages [13]. The number of online purchases such as daily necessities and food. The same trend was encountered in Thailand. Food delivery is now commonplace and more convenient option. Although the generation of municipal waste in Indonesia during the work from the home period decreases, production of plastic waste is predicted to increase. Another research report also mentions that the use of single-use plastics is getting worse during the COVID-19 pandemic because of enablement home delivery of food and essential goods [14]. In contrast, COVID-19 causes mass unemployment; it may lower spending capacity and possibly reduce waste generation [15]. Therefore, COVID-19 brings both indirect positive and negative effects on the environment. The latter will even worsen unless a sustainable approach is implemented to keep our environment clean [16]. Other research also mentions an increase in the number of solid waste generation during the COVID-19 pandemic in Brazil [17], Nigeria [18], Tehran [19], and South Korea [20]. This might be due to the habits and lifestyle related to shopping frequency and types of items purchased before and during the sanitation lockdown period.

3.2. COVID-19 overload pollution

Despite the unfavorable impact of COVID-19, stay at home restriction brings positive changes to the environment. Satellite data have indicated that air quality has improved in many cities worldwide due to suppressed human mobility [21]–[23]. On the contrary, conservationists have warned that the coronavirus pandemic could trigger a spike in ocean pollution. Large numbers of masks and gloves were found floating like on the seabed.

Despite the fact that the necessity to use personal protective equipment (PPE) is of utmost importance to overcome COVID-19, public awareness has not been followed. As a piece of evidence, the research team from the Indonesian institute of sciences (LIPI) discovered the change in the composition of waste that entered Jakarta Bay during the COVID-19 pandemic such as PPE waste (masks and face shields). This research was conducted during 2020 to mid 2021. In the year before the COVID-19 pandemic, the results of other studies showed that plastic was one of the main factors in marine debris [24]–[26]. Changes in the characteristics of marine debris after the COVID-19 pandemic is one of the most recent challenges and issues in Indonesia. This is also supported by research conducted in Cilincing and Marunda Rivers which shows that PPE waste such as medical masks, gloves, hazard suits, face shields, raincoats reach 15-16% [27]. In addition, the latest findings in Southern Bali Province also contain the potential for marine debris from PPE, especially medical mask waste [28]. Changes in the composition of waste during the COVID-19 pandemic will present new problems to aquatic biota and waste treatment. The example is the increasing amount of garbage that enters water bodies until it ends up in the sea. This causes the waste to disturb the life of the aquatic biota. In addition, water treatment will require greater water treatment because the water body is in a heavily polluted condition [29], [30].

The COVID-19 pandemic requires people to wear masks to protect themselves from infection. However, the massive use of disposable masks has had a significant impact on the environment. Medical mask waste, especially the N-95 mask made of several layers of polypropylene plastic polymer and synthetic materials can only be worn once, causing uncontrolled medical litter. The mask waste is thrown away carelessly and subsequently pollutes the environment and without a doubt, endangers sea animals. For example, waste masks can be eaten by marine animals. Mask waste will combine with other organic components in the sea, and then marine animals make it their food. As happened in Brazilian beach, penguin death was found after swallowing a face mask [31]. So that over time there will be many sea animals that get sick and die due to exposure to mask waste in sea waters. On the other side of the Americacontinent, namely 11 beaches along the coast of Lima, Peru, 138 PPE items were found [32].

3.3. Waste management for COVID-19

In China, the environment and health authority declared that masks and other protective equipment, especially items worn by medical personnel and people infected with the virus, must be treated as clinical waste and sterilized before being burned at high temperatures with special tools [3]. Combustion waste treatment was preferred in China, although industrialized countries were phasing out combustion treatment due to health and environmental concerns [3]. In addition to combustion, medical waste processing in China also encourages the waste-to-energy (WtE) and waste-to-material (WtM) approaches supporting zero waste [33]. The application of WtE needs to be applied because it is considered more environmentally friendly [28], [34].

The management of infectious waste in Indonesia refers to circular letter of Minister of Environment and Forestry No. SE.02/PSLB3/PLB.3/3/2020 concerning management of infectious waste B3 and household waste from handling COVID-19 and circular letter of Director-General PSLB3 number S-194/PSLB3/PLB.2/4/2020 concerning implementation of hazardous medical waste management from COVID-19 handling activities to heads of provincial environmental services throughout Indonesia. Infectious waste is mostly originating from health service facilities.

