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Potential of Waste to Energy Processing for Sustainable Tourism in Nusa Penida Island, Bali

Mega Mutiara Sari[1]✉, Takanobu Inoue[2], Regil Kentaurus Harryes[3], I Wayan Koko Suryawan[1], Kuriko Yokota[2], Suprihanto Notodarmojo[4], Ika Bagus Priyambada[5], Iva Yenis Septiariva[6]

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[1] Universitas Pertamina, Department of Environmental Engineering, Faculty of Infrastructure Planning, Jl. Teuku Nyak Arief, 12220, Indonesia
[2] Department of Architecture and Civil Engineering, Toyohashi University of Technology, Japan
[3] Faculty of Vocational Studies, Indonesia Defense University, Indonesia
[4] Department of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jl. Ganesa No.10, Lb. Siliwangi, 40132, Indonesia
[5] Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Jl. Prof. Sudarto, Tembalang, 50275, Indonesia Indonesia
[6] Civil Engineering Study Program, Departement Faculty of Engineering, Universitas Sebelas Maret, Jl. Ir. Sutami No.36, 57126, Indonesia

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Abstract

Solid waste management on Nusa Penida Island is one of the problems in tourism in Bali Province. To deal with this issue, the government has implemented various policies, where the policy that becomes an essential issue is the processing of energy waste. To support this, it is necessary to study the potential of waste characteristics on the island of Nusa Penida. This study aims to analyze the characteristics of waste on Nusa Penida Island as an energy source based on the generation and composition of waste. Solid waste generation and composition were measured based on land and marine debris data. The total waste generation on land and marine debris can reach 6364.4 kg/day and 762.8 kg/day, respectively. The waste composition materials consist of masks, plastics, metals, and biodegradable organics with a value of 4.12%, 32.77%, 19.54%, and 43.57%, respectively. Therefore, the potential use of organic biodegradable as solid fuel can reach 51,933.8 MJ/day or 14,426 kWh/day. However, in the thermogravimetric analysis (TGA) test, the residue was 18.6%. This shows that there is a considerable opportunity in processing waste in island tourism areas to be used as energy security. Further research needs to be done for sustainability and to prioritize programs to support the community economy and tourism on Nusa Penida Island.

INTRODUCTION

Waste management in Nusa Penida is currently limited to personal waste management and relies on Biaung Landfill as a final disposal site (Widyarsana & Agustina, 2020). At Biaung Landfill, the waste collection system is still in the form of an open dumping system. Open dumping shelters such as those carried out at the landfill are very susceptible to fire because piles of garbage produce flammable methane gas (Septiariva & Suryawan, 2021). Due to the limitations of the refuge in this landfill, most of the residents throw their garbage carelessly on vacant land or privately owned moor). Several community groups tried to carry out cleaning activities but could not optimally handle this condition of indiscriminate waste disposal. This will undoubtedly reduce the environmental quality and visual quality in the

✉ Corresponding author:
E-mail: mega.tiarasari1986@gmail.com

Nusa Penida area, which will indirectly show the inability of the village and sub-district governments to manage waste and affect the decrease in the number of tourist visits.

Tourism is the sector hardest hit by the COVID-19 pandemic. Tourism areas, especially Bali, have suffered the most from this pandemic. Therefore, local governments in Bali are starting to find ways to revive tourism that has been depressed by the pandemic (Bhaskara & Filimonau, 2021). In addition, in Klungkung Regency, there are social problems regarding landfills; it also needs to be considered for processing waste into pellets (Ain et al., 2021). This is part of implementing the waste to energy concept at the Local waste processing facility (TOSS), spreading in almost every district in the Klungkung Regency (Ain et al., 2021; Legino et al., 2019; Suryawan et al., 2021). However, villages in Nusa Penida do not yet have TOSS facilities for recycling their waste generation.

In preparing for a surge in tourists after the COVID-19 pandemic, it is necessary to prepare good waste management. This preparation can be done by preparing data on waste generation, composition, and characteristics, which are very supportive in preparing the waste management system in Nusa Penida. Therefore, this study aims to analyze waste generation, composition, and characteristics in tourist areas in Nusa Penida.

This research is significant to carry out as the first step in planning for waste management in island tourism areas, especially in dealing with the COVID-19 pandemic. This research can also be used by stakeholders to design policies and plans to support sustainable development. In addition, it can also be used by other countries that have a tourism sector on small islands to consider planning tourism destinations or infrastructure for residents.

MATERIALS AND METHODS

Measurement of Waste Generation and Composition

The data collected was primary data obtained by direct observation in the field. The measurement of coastal waste was carried out four times at each transect location. The transect line was used as a benchmark for data collection. Procedurally, the transect was drawn from the highest tide to the low tide point 50 meters long and 6m wide to the land, with 100 m^2. Marine debris collected on each transect is put into garbage bags. Next, the sample is dried, then the characterization of the type of waste is carried out based on the classification of plastic, mask, metal, and biodegradable organic waste. Finally, waste generation has been characterized weighed by using a digital scale so that the waste composition in this study is based on w/w.

Figure 1. Marine Debris Generation during Observations at Transect Sites.

Waste Characteristic

In this study, to determine the characteristics of the waste to be used, it was carried out using proximate. Proximate analysis was carried out by calculating the water and ash content using the gravimetric method. The calorific value measured is the initial calorific value of each type of waste. This calorific value measurement aims to determine the combustion potential of each type of waste sample. Calorific value analysis was carried out using a bomb calorimeter.

Data Analysis

The data obtained from this research is the value of the measured parameters. Parameters measured include water and ash content and calorific value at the beginning of the study using proximate analysis analytical procedures. From the results of this characteristic test, it can be determined which waste components meet the criteria as refuse-derived fuel (RDF) so that the

potential generation and composition of waste that can be used as RDF can be defined. The expected result of the research is that there is data on the potential for waste in Nusa Penida to become raw material for RDF from a technical point of view so that it can be considered for the construction of TOSS Nusa Penida. Energy potential analysis converts the potential calorific value in MJ/day and kWh/day units.

The final results of the waste that can be used as RDF are tested with TGA and DTA analysis. First, the sample was heated, starting at an initial temperature of 30°C and ending at a temperature of 800°C. At a constant speed of 10°C/minute with oxygen gas as a burner with a 20 ml/minute flow rate. The results of the thermal analysis were TGA and DTA thermograms.

RESULTS AND DISCUSSION

Waste Generation and Composition

The average marine debris generated in the coastal area of Nusa Penida reaches an average of 11.06 kg/km2. Day (Figure 2). Tourist activities in Nusa Penida certainly produce generally a solid waste. Solid waste management in Nusa Penida uses conventional methods, namely, collecting waste without segregation in a container. Sustainable tourism objects manage solid waste by first sorting waste from the source and differentiating the sorting container. The principle of waste management also needs to emphasize the 5Rs, namely reduce, reuse, recycle, repair and replace (Suryawardani & Wiranatha, 2016).

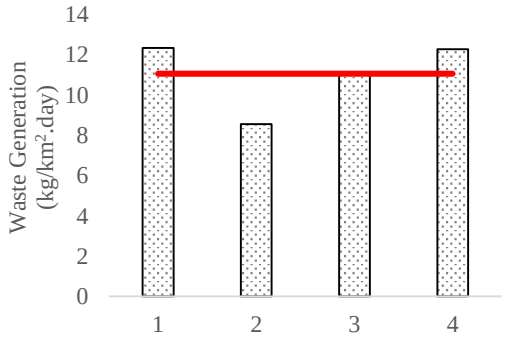


Figure 2. Marine Debris Generation During Observations at Transect Sites.

The types of waste collected around the waters of Nusa Penida consist of four general categories based on the observation. The composition types of waste are further differentiated based on the constituent materials of the waste obtained. The types and amounts of marine debris found during the study can be seen in Table 1.

The composition of waste in Nusa Penida is dominated by organic biodegradable waste and plastic waste, amounting to 45.57% and 32.77%, respectively (Figure 3). Plastic waste is a type of waste with quite a lot, 15% of the total waste generation has such a bad impact on nature. Furthermore, because plastic waste takes a very long time to be decomposed, plastic waste will only be destroyed within 200-400 years (Jiang et al., 2017). Meanwhile, the level of plastic consumption by the community is still relatively high (Pinto et al., 2019), especially during the COVID-19 pandemic, which requires the use of plastic to avoid virus contamination in products (Septiariva et al., 2022). Therefore, it is demanded the participation of all groups of society to manage plastic waste to reduce plastic buildup (Dilkes-Hoffman et al., 2019). Furthermore, damage to the preservation of the natural environment due to plastic waste can affect tourist attractions in Indonesia.

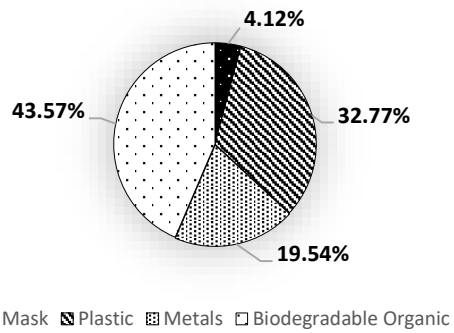


Figure 3. Waste Composition on Nusa Penida Island.

Tourist activities in conservation-based tourist attractions in the Wakatobi area cause an increase in the amount of waste generation, especially marine debris (Sejati et al., 2019). This has a terrible impact on the environment, especially the marine environment (Krelling et al., 2017; Lee et al., 2017; Olivelli et al., 2020). Moreover, marine animals can accidentally eat plastic waste, which can cause death for aquatic animals (Roman et al., 2021). In addition, Nusa Penida has diverse biodiversities, such as two manta points in the southern part of the island (Germanov et al., 2019).

Tabel 1. Waste Category and Composition in Nusa Penida Island

Category	Composition	Figure
Mask	Medical masks, non-medical masks, and cloth masks	
Plastic	Plastic bottles, plastic cups, plastic caps, plastic lighters, crackle and thick plastic wrap, rubber bands, straws, lunch boxes, plastic cup spoons, Styrofoam, ropes, fishing line, fishing tackle, rope, pipes, and plastic packaging.	
Metals	Cans, iron nails, other iron materials	
Biodegradable Organic Waste	Food waste, wood and twigs	

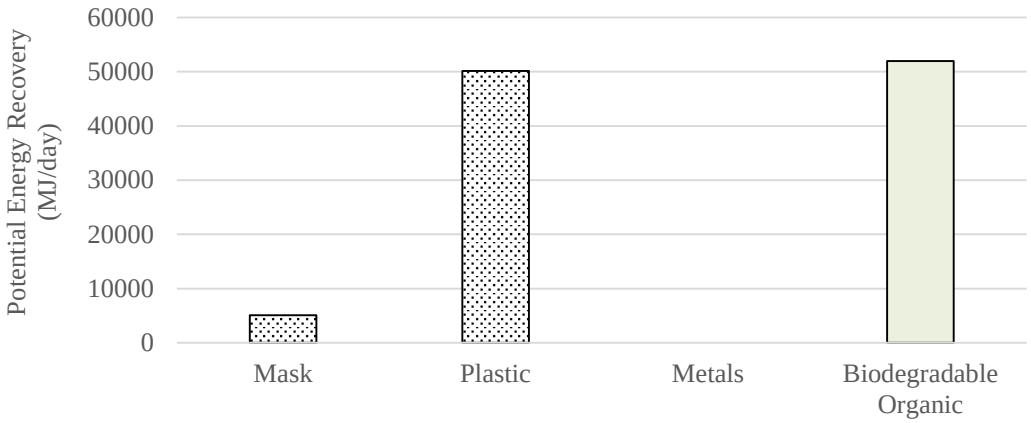
An article written by Andrew Marshall in the April 1, 2011 issue of Time magazine stated that Bali is a vacation spot like hell (Wardana, 2019). Bali is full of garbage, industrial waste and traffic jams in southern Bali are already acute. However, this news does not necessarily bring a better change to the environmental conditions in Bali. In March 2018, the world again witnessed the situation of the waters in Bali filled with plastic waste from a video recorded by a diver from the UK Rich Horner (The Guardian, 2018).

In the video recorded at the Manta Point Nusa Penida dive site, we can see Bali's sea waters' deplorable condition, filled with plastic waste. In addition, there are still many foreign media reporting about environmental conditions in Bali. The waste problem does not only occur on the island of Bali; based on data from Jambeck (Jambeck et al., 2015), Indonesia is ranked second in the world for producing plastic waste to the sea, which reached 187.2 million tons after China, which reached 262.9 million tons.

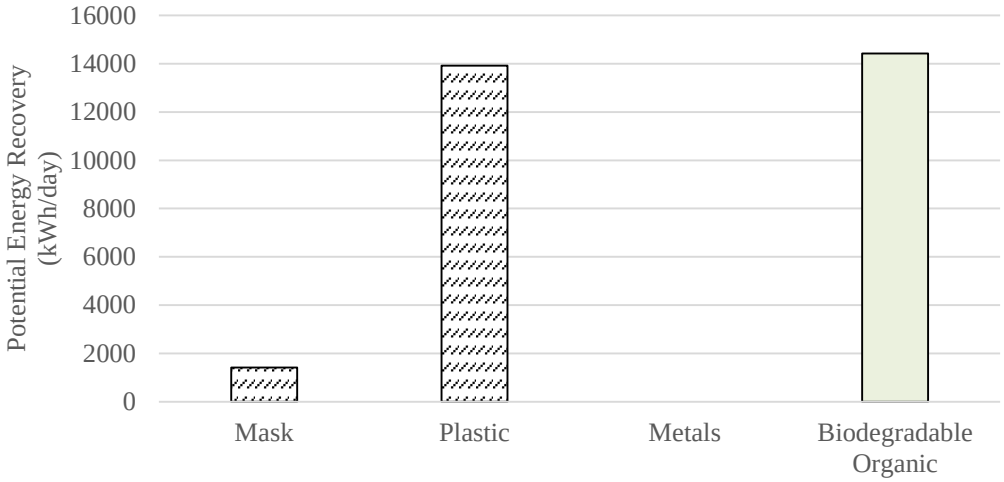
Table 2 compares waste generation by activities on land and the coast. The estimated waste generation in the area reaches 6364.4 kg/day, while the waste generation on the coast reaches 7127.2 kg/day. Thus, the amount of waste on land and at sea reaches 8.3: 1. Land waste can become marine waste if there is no proper management and handling of land waste, especially in coastal areas. Marine pollution by garbage has long been a global problem. Most of the waste from land that is not managed correctly will be carried away through rivers, rainwater flows, drainage, wind, or even by humans themselves and ends up in the sea (Barnes et al., 2009).

Tabel 2. Total Waste Generation on Nusa Penida Island.

Characteristic	Value	Unit
Total population	45460	capita
Waste Generation Rate	0.14	kg/cap.day
Total Domestic Waste Generation in Nusa Penida	6364.4	kg/day
Area of Tourism	6895	Ha
Tourist Coastal Area Waste Generation	11.1	kg/km^2.day
Total Tourism Waste Generation in Nusa Penida	762.8	kg/day
Total Waste Generation in Nusa Penida	7127.2	kg/day



(a)



(b)

Figure 4. Energy Recovery Potential for Each Type of Waste on Nusa Penida Island.

Waste Characteristic

The characteristics of waste in Nusa Penida can be seen in Table 3, where it can be seen that the water content of the debris tends to below.

Table 3. Proximate Characteristics and Calorific Value of Waste on Nusa Penida Island.

Characteristic	Mask	Plastic	Metals	Organic
Water Content (%)	1.8	0.8	0	18.4
Ash Content (%)	2.4	4.1	100	19.6
Caloric Value (kcal/kg)	4145	5129	0	3997

Increasing the moisture content will reduce the maximum adiabatic combustion temperature and increase the time required for complete combustion in the furnace (Sarwono et al., 2021). Therefore, the moisture content of biomass has great importance in terms of storage durability, net calorific value, self-ignition, plant design, calculation of quantities for boiler consumption. These water content test results can also be used for other characterizations. At the same time, the ash content of biomass is the residue from the rest of the combustion, which is non-combustible. It is a bulk mineral after carbon, oxygen, sulfur, and air combustion.

TOSS Application Opportunities in Nusa Penida

The echo of the Local Waste Processing Site (TOSS) program launched by the Klungkung Regency Government has indeed been heard at the national level.

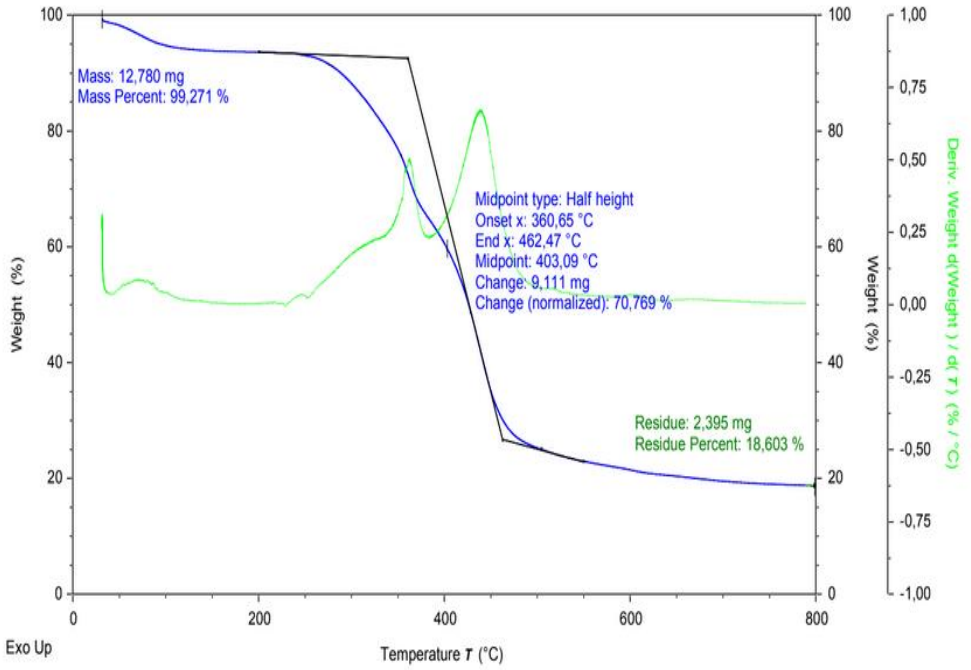


Figure 5. Results of Organic Waste Processing on Nusa Penida Island with Thermal TGA Process.

However, this innovative program can only be realized in mainland Klungkung (Chaerul et al., 2020; S Legino et al., 2019; Suryawan et al., 2021). As for the Nusa Penida sub-district, TOSS is planned to be built. The Klungkung Environment and Land Agency (DLHP) intends to use village funds to realize the program. Since the last few years, the tourism sector in Nusa Penida has started to boom, so it needs to be supported by cleaning facilities. