Modeling the impact of the COVID-19 pandemic on air emissions indicators of climate change originating from solid waste management in coastal settlements

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Abstract. COVID-19 was first reported in Indonesia on March 2, 2020. Several actions have been taken, such as limiting population mobility and prohibiting almost all activities that can be avoided. This policy has environmental consequences, especially the amount of solid waste generation. This study provides a view of the effect of COVID-19 on the amount of solid waste generation and composition in coastal settlements, the impact on air quality which has implications for climate change, and provides the most efficient solid waste management solution. Measurement of solid waste data using SNI 19-3964-1994 and air emissions analysis using the IWM2 software. On the basis of this quantitative analysis, we reached the following conclusions: (1) the reduction of solid waste generation is 15.47% with the composition during the pandemic namely organic 41.4%; wood 3.4%; fabric/textile 1.1%; rubber/leather 13.4%; plastic 21.3%, iron 5.5%; Glass 3.9%, paper 0.2% and residue 6.8%, (2) the resulting air emissions decreased by parameters CO₂ of 32.33 tons/year (37.97%), CH₄ of 14.37 tons/year (38.14%), and Global Warming Potential (GWP) of 334.01 tons/year (38.12%), (3) the most efficient management of solid waste for coastal settlements during the COVID-19 pandemic period is the process of recycling, biological processing, and bringing residues to landfill.

1. Introduction
The World Health Organization (WHO) declared that COVID-19 as a pandemic on 11 March 2020 [1]. These viruses have spreaded around 188 countries, then until 12 July 2020 amount 12.498.467 confirmed positive cases and conducted 560.269 deaths [2]. The first case was discovered in the city of Wuhan, China in December 2019, then identified as zoonosis coronavirus [3]. The outbreak of COVID-19 is more widespread through human-to-human transmission. Every country that have included as local transmission classification enacted some actions to slow the transition and lower the impact of the pandemic [4] [5], such as social or physical distancing to avoid the crowds, programs
that aim to increasing public awareness, mass testing and quarantine policies, and economic support packages for the susceptible community [6].

In Indonesia, until 12 July 2020, recorded more than 75,699 positive cases and 3,606 deaths, regional with the higher cases is East Java [7]. The outbreak of COVID-19 spread very fast, with expected reproduction number \( R_0 \) around 2-3. As a sign of the transmissibility of the virus, it means that the change of increasing cases number [8]. Indonesia as the fourth most populous country in the world has high risk of virus transmissions and likely to have an impact in a long time. As well as another country with the same crisis, Indonesia Government has released regulations for acceleration of handling COVID-19, such as Task Force for Rapid Response to COVID-19 and Big Scale Social Restriction for Accelerating COVID-19 Eradication [9]. The regulation is expected to decrease the curve of positive cases especially in settlements both in big cities and villages. Many populations live in dense settlements, with high risk of exposure to the virus.

COVID-19 pandemic has affected various sectors. In Indonesia, economic growth weakened especially in the first quarter [10]. Tourism and travel were the sectors which were the most severely affected by COVID-19. Tourism and travel restriction, both international and domestic in several areas affect the economics sector. The number of tourists decreases then triggers the loss of hotels, restaurants, and travel agencies business. Around 80% potential travel consumers canceled their trip plan because of the instruction for reducing the outdoor activities [9].

On the other side, COVID-19 pandemic brings another impact in the environment sector. The tourist objects with natural attraction look cleaner than before. Beach, as one of favorite tourist objects, that usually bear waste heap from irresponsible people or from marine debris, able to recover the environment while this pandemic happens [11]. It is related with the travel restriction regulations that are enforced in various countries, which is caused by the lack of tourists and sea transportation activities. Nevertheless, this condition is also faced with another problem, that is medical waste that is made from difficult material to decompose. It needs standardization and strict implementation of the medical waste management [12].