Infectious waste must be stored in packaging and closed for a maximum of two days before transporting and further processing. Further processing is performed using incinerator with a minimum combustion temperature of 800°C, or an autoclave equipped with a customarily shredder. The residue resulting from combustion or shredded autoclave is packed and marked with a symbol of "toxic" and label for hazardous waste and then stored in a temporary designated storage place for hazardous waste prior handed over to the hazardous waste manager. The handling stage starts by collecting infectious waste in PPE waste, including masks, gloves, and personal protective clothing, then continues by packing separately using a closed container. Following that, transporting, destroying the hazardous waste, as well as conveying information to the public about managing infectious waste from the community, such as PPE waste, including masks, gloves, personal protective clothing, and packaging separately using a closed container labeled with "infectious waste" are required. The agency, responsible for the environmental, hygiene, and health sectors, collects it from each sourceand transports it to the designated location before being handed over to the hazardous waste processor. Lastly, municipal waste, including household waste and similar waste, needs to be properly handled [35]. The dumped waste must be treated with UV-C light [36], [37], ozone gas [38], [39], ionized hydrogen peroxide [40], or dry heat [41] to prevent the spread of viruses in PPE waste.

This pandemic encourages a policy to ban single-use plastics. Several businesses have replaced the use of non-reusable containers with cloth bags [42]. This has implications for implementing a circular economy, from waste management to new business models to prevent waste. Some countries are also changing the approach of collecting and treating waste. To support zero waste efforts from COVID-19, monitoring is an important task. It is necessary to quickly adjust the monitoring program not only to update the list of waste categories but also to prepare a monitoring team (for example, staff, researchers, volunteers, and citizen scientists) for anticipating a steep rise of PPE waste and how to appropriately handle these items potentially contaminated with COVID-19 [43]. Due to the global adoption of municipal PPE, future research should aim at developing biodegradable and environmentally friendly to achieving sustainable patterns towards a greener environment [44].

Most of the PPE waste from COVID-19 is polymers such as N95 respirators made of polypropylene and standard surgical masks made of polypropylene [45]. The application of waste to energy needs to be executed to reduce the generation of medical waste. The application of waste to energy in PPE waste treatment is a suitable step in starting a sustainable environmental policy [33], [46]. Thermo-chemical conversion is another alternative to reduce PPE plastic waste and to produce value-added products [47]. Using pyrolysis, the face mask waste can be converted aromatic and aliphatic compunds such as 2,4-dimethyl-1-heptene [48] or oil as high as 80.7 wt% [49].

4. CONCLUSION

COVID-19 shifts the waste composition, due to regulation for the use of personal protective equipment and people's lifestyles during pandemic. This consequently contributes to the increase debris in water bodies, both rivers, and marine. Infectious waste treatment policies need to be implemented, especially innovations in the manufacture of biodegradable personal protective equipment (PPE).

REFERENCES

[1] N. van Doremalen *et al.*, “Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1,” *New England Journal of Medicine*, vol. 382, no. 16, pp. 1564–1567, Mar. 2020, doi: 10.1056/NEJMc2004973.

[2] S. S. Siwal *et al.*, “Key ingredients and recycling strategy of personal protective equipment (PPE): Towards sustainable solution for the COVID-19 like pandemics,” *Journal of Environmental Chemical Engineering*, vol. 9, no. 5, p. 106284, 2021, doi: 10.1016/j.jece.2021.106284.

[3] S. Jiangtao and W. Zheng, “Coronavirus: China struggling to deal with mountain of medical waste created by epidemic,” 2020. [Online]. Available: https://www.scmp.com/news/china/society/article/3065049/coronavirus-china-struggling-deal-mountain-medical-waste-created.

[4] J. Rodríguez-Pardo *et al.*, “Acute stroke care during the COVID-19 pandemic. Ictus Madrid Program recommendations,” *Neurología (English Edition)*, vol. 35, no. 4, pp. 258–263, 2020, doi: 10.1016/j.nrleng.2020.04.007.

[5] C. Wang, P. W. Horby, F. G. Hayden, and G. F. Gao, “A novel coronavirus outbreak of global health concern,” *The Lancet*, vol. 395, no. 10223, pp. 470–473, 2020, doi: 10.1016/S0140-6736(20)30185-9.

[6] J. Y. Haji, A. Subramaniam, P. Kumar, K. Ramanathan, and A. Rajamani, “State of Personal Protective Equipment Practice in Indian Intensive Care Units amidst COVID-19 Pandemic: A Nationwide Survey,” *Indian Journal of Critical Care Medicine : Peer-Reviewed, Official Publication of Indian Society Of Critical Care Medicine*, vol. 24, no. 9, pp. 809–816, Sep. 2020, doi: 10.5005/jp-journals-10071-23550.

