Prediction and management of household solid waste generation during COVID-19 pandemic in Bandung City using system dynamics model

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Abstract. WHO declared a novel coronavirus in humans as Coronavirus Disease 2019 (COVID-19) on February 2020, and Indonesia as well as Bandung City have been suffering from COVID-19 since the first case in March, 2020. Currently, the outbreak of COVID-19 has occurred for more than a year. The COVID-19 pandemic had a severe impact on the environment, like the enhancement of household solid waste as a result of work and school from home policies to decrease the rates of COVID-19 cases. This study aimed to predict the amount of household solid waste generation and analyze the waste management during COVID-19 in Bandung City using a system dynamics model. Data for model input was obtained from questionnaire to 200 respondents from Bandung spread across the sub-districts. The results revealed that the household solid waste generation was increased by 1.3 to 3.8% compared to the year before the COVID-19 pandemic. The composition of household solid waste was dominated by food and plastic waste, which have increased to 76.43% and 25.81%, respectively. The system dynamics model has predicted the household waste generation from three management scenarios for 30 years of model simulation. Scenario I: the household solid waste was totally managed by a local sanitary agency (existing condition); Scenario II: each household manage their waste by recycling; and Scenario III: the utilization of a local waste bank to manage the waste. The scenario III showed the most effective waste management to reduce the amount of household solid waste generation up to 24% by using waste bank. This scenario can be applied for more prolonged landfill operations up to 17 years.

Keywords: Bandung City; COVID-19 pandemic; household solid waste management; system dynamics model

1. Introduction
The novel Coronavirus first emerged in December 2019 in Wuhan, China, and until January 2020 the virus was classified as ordinary pneumonia [1]. The spread of this epidemic continues to grow until there are reports of death and new cases outside China. It is finally known that the cause of this pneumonia cluster is a new type of Coronavirus [2]. Due to the easy transmission of Coronavirus disease (COVID-19) through droplets released from an infected individual’s mouth or nose, the virus soon spread almost to every country worldwide. Hence in February 2020, the World Health Organization (WHO) classified COVID-19 as a pandemic [3].
The first case of COVID-19 in Indonesia was found in March 2020 as well as in Bandung city [4]. As a result, the government announced a national “social distancing” and instructed people to stay at home [5] in order to decrease the rates of COVID-19 cases. Furthermore, the local government in Bandung city has implemented the Large-Scale Social Restrictions since April 22, 2020 to prevent the expansion of COVID-19 [6].

The outbreak of COVID-19 has caused many social and economic problems and also led to some environmental ones. The most severe effects of the pandemic were felt in households and day-to-day life due to work and school from home policies [7]. With so many activities conducted from home, it impacts the generation and composition of the waste produced. The enhancement of household solid waste during COVID-19 in Padang and Surabaya cities has been reported [8][9].

This study aimed to predict the amount of household solid waste generation and composition, and analyze the waste management during COVID-19 in Bandung city using a system dynamics model. Modelling waste management can be a useful tool for assessing people's behavior and predicting its impact in the environment for which system dynamics model can play an important role, because in most cases, this cannot be measured directly [10]. Therefore, findings from this study provide valuable insights for people and local government to manage household solid waste, especially during and after the pandemic of COVID-19.

2. Methodology

2.1. Data collection

Due to the social restrictions, the primary data was obtained from questionnaire using Google form application, which can be distributed quickly and broadly through links shared to respondents. Primary data collection was carried out from June – September 2020 that consisted of 200 respondents spread across 30 sub-districts in Bandung city. The minimum sample size for sampling at household sources for metropolitan city categories is determined based on Indonesian National Standard (SNI) number 19-3964-1994, which is 200 samples/respondents [11]. In accordance with research ethics protocols, respondents were informed that their participation in the study was voluntary, the answers would be used only for research, and the protection of their personal data will be upheld at all times.

