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LIFE CYCLE ASSESSMENT OF SOLID WASTE GENERATION DURING AND BEFORE PANDEMIC OF COVID-19 IN BALI PROVINCE

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Abstract: The outbreak of coronavirus diseases (COVID-19) receives much attention globally. On January 30, 2020, WHO has stated it was a global health emergency. The Indonesian Government requiring that all work from home and restricting access to activities outside the home. In the Bali Province, it has had a positive impact on the environment, especially for the amount of waste generation and emissions. The main objectives of this study were to analyse solid waste generation and to provide a review of issues in environmental impact during and before the pandemic of COVID-19 in Bali Province. LCA technique has been used extensively to evaluate the environmental performance of several municipal solid waste management technologies. An LCA study consists of four stages, such as goal and scope, life cycle inventory, life cycle impact analysis, and interpretation. The degraded organic carbon (DOC) value before the pandemic was 0.121 while after the pandemic the DOC reduced to 0.058. Moreover, methane and carbon dioxide production from waste generation per day was counted in this study. The total global warming potential from waste generation has been drastically reduced from 1,859.6 kg CO_{2eq}/day to 420.8 kg CO_{2eq}/day.

Keywords: Bali Province, COVID-19, environmental quality, life cycle assessment, solid waste management.

Introduction

At the end of December 2019, in a hospital located in Wuhan City, China, unusual pneumonia was noticed with a link to an animal market that sells poultry, fish, and other animals to the public (Xu *et al.*, 2020). This event was soon reported to the world health organization (WHO). On January 26, 2020, the causal microorganism had been identified as a novel coronavirus that was named coronavirus disease (COVID-19) (Saadat *et al.*, 2020). The new coronavirus (SARS-CoV2) has generated an unprecedented impact in most countries of the world. The virus has affected almost every country in the world (213 in total), spread to more than 2 million people, and caused around 130,000 deaths (WHO, 2020). This disease is caused by systemic acute respiratory syndrome (SARS) Coronavirus-2 (SARS-COV2). Besides, other global environmental changes such as soil degradation, ozone layer depletion, pollution, and urbanization, changing environment create an indisputable threat to our planet and human health (Chakraborty & Maity, 2020)

Then it was said that this virus can spread out through droplets (particles) when humans contact each other. To counter that problem, the Indonesian Government has taken preventive action by releasing a policy about learning from home, working from home, and worshiping from home (Ihsanuddin, 2020). In Indonesia, there are 8,882 cases until Sunday, April 27, 2020, including the Province of Bali which has now reached 186 cases (National

Disaster Management Agency of the Republic of Indonesia, 2020). In addition to influencing various aspects of the economy, the application of this policy turned out to have an indirect positive impact on environmental quality. Anjum (2020) mentioned the positive impact is by decreasing air pollution. The decreasing of NO_2 concentration in major cities in China were also reported from the lockdown policy (McGrath, 2020). The Province of Bali recently mentioned the reduced occurrence of transportation of solid waste to landfills than the previous time (Suadnyana, 2020).

In addition to increasing landfill capacity, reducing solid waste generation can also reduce gas emissions from the landfill process. An environmental impact assessment during and before the pandemic of COVID-19 can be accomplished by using the life cycle assessment (LCA) approach. LCA is an environmental evaluation technique used to quantitatively analyse the environmental impacts of a given system through its entire life cycle (from raw material extraction to ultimate disposal) (Li *et al.*, 2019). According to Ekvall *et al.*, (2007) LCA is an analytical tool that allows the comparison of environmental performance for solid waste management. The application of LCA to landfills is, however, more challenging compared to other waste management solutions, given the complexity of landfill sites and their management strategies, and given the long term effects of this disposal solution (Sauve & Acker, 2020).

In waste management, LCA studies the potential impacts of the waste life cycle on the environment. The popularity of LCA for analyzing municipal solid waste management systems has been illustrated in numerous published studies (Khandelwal *et al.*, 2018). But most of them mainly focus on a specific solid waste or waste treatment systems.

In this research, we determined changes in environmental impact before and during the COVID-19 pandemic in Bali Province, especially in the field of solid waste management. There are many issues related to inappropriate waste management as a tourism island. This study is expected to provide information on a global perspective in solid waste management based on the LCA approach. It is an issue that must be addressed to save our most valuable resource and the environment in Bali Province.