The indirect impact of the virus on the environment has been little analyzed. The first studies estimated a positive indirect impact on the environment. On the one hand, climate experts predict that greenhouse gas (GHG) emissions could drop to proportions never before seen since World War II [13]. This outcome is mainly due to the social distancing policies adopted by the governments following the appearance of the pandemic. For example, in Hubei province (China), strong social distancing measures were implemented in late 2019. These measures affected the country's main economic activities. As a result, power plants and industrial facilities halted their production. Also, the use of vehicles decreased considerably. All this led to a dramatic reduction in the concentrations of Nitrogen Dioxide (NO) and Particulate Matter that have a diameter of less than 2.5 µm (PM 2.5) in the main Chinese cities [11]. As a result of the pandemic, countries such as the USA have stopped recycling programs in some of their cities, as authorities have been concerned about the risk of COVID-19 spreading in recycling centers. In particularly affected European countries, waste management has been restricted. For example, Italy has prohibited infected residents from sorting their waste. Also, the industry has seized the opportunity to repeal disposable bag bans, even though single-use plastic can still harbor viruses and bacteria [14].

Climate change occurs due to increased greenhouse gas concentrations in the atmosphere, as a result of transportation, industrial, heap urban waste, livestock, agriculture, change of land use, forest conversion, and so on. One of the Greenhouse gases causes climate change is methane gas (CH\(_4\)), which is produced by landfill. The higher landfill, with no further processing, raises the larger emissions of methane gas. Increased CH\(_4\) emissions resulted in the wider impacts of climate change. It is caused because methane gas has a defective power 20-30 times stronger than CO\(_2\). In fact, the concentration of CH\(_4\) that persisted in the atmosphere for 7-10 years can increase the Earth's temperature by 1.30°C [15]. This study provides a view of the effect of COVID-19 on the amount of solid waste generation and composition in coastal settlements, the impact on air quality which has implications for climate change, and provides the most efficient solid waste management solution.
2. Material and methods
This research was conducted in coast of Wakatobi Regency during COVID-19 which consisted of three main stages as follows: (1) Estimation of the amount of solid waste produced (2) Characteristics of waste, analysis of the amount and type of waste and (3) Analysis of waste management.

2.1 Estimation of the amount of solid waste produced
Collection and measurement of waste dumps were carried out for 8 days in the settlement's coastal area. The method used in the collection and measurement of waste dumps is the Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste (SNI 19-3964-1994). According to American Standard Testing and Material (ASTM) recommendations, samples weighing 200-300 pound (91-136 kg) can be chosen and a single sample of 100 kg is a good representative of the total waste characteristics. The total waste is put in a measuring box then weighed. After weighing the waste placed on a tarp for sorting based on its composition.

2.2 Waste characterization
In the SNI method 19-3964-1994, the categorization of waste is divided into 9 categories: organic, wood, fabric/textiles, rubber/leather, plastics, irons, glass/glass, paper and residue. The percentages for each group was calculated using the following equation:

\[ PC = \frac{PL}{PT} \times 100\% \]

where PC is the percentage of each group, PL is the amount of group present in kg, and PT is the total weight of the waste in kg [16].

2.3 Waste management analysis
The method of analyzing waste management systems uses Integrated Waste Management 2 (IWM2) software. Results of the model from IWM2 can give facilities for waste management in determining the concept of integrated management [17]. The IWM2 model provides several aspects of the waste management system namely the level of water pollution, the level of air pollution, energy analysis, economic analysis and the total waste produced. Modelling of waste in coastal settlement area uses four scenarios, namely: 1) Scenario 1 by the way the collected garbage is sent directly to the landfill without prior processing (same as the current management system); 2) Scenario 2 with a waste management system there is a separation consisting of 25% paper and 50% organic material for the composting process and the rest will be sent directly to the landfill site; 3) Scenario 3 by the generation of waste generated entirely will be sent to the landfill the same as Scenario 1, but the material that can be recycled will be managed through the management of the recycling system and 4) Scenario 4 where the waste management system already has waste sorting and sorting activities waste that can still be used will be recycled. In addition, in this Scenario 4 there is a biological treatment process through composting activities, while the resulting residue will be processed at the landfill.