The primary and secondary data for model variables (Table 1) were collected from questionnaires, previous studies, published data, and literature related to household solid waste generation in Bandung City. In addition, the percentage value of some fraction variables was obtained from the questionnaire data analysis.

2.2. Model development and analysis

A system dynamics model is a graphical approach to building dynamical systems models by combining the relations we perceive in such systems. It makes use of very few structures which are projected onto virtually any type of dynamical system and its processes, i.e., it makes strong use of analogical reasoning. Using system dynamics model, a simple idea can be combined into models of complex system and process, it makes the integration of modelling and experimenting a simple matter also the simple concepts behind the system dynamics model correspond to a basic form of human thought [12].

The system dynamics model has been used frequently to identify the best scenario to reduce waste generation [13][14][15], minimize the cost of waste management [16][17], and to extend the life of landfills [18][19]. This study used system dynamics model to predict the household solid waste generation that was developed using Vensim PLE (Ventana System, Inc.) software based on three assumptions that were considered to formulate the model:

- The number of respondents was 200 households for model input that represent Bandung City
- There was no delay in the process of household solid waste management
- The time unit that used in the model was year
Table 1. Values, unit, methods, and references of a variable used in the model.

| Variable                         | Value       | Method/Reference |
|----------------------------------|-------------|------------------|
| Population growth rate           | 1.15%       | [20]             |
| Organic waste fraction           | 63.72%      | Questionnaire    |
| Inorganic waste fraction         | 36.28%      | Questionnaire    |
| Waste generation per capita      | 0.59 kg/capita/day | [21]         |
| Recycling fraction               | 2.4%        | Questionnaire    |
| Composting fraction              | 0.60%       | Questionnaire    |
| Burning fraction                 | 2.79%       | Questionnaire    |
| Discharging to the river fraction| 0.40%       | Questionnaire    |
| Burying fraction                 | 1.70%       | Questionnaire    |
| Discharging to unused land fraction| 0.13%    | Questionnaire    |
| Other fraction                   | 0.8%        | Questionnaire    |
| Laysitall fraction*              | 87.20%      | Questionnaire    |
| Waste bank fraction              | 4.07%       | Questionnaire    |
| Anaerobic digestion fraction     | 21.4%       | [22]             |
| Composting in laystall fraction  | 44.3%       | [22]             |
| Waste sorting fraction           | 23%         | [22]             |
| Landfill fraction                | 11.3%       | [22]             |
| Destruction fraction             | 10%         | [23]             |

*Laysitall is a place for deposit waste for a temporary period.

2.3. Scenario analysis
Scenario analysis was conducted by applying three household solid waste management scenarios based on respondents’ answers from the questionnaire. The model simulation will predict the waste generation starting from 2020 to the next few years by considering the maximum landfill capacity.

3. Results and Discussion

3.1. Household solid waste management during the COVID-19 pandemic
The result of questionnaire analysis is shown by Figure 1 to Figure 4. The gender of respondents consisted of male (47%) and female (53%) with the age range: 20 years and under, 21-30 years, 31-40 years, 41-50 years and more than 50 years. The highest percentage of age was in the range of 41-50 years at 58%, followed by 31-40 years at 39%.

Figure 1 shows the income level of the respondents, namely high income (HI), medium income (MI), and low income (LI) classes based on Indonesia's Central Statistics Agency [24]. HI class has a monthly income above 3,500,000 IDR, MI class is in the range of 2,500,000 – 3,500,000 IDR, and LI class are under 2,500,000 IDR. From Figure 1a, this study's respondents were mainly households with high incomes.