Methodology of LCA

LCA methodology follows a cradle to grave (from raw material extraction to production, use, and disposal), cradle to gate (raw material extraction to the factory for production), and gate to gate (a receipt of material by a factory to shipping the produced material to the gate) approaches as per the requirements and objectives of any study (Yadav & Samadder, 2018). LCA methodology was used to compare the environmental impacts of solid waste management before and during the pandemic, based on ISO 14040-1997. The LCA stages consist of goal and scope definition, life cycle inventory, life cycle impact analysis, and interpretation.

Goal dan Scope

This research aims to determine the environmental impact of global warming potential (GWP) from solid waste management in Bali Province with a database of solid waste transport to landfills. The data of solid waste transporting to landfills was obtained from the Regional Environmental Office of Bali Province (Table 1). Then the data used as a scope of the problem in LCA analysis.

Life Cycle Inventory (LCI)

This section is carried out to identify and to quantify the flow of solid waste and emissions released into the environment. The research method used to calculate carbon emissions from solid waste processing uses the Intergovernmental Panel on Climate Change (IPCC) 2006 approach. The IPCC 2006 Manual is a method that can be applied to all countries or regions because it provides default values,

Table 1: Waste transportation from the urban area to the landfill site in Bali Province

Regency	Before Pandemic 2019 (ton/day)	During Pandemic (ton/day)	Landfill Name
Badung	600.35	101.68	TPA Sarbagita Suwung
Bangli	47.34	13.26	TPA Bangklet
Buleleng	125.36	102	TPA Bengkala
Gianyar	254.09	71.15	TPA Temesi
Jembrana	38	31.28	TPA Peh
Karangasem	43.86	50	TPA Linggasana
Klungkung	43.22	12.1	TPA Sente
Tabanan	64.58	18.08	TPA Mandung
Kota Denpasar	739	530.77	TPA Sarbagita Suwung
Total	**1,955.8**	**930.32**	

Source: Regional Environmental Office of Bali Province, 2020; Suadnyana, 2020

estimates, and calculation methods to overcome the lack of data using emission factors that has been determined by the IPCC. The data required include the generation and composition of solid waste in landfills, water content, and the percentage of carbon values from the ultimate analysis. These data were obtained from literature studies that have been conducted before. The formula for calculating emissions of solid waste is shown in equations (1) to (3).

$$DDOC_m = W \times DOC \times DOC_F \times MCF \quad (1)$$

Where:

$DDOC_m$ = Mass of DOC decomposed, Gg W = Mass of solid waste disposal, Gg

DOC = Degraded organic carbon, Gg C/Gg solid waste

DOC_F = DOC fraction, in the amount of 0.5 based on IPCC 2006

MCF = The methane correction factor, in the amount of 0.8 due to the landfill in Bali Province is not well managed

$$Lo = DDOC_m \times F \times \left(\frac{16}{12}\right) \quad (2)$$

Where:

Lo = CH4 emissions (Gg CH4/year)

F = Fraction of CH4 by volume in the amount of 0.5 based on IPCC

16/12 = Molecular weight ratio of CH_4/C

$$CO_2 = \left(\frac{44}{12}\right) x\, W x\, DOC x\, DOC_F\, x\, (1 - MCF) \quad (3)$$

Where:

44/12 = Molecular weight ratio of CO_2/C

Life Cycle Impact Analysis

Life cycle impact was estimated by using OpenLCA ver. 1.9 software. The database in OpenLCA ver. 1.9 software that was used to estimate the magnitude of the impact of this research was the environmental product declaration (EPD) 2013.

Interpretation

The interpretation step was carried out to identify and to evaluate the results of the GWP potential analysis. The interpretation was based on the weighting results which were the output of the processed data in OpenLCA ver. 1.9 software.

Results and Discussion

Determination of Goal dan Scope

Solid waste generation is the amount of solid waste produced by humans in an area. The data of the generation of solid waste was very necessary for designing solid waste management systems. Amounts of solid waste generation recorded using the weighbridge facility. The transportation fleet carried out twice weighing; the first weighing was the transportation fleet containing solid waste and the second weighing was the transport fleet in an empty state. Based on the data in Table 1 solid waste generation per capita for each region can be seen in Figure 1.

As explained in Figure 1, the generation of solid waste in most regions in Bali Province has decreased, except in the Karangasem region. Before the pandemic, the highest solid waste generation is in Badung Regency compared to other regions. Badung Regency has solid waste generation with a value of 0.9 kg/capita.day and during the pandemic, the waste generation has drastically reduced to 0.15 kg/capita.day. Solid waste generation in Denpasar has slight decrease from 0.78 kg/capita.day to 0.56 kg/ capita.day. Badung Regency is one of the tourist destinations, where the waste generation in this area is greatly influenced by community participation (Yuliastuti *et al.*, 2013). The reduction of tourist arrivals and the closure of tourist areas contributed to the reduction in waste generation. Whereas Karangasem Regency experiences a slight increase in waste generation from 0.11 kg/capita.day to 0.14 kg/capita.day. Karangasem Regency is an area located in the eastern part of Bali Island. Karangasem regency residents are agricultural areas with major residents working as farmers. Tourism in this area is low compared to another regency in Bali Province which relies on the tourism sector (BPS, 2020). Tourism areas visit in Karangasem were decreased by 0.50% from 2015 (Prawerti *et al.*, 2015). The low formal sector that can implement work from home in this area causes the solid waste generation did not decrease.

Widyarsana *et al.* (2020) reported that the waste generation study in 2018 in Denpasar City and Badung Regency was the largest producer of the waste generation with a value of 0.81 kg/capita.day and 0.74 kg/capita.day. The measurement results showed an increase in waste generation and a decrease in generation in Badung Regency in 2019 in Denpasar City. The study of Widyarsana *et al.* (2020) also showed a decrease in waste generation from 2018 to 2019 for each other district, except Gianyar Regency. Widyarsana *et al.* (2020) mentioned that waste generation in 2018 in Gianyar Regency was only 0.36 kg/capita.day while in 2019 there was an increase in the waste generation to 0.5 kg/ capita.day. According to the information from Widyarsana *et al.* (2020) waste generation in Bali Province has decreased from 0.54 kg/capita. day to 0.36 kg/capita.day. The reduction in a waste generation may also be caused by local government policy through the Governor of Bali Province Regulation No. 97 of 2018 concerning Restrictions on the Use of Disposable Plastic Waste Generation. The implementation of waste

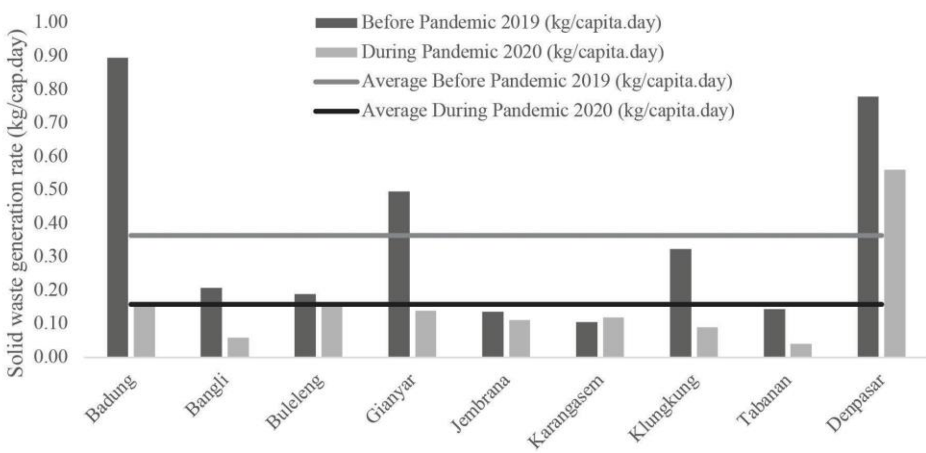

Figure 1: Solid waste generation in the Bali Province

regulation is still valid when the pandemic period, the types of disposable plastics are plastic bags, polystyrene (Styrofoam), and straws which are still not provided in shopping centres.

During the pandemic of COVID-19, the average waste generation in the Province of Bali was 0.16 kg/capita.day. It was lesser than before the pandemic. Figure 2 shows graphical information on the generation of waste before and during the pandemic in Badung, Gianyar, Klungkung, and Bangli Regencies. Considering that the Province of Bali is the center of tourist destinations in the world, waste generation is also influenced by the fulfillment of hotels, culinary, souvenirs, and tourism businesses. However, during this pandemic, there was a decline in the tourism sector, which is related to the decreasing in solid waste generation. This problem was mentioned also in Bintan Island which shows the decrease in demand for hotel rooms, gifts, and food consumption (Dinarto *et al.*, 2020).