[7] WHO, “Water, sanitation, hygiene, and waste management for the COVID-19 virus: interim guidance,” *World Health Organization*, 2020. [Online]. Available: https://www.who.int/publications-detail/water-sanitation-hygiene-and-waste-management-for-covid-19.

[8] A. K. Das, M. N. Islam, M. M. Billah, and A. Sarker, “COVID-19 pandemic and healthcare solid waste management strategy – A mini-review,” *Science of The Total Environment*, vol. 778, p. 146220, 2021, doi: 10.1016/j.scitotenv.2021.146220.

[9] N. J. Rowan and J. G. Laffey, “Unlocking the surge in demand for personal and protective equipment (PPE) and improvised face coverings arising from coronavirus disease (COVID-19) pandemic – Implications for efficacy, re-use and sustainable waste management,” *Science of The Total Environment*, vol. 752, p. 142259, 2021, doi: 10.1016/j.scitotenv.2020.142259.

[10] G. Kampf, D. Todt, S. Pfaender, and E. Steinmann, “Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents,” *Journal of Hospital Infection*, vol. 104, no. 3, pp. 246–251, 2020, doi: 10.1016/j.jhin.2020.01.022.

[11] N. Singh, Y. Tang, Z. Zhang, and C. Zheng, “COVID-19 waste management: Effective and successful measures in Wuhan, China,” *Resources, conservation, and recycling*, vol. 163, p. 105071, Dec. 2020, doi: 10.1016/j.resconrec.2020.105071.

[12] Y. Ma, X. Lin, A. Wu, Q. Huang, X. Li, and J. Yan, “Suggested guidelines for emergency treatment of medical waste during COVID-19: Chinese experience,” *Waste Disposal & Sustainable Energy*, vol. 2, no. 2, pp. 81–84, 2020, doi: 10.1007/s42768-020-00039-8.