From the questionnaire data that was carried out during June-September 2020, it was found that 97% of respondents did work from home (WFH), and school from home (SFH), and the rest of 3% still had activities outside the house, as shown in Figure 1b.
During the pandemic, all the respondents answered that their using masks to anticipate the spread of COVID-19. This condition led to a drastic change of household solid waste generation. Masks became a part of daily lives, and the waste generated from it has added a voluminous load to waste management systems. Figure 2 shows the masks waste management in the household. Although, mostly, the respondents from all classes discharged and mixed masks waste with other waste (78.16% for HI, 90.35% for MI and 100% for LI), only 21.84% and 9.65% of respondents (HI and MI classes, respectively) disposed and separated the masks waste in a particular container. Figure 2 revealed that public awareness over the risks of masks waste remains low. Disposable masks need to be disposed of attentively since they can be a vector of infection for other family members and waste collectors [25]. Disposable masks that are ready to be discarded must be sprayed first using disinfectant, then clipping the masks in order to prevent misuse of the used masks [26].

The questionnaire analysis found that the most massive composition of household solid waste was an organic waste at 63.72%, while inorganic waste was 36.28%. Figure 3 shows the composition of household solid waste during COVID-19. The biggest waste components for every class are food waste, followed by plastic waste. Due to the restriction and stay-at-home policy, this condition triggered respondents to cook at home, causing higher food consumption. Furthermore, the high percentage of plastic waste was related to increased online shopping and delivery ordering, where single-use plastic is used as packaging for food or household items. Those new trends have contributed tremendously to household solid waste.
Figure 3. Composition of household solid waste during COVID-19.

Figure 4 shows the household solid waste management during the pandemic by all the classes. Primarily, the respondents transport their waste to laystall or TPS (Tempat Penampungan Sementara). This was an existing condition that respondents just followed the normal activities of waste management provided by the local sanitary agency. Although, most of them did not manage or treat their waste, only a few respondents managed their waste by transporting to a waste bank (4.07%), burning the waste (2.70%), recycling (2.40%), and burying the waste (1.70%).

Figure 4. Household solid waste management during COVID-19.
3.2. Model formulation and prediction of household solid waste generation

The complete system dynamics model of household solid waste can be developed from the result of questionnaire analysis (Figure 5). There were seven stocks: population, organic household solid waste, inorganic household solid waste, household solid waste, waste bank, laystall, and landfill. The arrow sign shows the connection from the variable that influenced the stock. Figure 5 also describes the household solid waste management chain that is generated from households until landfills. The household solid waste management simulated in the model is based on the information and the result from Figure 4.

Figure 5. Stock flow diagram of household solid waste management during COVID-19.

The model prediction for household solid waste composition before and during COVID-19 is shown in Figure 6. As seen in Figure 6, the waste generation in pandemic era has increased 1.3 to 3.8% compared to 2019, before the pandemic [27]. A recent study in Padang City found that during the COVID-19 pandemic, household solid waste increased by 2 to 3% [8]. Several cities in other countries have also experienced the COVID-19 pandemic's impact on the increase in household solid waste generation. For example, research conducted in Kenififra City, Morocco, found an increase in household waste by 3.8%, while in New York City, the household waste was increased by 3.3% [28].
3.3. Model prediction of household solid waste generation to capacity of landfill

All the waste generation in Bandung City was transported to Sarimukti landfill in West Bandung District. The landfill capacity was 1,200 ton/day; however, recently driven by population growth and changing consumption patterns, the waste generation is increasing at 2,000 ton/day [29]. Sarimukti landfill has been overloaded and can only accommodate waste until 2023. Therefore, the local government of Bandung area has prepared for the new landfill, namely Legok Nangka, which will replace Sarimukti landfill. It has a capacity of 2,131 ton/day and will be operated in 2022 [30].

The system dynamics model has predicted the household waste generation from three management scenarios for 30 years of model simulation. The result of the model prediction is shown in Figure 7.

- Scenario I: the household solid waste was managed by the local sanitary agency (existing condition)
- Scenario II: each household manages their waste by recycling
- Scenario III: local waste bank utilization

Scenario I shows that the waste will exceed the maximum capacity of landfill (red line) after 8 years, while Scenario II shows that the waste will exceed the maximum capacity of landfill after 13 years, and Scenario III shows the longest time to reach the maximum capacity of landfill after 17 years.

Waste bank has been established and regulated by the Ministry of Environment and Forestry, Republic of Indonesia since 2012 [31]. Waste Bank is a place for sorting and collecting waste that can be recycled and/or reused that has economic value. Waste Bank is a concept of collecting and segregating solid waste involving banking systems. Waste deposited by the customer will be weighed and valued with a sum of money. The waste will later be sold at factories or recycling agents or handed over to local upcycling agents for processing [32]. In Bandung City, a waste bank was introduced by the local sanitary agency since 2015. Furthermore, the waste bank also comes from the non-government organization and private sector. Waste management using waste bank concept is beneficial in making a clean environment and impacts the local economy by increasing the community's income.

Although recycling for household solid waste management in Scenario II impacts the longer use of landfill, based on the result of the questionnaire in Figure 4, only a few respondents are willing to recycle their waste. Hence, Scenario III was the most effective way to reduce the amount of household solid waste generation up to 24% by using a waste bank. This scenario can be applied for the more prolonged operation of the landfill.
Figure 7. The result of the model prediction; (a) Scenario I; (b) Scenario II; and (c) Scenario III.
4. Conclusion
The household solid waste generation has been predicted using a system dynamics model supported by questionnaire analysis. The results found that the household solid waste generation increased 1.3 to 3.8% compared to the year before the COVID-19 pandemic. The composition of household solid waste was dominated by food and plastic waste, which have increased to 76.43 % and 25.81 %, respectively. Therefore, scenario III was the most effective way to reduce the amount of household solid waste generation up to 24% by using a waste bank. Furthermore, this scenario can be applied for more prolonged landfill operations up to 17 years.

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References
[1] Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, Qiu Y, Wang J, Liu Y, Wei Y, Xia J, Yu T, Zhang X and Zhang L 2020 Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study Lancet 395 507–13
[2] Yuniti I G A D, Sasmita N, Komara L L, Purba J H and Pandawani N P 2020 The impact of Covid-19 on community life in the province of Bali, Indonesia Int. J. Psychosoc. Rehabil. 24
[3] WHO 2020 Coronavirus disease 2019 (COVID-19) situation report – 51 WHO
[4] Ihsanuddin 2020 Fakta Lengkap Kasus Pertama Virus Corona di Indonesia Kompas.com
[5] Halidi R 2020 Bukan Lockdown, Ini Kebijakan Presiden Jokowi Terkait Pencegahan Covid-19 Suara.com
[6] Simbolon H 2020 PSBB Bandung Raya Resmi Dimulai 22 April 2020 Liputan6.com
[7] Filho W L, Voronova V, Kloga M, Paço A, Minhas A, Salvia A L, Ferreira C D and Sivapalan S 2021 COVID-19 and waste production in households: A trend analysis Sci. Total Environ. 777
[8] Juwono K F and Diyanah K C 2021 Analisis pengelolaan sampah rumah tangga (sampah medis dan non medis) di kota Surabaya selama pandemi COVID-19 J. Ekol. Kesehat. (The Indones. J. Heal. Ecol. 20) 12–20
[9] Ruslinda Y, Aziz R and Putri F F 2020 Analysis of Household Solid Waste Generation and Composition During The Indonesia J. Environ. Manag. Sustain. 4 116–24
[10] Sunaryani A and Rosmalina R T 2021 Persistence of carbaryl pesticide in environment using system dynamics model IOP Conf. Ser. Earth Environ. Sci. 623
[11] Badan Standarisasi Nasional 1994 Metode pengambilan dan pengukuran contoh timbulan dan komposisi sampah perkotaan
[12] Fuchs H U 2006 System dynamics modeling in science and engineering 42
[13] Fauzan A 2017 Strategi pengelolaan sampah untuk mengurangi timbulan sampah plastik (sistem pengelolaan sampah dengan simulasi model sistem dinamik di Pulau Pramuka Kabupaten Administrasi Kepulauan Seribu). (Universitas Indonesia)
[14] Rahayu N, Arai T, Yudoko G and Morimoto H 2013 System dynamics models for planning long-term integrated municipal solid waste management in Bandung city Sustainable City 2021 pp 1153–68
[15] Zulfinar Z and Sembiring E 2015 Dinamika Jumlah Sampah yang Dihasilkan di Kota Bandung J. Teh. Lingkung. 21 18–28
[16] Kohli K 2005 Rekayasa model sistem dinamik pengelolaan sampah terpadu berbasis nirlimbah (zero waste) studi kasus di Jakarta Selatan (Institut Pertanian Bogor)
[17] Yudiyanto Y 2014 Analisis sistem pengelolaan sampah permukiman di Kota Bogor (Institut Pertanian Bogor)
[18] Giannis A, Chen M, Yin K, Tong H and Veksha A 2017 Application of system dynamics modeling for evaluation of different recycling scenarios in Singapore J. Mater. Cycles Waste Manag. 19 1177–85
[19] Handono M 2010 *Model pengelolaan tempat pemrosesan akhir (TPA) sampah secara berkelanjutan di TPA Cipayung Kota Depok-Jawa Barat* (Institut Pertanian Bogor)

[20] Bandung B P S K 2020 *Kota Bandung Dalam Angka 2020* (Bandung)

[21] Damanhuri E and Padmi T 2006 *Pengolahan Sampah* (Bandung)

[22] Mulianingsih S 2019 *Manajemen sampah padat di kota Bandung dan metode alternatif pengolahannya* J. Papatung 2 170–9

[23] Indartik, Suryandari E Y, Djaenudin D and Pribadi M A 2018 *Penanganan Sampah Rumah Tangga Di Kota Bandung: Nilai Tambah dan Potensi Ekonomi* J. Penelit. Sos. dan Ekon. Kehutan. 15 195–211

[24] Statistik B P 2008 *Penggolongan Pendapatan Penduduk* (Jakarta, Indonesia)

[25] Mol M and Caldas S 2020 *Can the human coronavirus epidemic also spread through solid waste?* Waste Manag. Res. 5 485–486

[26] Kehutanan K L H dan 2020 *Surat Edaran Menteri Lingkungan Hidup dan Kehutanan Nomor: SE.2/MENLHK/PSLB3/PLB.3/3/2020 Tahun 2020 tentang Pengelolaan Limbah Infeksius (Limbah B3) dan Sampah Rumah Tangga dari Penanganan Corona Virus Disease (COVID-19)*

[27] Khairunisa N S and Safitri D R 2020 *Integrasi Data Sampah Sebagai Upaya Mewujudkan Zero Waste Management: Studi Kasus Di Kota Bandung* J. Anal. Sosiol. 9 108–23

[28] Ouhsine O, Ouigmane A, Layati E, Aba A, Isaifan R and Berkani M 2020 *Impact of COVID-19 on the qualitative and quantitative aspect of household solid waste* Glob. J. Environ. Sci. Manag. 6 41–52

[29] Gunawan D 2021 *TPA Sarimukti Bandung Barat Overload Sampah* Mediaindonesia.com

[30] Hayati D 2021 *Pemprov Jabar Targetkan Pembangunan TPPAS Regional Legok Nangka Rampung pada 2023* Kompas.com

[31] Kementerian Lingkungan Hidup dan Kehutanan 2012 *Peraturan Menteri Negara Lingkungan Hidup Republik Indonesia Nomor 13 Tahun 2012 tentang Pedoman Pelaksanaan Reduce, Reuse, dan Recycle Melalui Bank Sampah* (Indonesia)

[32] Bahraini A 2020 *Waste Bank to Support Indonesia Clean-from-Waste 2025* waste4change.com