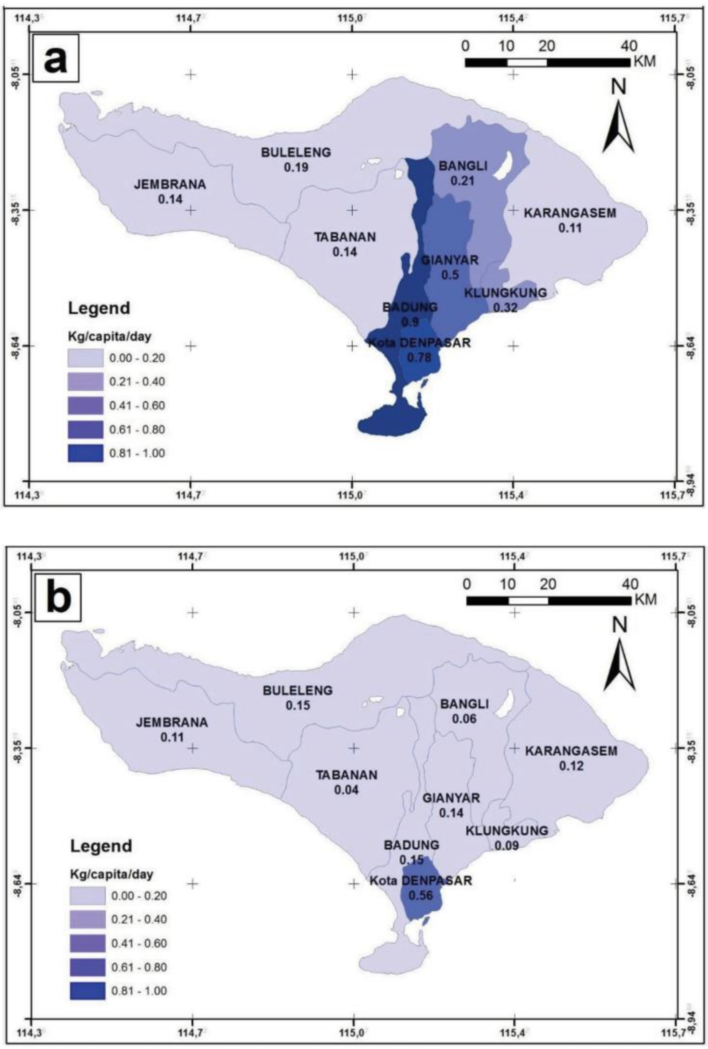

Figure 2: Geographical information systems (GIS) comparison of solid waste generation in Bali Province before (a) and during pandemic (b)

If looking from the percentage of solid waste reduction in each regency of Badung, Bangli, Gianyar, Klungkung, and Tabanan, the waste reduction rate was greater than 70% (Figure 3). The role of the citizens to stay at home was very positively reducing the generation of solid waste. Activities at home reduced consumption patterns in the citizens. Basically, before the pandemic, people tend to buy goods or services that were lack or not needed so that it became excessive. Since there was an appeal to not panic buying, the citizens limit their spending. People were encouraged to buy goods that are more needed than desired. This is in line with Urbanus and Febiant (2017) which states that the development of tourism will influence people to consume goods.

Result of Life-Cycle Inventory

DOC is a solid waste characteristic that determined the amount of CH_4 gas formed during the degradation process of organic carbon components, contained in the waste. In solid waste, the amount of DOC depends on the composition (% weight) of each waste component (Table 2). Indonesia itself does not yet have a default DOC number. To determine the DOC number, ultimate analysis (dry base) of the elementary components of C, H, N, O, S, ash was necessary. This research used proximate analysis to determine the dry base and ultimate analysis from previous studies conducted by Kustiasih *et al.* (2014). The composition of solid waste of the Bali Province was 6.15% of food waste, 53.07% of wood leaves, 15.23% of paper, 13.92% of plastics, 2% of metals, 1.81% of textile fabrics, 0.91% of leather rubber, 1.92% of glass, and 4.99% of others. The calculation result of the DOC value before the pandemic was 0.121 while after the pandemic the DOC reduced to 0.058. The DOC value before the pandemic was nearly equal to the Kustiasi *et al.*, (2014) research which had a value of 0.15.

By using equation (1) to equation (4) methane and carbon dioxide emissions in solid waste management in the landfills were obtained. The calculation result of methane and carbon dioxide production from solid waste generation per day can be seen in Table 3.

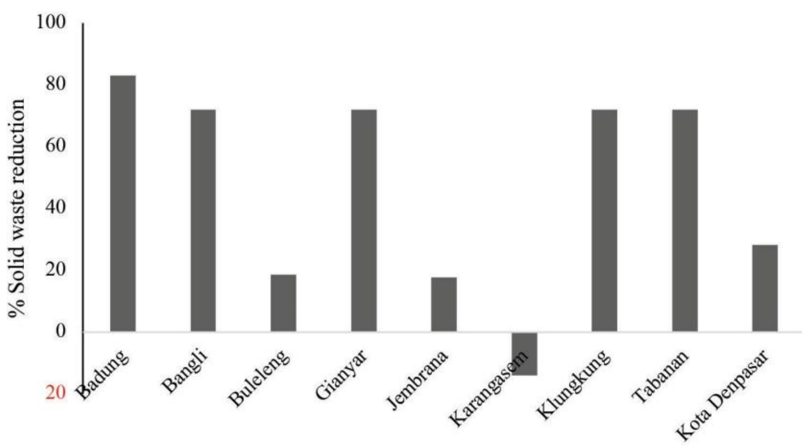

Figure 3: Percentage of solid waste reduction in the Bali province before and during the pandemic

Table 2: Calculation of DOC waste value in landfills for the Bali province before and during the pandemic

Component	%*	W before pandemic	W during pandemic	DOC before pandemic	DOC during pandemic
		Gg	Gg		
Food waste	6.15%	0.044	0.021	0.006	0.003
Wood leaves	53.07%	0.379	0.180	0.072	0.034
Paper	15.23%	0.109	0.052	0.036	0.017
Plastics	13.92%	0.099	0.047	0.000	0.000
Metals	2.00%	0.014	0.007	0.000	0.000
Textile fabrics	1.81%	0.013	0.006	0.005	0.002
Leather rubber	0.91%	0.006	0.003	0.002	0.001
Glass	1.92%	0.014	0.007	0.000	0.000
Others	4.99%	0.036	0.017	0.000	0.000
			Total	**0.121**	**0.058**

*SIPSN, 2018

Table 3: The methane and carbon dioxide emission in the landfill for the Bali province before and during the pandemic

Wilayah	Methane (kg/day)		Carbon dioxide (kg/day)	
	Before Pandemic	During Pandemic	Before Pandemic	During Pandemic
Badung	19.43	1.57	26.72	2.15
Bangli	1.53	0.20	2.11	0.28
Buleleng	4.06	1.57	5.58	2.16
Gianyar	8.22	1.10	11.31	1.51
Jembrana	1.23	0.48	1.69	0.66
Karangasem	1.42	0.77	1.95	1.06
Klungkung	1.40	0.19	1.92	0.26
Tabanan	2.09	0.28	2.87	0.38
Kota Denpasar	23.92	8.17	32.89	11.24

Result of Life Cycle Impact Analysis (LCIA)

The LCIA determination used the environmental product declaration (EPD) 2013 database with the emission factors of methane and carbon dioxide, respectively, 1 and 28. The total of GWP from solid waste management has been drastically reduced from 1,859.6 kg CO_{2eq}/day (678.8 tons CO_{2eq}/year) to 420.8 kg CO_{2eq}/day (153.6 tons CO_{2eq}/year). A comparison of GWP impact analysis from the solid waste sector can be seen in Figure 4. Winongo Landfill in Madiun City in 2017 showed the GWP impact value of 5,905.6 tons CO_{2eq}/year with waste generation to landfills of 25,007 tons/year (Kiswandayani *et al.*, 2016). Besides, Kendari City has generated waste for around 43,161 tons/year with the emissions of CO_2 reached 50,010 tons CO_{2eq}/year (Chaerul *et al.*, 2016). The high emission from that study was predicted due to the DOC value of 0.15-0.45, with the highest composition of waste, which is food waste (40.89%). Whereas, in this study, the DOC has a value of 0-0,072 with the highest waste composition was wood (53.07%). The emergence of food waste in Bali Province was arguably low with a value of 6.15%. Gao *et al.*, (2018) explained that globally food waste contributed to GWP with a value of 4.4 $GtCO_{2eq}$/year. Mamduhan *et al.*, (2015) mentioned that the value of CO_2 emissions from the solid waste sector in the City of Semarang only reached 54.21 tons of CO_2eq/ year. Romawati (2018) stated that the total CO_2 emissions from the solid waste sector in the Bula District of Surabaya City were 616.54tons CO_{2eq}/year. When compared with the data of the Bali Province, the generation of waste in Bula District could reach 0.414 kg/capita.day with the highest composition of food scraps (41.26%).

Interpretation Analysis

The GWP reduction from solid waste management showed a high value. GWP reduction could reach more than 50% for each region except in Karangasem Regency (Figure 5). The highest reduction in GWP emissions was found in Badung Regency. This is in line with the level of waste reduction.

The results of a GWP impact analysis from the generation of waste in each region of Bali Province before and during the pandemic can be seen in Figure 6. The amount of CO_2 emissions has decreased significantly from each district. The City of Denpasar also experienced a decrease in GWP from 702.6 kg CO_{2eq}/day to 240.1 kg CO_{2eq}/day. Mitra *et al.* (2020) also explained the differences in CO_2 emissions before and during the pandemic in the City of Kolkata. He *et al.* (2020) mentioned that the Air Quality Index in China during lockdown conditions that were previously 20-30 points will decrease from 0-10 points in warmer or Southern cities.

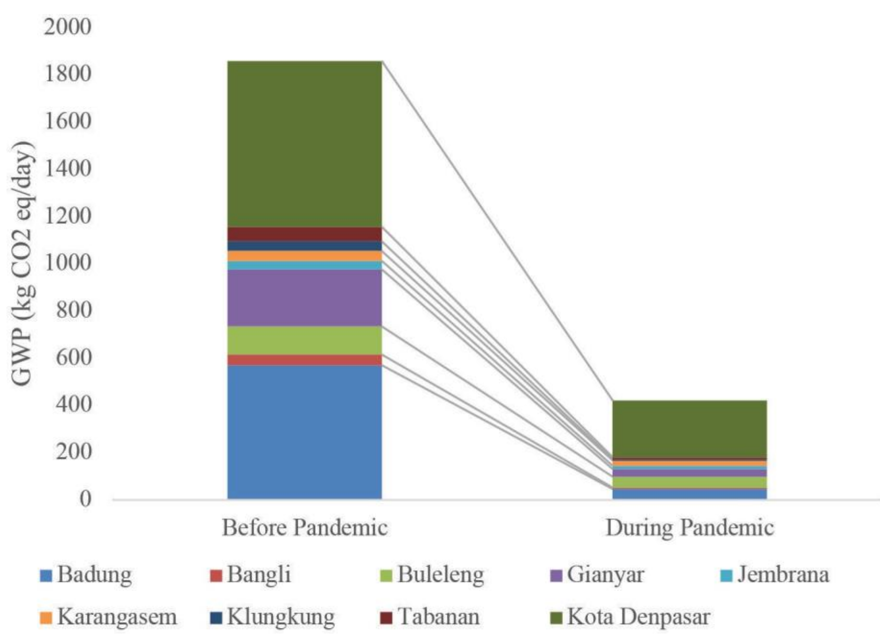

Figure 4: Comparison of GWP impact from the solid waste management sector in Bali Province

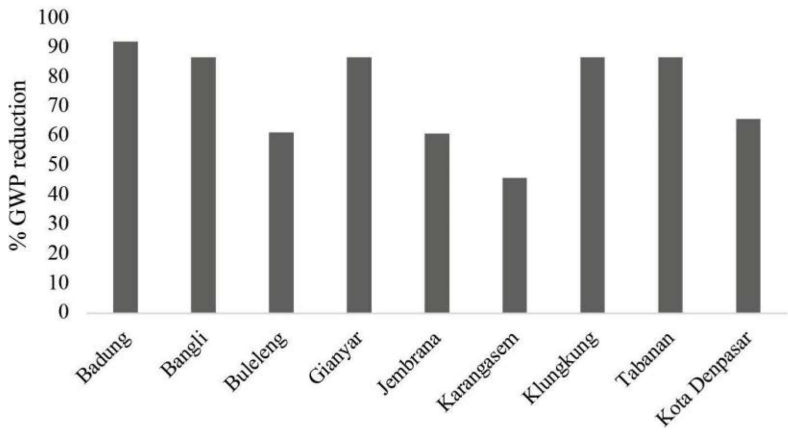

Figure 5: Comparison of GWP reduction from the solid waste generation in Bali Province

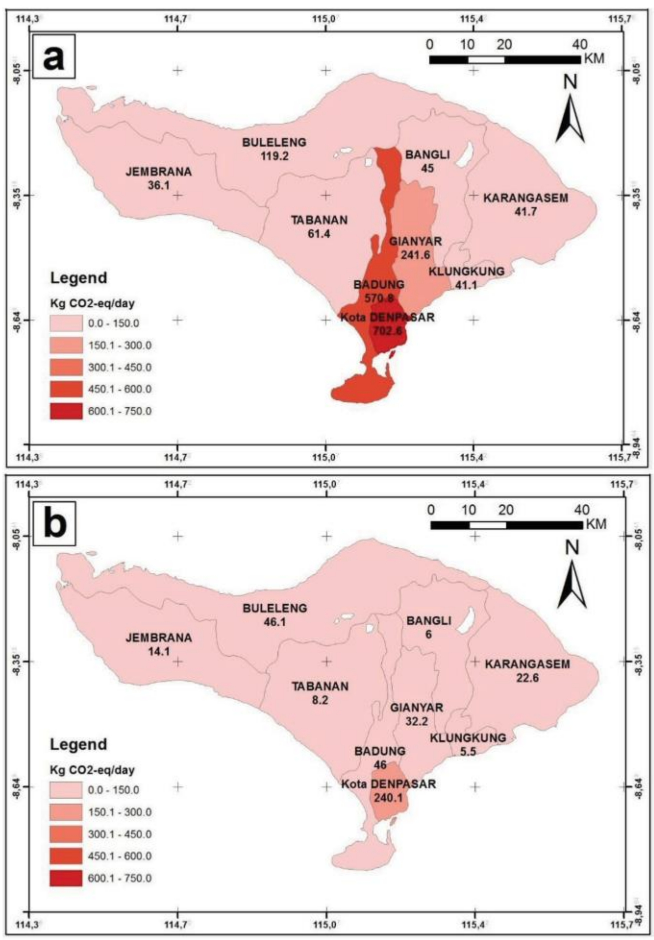

Figure 6: GIS comparison of GWP from solid waste generation in Bali Province before (a) and during (b) pandemic

Conclusion

This study has comprehensively analysed the generation of solid waste during and before the pandemic of COVID-19 in Bali Province through LCA analysis. Badung Regency has solid waste generation with a value of 0.9 kg/capita.day and during the pandemic, the waste generation has drastically reduced to 0.15 kg/capita.day. Solid waste generation in Denpasar has slight decrease from 0.78 kg/capita.day to 0.56 kg/capita.day. The percentage of solid waste reduction in each regency of Badung, Bangli, Gianyar, Klungkung, and Tabanan, the waste reduction rate is greater than 70%. The calculation result of the DOC value before the pandemic is 0.121 while after the pandemic the DOC reduced to 0.058. As a result of declining waste generation, the total GWP has been drastically reduced from 1,859.6 kg CO_{2eq}/day.to 420.8 kg CO_{2eq}/day. GWP reduction from solid waste management showed a greater value. The highest reduction in GWP emissions was found in Badung Regency. The amount of CO_2 emissions has decreased significantly from each district. The City of Denpasar also experienced a decrease in GWP from 702.6 kg CO_{2eq}/day.to 240.1 kg CO_{2eq}/day.

From the COVID 19 pandemic, it can be learned that waste generation can be reduced if we can wisely reduce the use of materials that can produce waste. Moreover, by obeying government regulations, the application of single-use of plastic bags in Bali Province is also a step to reduce solid waste generation. The reduction in a waste generation will have an impact on reducing the amount of methane and carbon dioxide released in the landfill process. So that the potential for environmental pollution can be suppressed.

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