[13] L. Ecola, H. Lu, and C. Rohr, *How is COVID-19 changing Americans' online shopping habits? Five months into the pandemic*. Santa Monica, CA: RAND Corporation, 2020.
[14] N. Rangel-Buitrago *et al.*, "Plastic pollution on the Colombian central Caribbean beaches," *Marine Pollution Bulletin*, vol. 162, p. 111837, 2021, doi: 10.1016/j.marpolbul.2020.111837.
[15] C. C. Naughton, "Will the COVID-19 pandemic change waste generation and composition?: The need for more real-time waste management data and systems thinking," *Resources, conservation, and recycling*, vol. 162, p. 105050, Nov. 2020, doi: 10.1016/j.resconrec.2020.105050.
[16] M. A. Zambrano-Monserrate, M. A. Ruano, and L. Sanchez-Alcalde, "Indirect effects of COVID-19 on the environment," *The Science of the total environment*, vol. 728, p. 138813, Aug. 2020, doi: 10.1016/j.scitotenv.2020.138813.
[17] H. B. Sharma *et al.*, "Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic," *Resources, Conservation and Recycling*, vol. 162, p. 105052, 2020, doi: 10.1016/j.resconrec.2020.105052.
[18] T. C. Nzeadibe and A. U. P. Ejike-Alieji, "Solid waste management during COVID-19 pandemic: policy gaps and prospects for inclusive waste governance in Nigeria," *Local Environment*, vol. 25, no. 7, pp. 527–535, Jul. 2020, doi: 10.1080/13549839.2020.1782357.
[19] A. D. Zand and A. V. Heir, "Emerging challenges in urban waste management in Tehran, Iran during the COVID-19 pandemic," *Resources, conservation, and recycling*, vol. 162, p. 105051, Nov. 2020, doi: 10.1016/j.resconrec.2020.105051.
[20] S. W. Rhee, "Management of used personal protective equipment and wastes related to COVID-19 in South Korea," *Waste Management and Research*, vol. 38, no. 8, pp. 820–824, 2020, doi: 10.1177/0734242X20933343.
[21] Q. Liu *et al.*, "Spatiotemporal patterns of COVID-19 impact on human activities and environment in Mainland China using nighttime light and air quality data," *Remote Sensing*, vol. 12, no. 10, 2020, doi: 10.3390/rs12101576.
[22] S. Wan *et al.*, "Impact of the covid-19 event on trip intensity and air quality in southern china," *Aerosol and Air Quality Research*, vol. 20, no. 8, pp. 1727–1747, 2020, doi: 10.4209/aaqr.2020.07.0364.
[23] Q. Wang and M. Su, "A preliminary assessment of the impact of COVID-19 on environment – A case study of China," *Science of The Total Environment*, vol. 728, p. 138915, 2020, doi: 10.1016/j.scitotenv.2020.138915.
[24] N. P. Purba *et al.*, "Distribution of Macro Debris in Savu Sea Marine National Park (Kupang, Rote, and Ndana Beaches)," *World News of Natural Sciences*, vol. 21, no. September, pp. 64–76, 2018.
[25] M. R. Cordova and I. S. Nurhati, "Major sources and monthly variations in the release of land-derived marine debris from the Greater Jakarta area, Indonesia," *Scientific Reports*, vol. 9, no. 1, p. 18730, 2019, doi: 10.1038/s41598-019-55065-2.
[26] I. S. Nurhati and M. R. Cordova, "Marine plastic debris in Indonesia: Baseline estimates (2010-2019) and monitoring strategies (2021-2025)," *Marine Research in Indonesia*, vol. 45, no. 2, pp. 97–102, Dec. 2020, doi: 10.14203/mri.v45i2.581.
[27] M. R. Cordova, I. S. Nurhati, E. Riani, Nurhasanah, and M. Y. Iswari, "Unprecedented plastic-made personal protective equipment (PPE) debris in river outlets into Jakarta Bay during COVID-19 pandemic," *Chemosphere*, vol. 268, p. 129360, Apr. 2021, doi: 10.1016/J.CHEMOSPHERE.2020.129360.
[28] I. W. K. Suryawan, A. Sarwono, I. Y. Septiariva, and C.-H. Lee, "Evaluating Marine Debris Trends and the Potential of Incineration in the Context of the COVID-19 Pandemic in Southern Bali, Indonesia," *Jurnal Ilmiah Perikanan dan Kelautan*, vol. 13, no. 1, 2021.
[29] I. Suryawan *et al.*, "Comparison of Ozone Pre-Treatment and Post-Treatment Hybrid with Moving Bed Biofilm Reactor in Removal of Remazol Black 5," *International Journal of Technology*, vol. 12, no. 2, 2021.
[30] I. Y. Septiariva and I. W. K. Suryawan, "Development of water quality index (WQI) and hydrogen sulfide (H2S) for assessment around suwung landfill, Bali Island," *Journal of Sustainability Science and Management*, vol. 16, no. 4, pp. 137–148, 2021.
[31] F. D. de Sousa, "Pros and Cons of Plastic during the COVID-19 Pandemic," *Recycling*, vol. 5, no. 4. 2020, doi: 10.3390/recycling5040027.
[32] G. E. De-la-Torre, M. R. J. Rakib, C. I. Pizarro-Ortega, and D. C. Dioses-Salinas, "Occurrence of personal protective equipment (PPE) associated with the COVID-19 pandemic along the coast of Lima, Peru," *Science of the Total Environment*, vol. 774, p. 145774, 2021, doi: 10.1016/j.scitotenv.2021.145774.
[33] C. Zhou, G. Yang, S. Ma, Y. Liu, and Z. Zhao, "The impact of the COVID-19 pandemic on waste-to-energy and waste-to-material industry in China," *Renewable and Sustainable Energy Reviews*, vol. 139, p. 110693, 2021, doi: 10.1016/j.rser.2020.110693.
[34] R. Raksasat *et al.*, "Blended sewage sludge–palm kernel expeller to enhance the palatability of black soldier fly larvae for biodiesel production," *Processes*, vol. 9, no. 2, pp. 1–13, 2021, doi: 10.3390/pr9020297.
[35] O. Ouhsine, A. Ouigmane, E. Layati, B. Aba, R. J. Isaifan, and M. Berkani, "Impact of COVID-19 on the qualitative and quantitative aspect of household solid waste," *Global Journal of Environmental Science and Management*, vol. 6, pp. 41–52, 2020, doi: 10.22034/GJESM.2019.06.SI.05.
[36] J. L. Cadnum, D. F. Li, S. N. Redmond, A. R. John, B. Pearlmutter, and C. J. Donskey, "Effectiveness of ultraviolet-c light and a high-level disinfection cabinet for decontamination of N95 respirators," *Pathogens & immunity*, vol. 5, no. 1, pp. 52–67, Apr. 2020, doi: 10.20411/pai.v5i1.372.
[37] I. H. Hamzavi *et al.*, "Ultraviolet germicidal irradiation: Possible method for respirator disinfection to facilitate reuse during the COVID-19 pandemic," *Journal of the American Academy of Dermatology*, vol. 82, no. 6, pp. 1511–1512, 2020, doi: 10.1016/j.jaad.2020.03.085.
[38] E. Grignani *et al.*, "Safe and effective use of ozone as air and surface disinfectant in the conjuncture of COVID-19," *Gases*, vol. 1, no. 1, pp. 19–32, 2020, doi: 10.3390/gases1010002.
[39] R. Dennis, B. Pourdeyhimi, A. Cashion, S. Emanuel, and D. Hubbard, "Durability of disposable N95 mask material when exposed to improvised ozone gas disinfection," *The Journal of Science and Medicine*, vol. 2, no. 1, Apr. 2020, doi: 10.37714/josam.v2i1.37.
[40] A. Schwartz *et al.*, "Decontamination and Reuse of N95 Respirators with Hydrogen Peroxide Vapor to Address Worldwide Personal Protective Equipment Shortages During the SARS-CoV-2 (COVID-19) Pandemic," *Applied Biosafety*, vol. 25, no. 2, pp. 67–70, 2020, doi: 10.1177/1535676020919932.
[41] T. Teymourian, T. Teymoorian, E. Kowsari, and S. Ramakrishna, "Challenges, Strategies, and recommendations for the huge surge in plastic and medical waste during the Global COVID-19 pandemic with circular economy approach," *Materials Circular Economy*, vol. 3, no. 1, p. 6, 2021, doi: 10.1007/s42824-021-00020-8.
[42] M. A. Zambrano-Monserrate and M. Alejandra Ruano, "Do you need a bag? Analyzing the consumption behavior of plastic bags of households in Ecuador," *Resources, Conservation and Recycling*, vol. 152, p. 104489, 2020, doi: 10.1016/j.resconrec.2019.104489.
[43] J. Canning-Clode, P. Sepúlveda, S. Almeida, and J. Monteiro, "Will COVID-19 Containment and Treatment Measures Drive

Shifts in Marine Litter Pollution?," *Frontiers in Marine Science*, vol. 7. p. 691, 2020.
[44] S. A. Sarkodie and P. A. Owusu, "Impact of COVID-19 pandemic on waste management," *Environment, Development and Sustainability*, vol. 23, no. 5, pp. 7951–7960, 2021, doi: 10.1007/s10668-020-00956-y.
[45] S. Jain, B. Yadav Lamba, S. Kumar, and D. Singh, "Strategy for repurposing of disposed PPE kits by production of biofuel: Pressing priority amidst COVID-19 pandemic," *Biofuels*, pp. 1–5, Aug. 2020, doi: 10.1080/17597269.2020.1797350.
[46] T. A. Aragaw and B. A. Mekonnen, "Current plastics pollution threats due to COVID-19 and its possible mitigation techniques: a waste-to-energy conversion via pyrolysis," *Environmental Systems Research*, vol. 10, no. 1, p. 8, Dec. 2021, doi: 10.1186/s40068-020-00217-x.
[47] S. Jung, S. Lee, X. Dou, and E. E. Kwon, "Valorization of disposable COVID-19 mask through the thermo-chemical process," *Chemical Engineering Journal*, vol. 405, p. 126658, 2021, doi: 10.1016/j.cej.2020.126658.
[48] S. Yousef, J. Eimontas, N. Striūgas, and M. A. Abdelnaby, "Pyrolysis kinetic behaviour and TG-FTIR-GC–MS analysis of Coronavirus Face Masks," *Journal of Analytical and Applied Pyrolysis*, vol. 156, p. 105118, 2021, doi: 10.1016/j.jaap.2021.105118.
[49] S. B. Lee *et al.*, "Production of value-added aromatics from wasted COVID-19 mask via catalytic pyrolysis," *Environmental Pollution*, vol. 283, p. 117060, Aug. 2021, doi: 10.1016/j.envpol.2021.117060.

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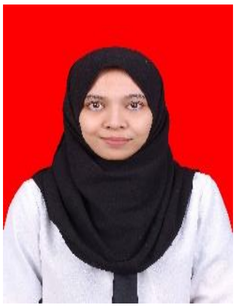

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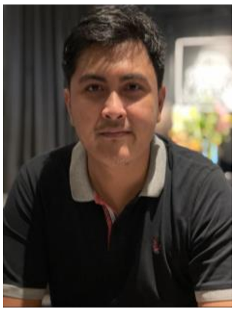

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