2.4 Research site
The data of solid waste before COVID-19 pandemic use a study was carried out on the Analysis and Modelling the Impact of pollutants in the Waha Raya Coastal Area which consists of 3 coastal villages of Wapia-pia Village, Waha Village, and Koroe Onowa Village [17]. According to the study, the waste generation by the Waha Raya Coastal Area is included in the group of moderate the middle municipal waste generation, amounting to 1,875 tons/day and/or 0.72 kg/person/day. This waste generation is caused by people’s dependence on packaging products. This research was conducted by taking samples from 4 islands in Wakatobi during the COVID-19 pandemic (April-May 2020). The occurrence of COVID-19 certainly provides a change in lifestyle and behavior of people in almost all corners of the world, as well as in Wakatobi. One is the decline in local people outdoor activities as a
form of Social Distancing. As a tourism destination with maritime tourism based, Wakatobi also felt the impact of COVID-19, where there was a drastic decline (zero) of tourist visits both foreign and domestic, due to obstructed transport flows, especially air transportation which was totally stopped. The decline in activities from both local people and tourists in Wakatobi will certainly also affect the condition of waste generation in the coastal areas of Wakatobi. Wakatobi is one of the island districts of Southeast Sulawesi Province, which is dominated by ±97% of the sea waters area and ±3% of the land area of the total Wakatobi Region. Wakatobi are composed of 4 islands of Wangi-Wangi Island, Kaledupa Island, Tomia Island, and Binongko Island as shown in Figure 1. Rural topographical conditions of Wakatobi District 75% are in the overland (flat) and 90% of its site is on the coast [10]. Wakatobi has 90 coastal villages of 100 total marine potential, so local community activities will also come in contact with coastal areas that can affect coastal ecosystems. Certainly, tourism activities will also give to the condition of coastal ecosystems, if the management and use do not fit into the rules of sustainable coastal ecosystems.

![Figure 1. Area of Wakatobi Regency](image)

3. Results and discussions
3.1 Waste generation and composition before and during the COVID-19 pandemic
Waste generation before COVID-19 in the coastal settlement area is 1,875 tons/day or 0.72 kg/person/day while during the pandemic COVID-19 in the Coastal settlement area is 1,589 tons/day or 0.61 kg/person/day. Thus, decreasing waste generation by 15.47%. Waste generation during the COVID-19 pandemic is lower due to semi-lockdown community activities, the lack of marine tourism activities [18], distribution bans, and various other policies. This policy also considers conditions on
the beach. The lack of tourists, as a result of social distance measures due to the new coronavirus pandemic, has caused important changes in the appearance of many beaches in the world, now looks cleaner than solid waste and with clear water [11]. The coast is one of the most important natural capital assets found in coastal areas [19]. They offer services (land, sand, recreation and tourism) that are essential for the survival of coastal communities and have intrinsic value that must be protected from over-exploitation. However, irresponsible use by people has caused many of the world's beaches to present pollution problems [20].

However, this condition does not apply in some special urban areas. The quarantine policy, established in most countries, has directed consumers to increase their demand for online shopping for home delivery. As a result, organic waste generated by households increases. Also, food purchased online is shipped packaged, so that inorganic waste also increases. Medical waste is also increasing. Hospitals in Wuhan produced an average of 240 metric tons of medical waste per day during the outbreak, compared to the previous average of less than 50 tons. In other countries such as the US, there has been an increase in waste from personal protective equipment such as masks and gloves [21]. In addition to waste generation, the composition of waste in coastal settlement areas also experienced a significant change, especially in the composition of organic waste which decreased by 9.8%. In full, a comparison of the composition of waste before and during the COVID-19 pandemic is shown in Figure 2 and Figure 3. This change in composition was caused by the consumption patterns of the people who relied more on special seasoned food packaging materials, such as turmeric, pepper, and so on. This change in consumption patterns also causes the composition to accumulate flexible plastic and rigid plastic to increase by about 2-fold.

![Figure 2. Composition of waste in coastal settlement areas before COVID-19 pandemic](image1)

![Figure 3. Composition of waste in coastal settlement areas during COVID-19 pandemic](image2)

3.2 Air Emission changes before and during the COVID-19 period

The decrease in the quantity of generation and change in the composition of waste results in air emissions resulting from waste management also changing. Comparison of air emissions is carried out in accordance with current waste management using sanitary landfills without pre-treatment before being taken to landfills. Before the Pandemic, the amount of CO₂ emissions produced was around 85.14 tons CO₂/year where after the pandemic produced CO₂ air emissions around 52.81 tons CO₂/year. Thus, the resulting air emissions decreased by CO₂ parameters of 32.33 tons/year (37.97%), the CH₄ parameter produced air emissions before the pandemic around 37.67 tons CH₄/year and when the pandemic was around 23.30 tons CH₄/year, with a decrease of 14.37 tons CH₄/year (38.14%). In the
GWP value, the amount of emissions produced was around 875.29 tons/year and when the pandemic produced emissions around 542.21 tons/year with a reduction in emissions of around 334.01 tons/year (38.12%). Completely displayed in Figure 4.

![Figure 4](image-url)

**Figure 4.** Comparison of air emission CO\(_2\) (a), CH\(_4\) (b), and GWP (c) concentrations before and during COVID-19 pandemic from current solid waste management system

3.3 **Modeling of waste management systems before and during the COVID-19 pandemic**

The current waste management in Wakatobi Regency and most of the other coastal areas uses conventional methods, namely collection, transportation and final processing in the landfill, which are not by PP 82 of 2012 about Management of Household Waste and Similar Household Waste. This study also provides recommendations for efficient waste management using the IWM2 method. The efficiency indicator of waste management is based on the level of air emissions that have both direct and indirect impacts on climate change, namely the concentration of CO\(_2\), CH\(_4\), and GWP. The waste management system that is modeled consists of the stages of collection, sorting, biological processing,
thermal treatment, and landfills. Each stage produces emission levels so that the total air emissions from each scenario can be obtained as shown in Figure 5 as follows.

![Air emission concentrations from waste management in coastal settlement area CO\(_2\) (a), CH\(_4\) (b), and GWP (c) concentrations (1,3,5,7 is during pandemic scenario and 2,4,6,8 is before pandemic scenario)](image)

**Figure 5.** Air emission concentrations from waste management in coastal settlement area CO\(_2\) (a), CH\(_4\) (b), and GWP (c) concentrations (1,3,5,7 is during pandemic scenario and 2,4,6,8 is before pandemic scenario)

Based on Figure 5, the most suitable waste management system applied in the Coastal Settlement Area both before and during COVID-19 is Scenario 4 with an estimated air emission level of each CO\(_2\) of -63.59 tons/year; CH\(_4\) of 0.67 tons/year; and GWP of -51.19/year. The current management system can cause a decrease in air quality, pollution of groundwater, leachate, and disturbance of comfort [22]. Waste management system by relying on landfill will produce air pollution, especially CH\(_4\) and CO\(_2\). In addition, groundwater pollution can also occur through leachate infiltration. The level of leachate water pollution concentrations is very high based on BOD\(_5\) of 762-2397 mg/l, COD of 1299-4402 mg/l, NH\(_4^+\)-N of 1012-1023 mg/l, and NO\(_3^-\)-N of 27-34 mg/l [23]. Decreased air and water quality can affect the health of the community around the landfill, so a change in waste management
system is needed. One of the factors causing this scenario is better because of the sorting and recycling. Waste recycling has always been a major environmental problem of interest to all countries [8]. Recycling is a common and effective way to prevent pollution, save energy, and conserve natural resources [24]. However, it should be noted that as a result of the pandemic, countries such as the USA have stopped recycling programs in some of their cities, as authorities have been concerned about the risk of COVID-19 spreading in recycling centers. In particularly affected European countries, waste management has been restricted. For example, Italy has prohibited infected residents from sorting their waste. Also, the industry has seized the opportunity to repeal disposable bags, even though single-use plastic can still harbor viruses and bacteria [14]. Thus, waste management in coastal settlements can be very important during COVID-19 emergencies because it has an impact on air emissions and other pollution. Finally, it was concluded that COVID-19 will produce positive and negative indirect effects on the environment. Reducing CO₂, CH₄, and GWP concentrations is expected to be consistent until after the pandemic by applying the most efficient waste management.

4. Conclusion
The occurrence of COVID-19 provides the decline in activities from coastal settlement area will certainly affect to the reduction of solid waste generation is 15.47% with the composition during the pandemic namely organic 41.4%; wood 3.4%; fabric/textile 1.1%; rubber/leather 13.4%; plastic 21.3%, iron 5.5%; Glass 3.9%, paper 0.2% and residue 6.8%. The resulting air emissions decreased by parameters CO₂ of 32.33 tons/year (37.97%), CH₄ of 14.37 tons/year (38.14%), and GWP of 334.01 tons/year (38.12%). Recommendation the most efficient management of solid waste for coastal settlements during the COVID-19 pandemic period is the process of Separated, sorting, recycling, biological treatment process through composting activities, and bringing residues to landfill (Scenario 4).

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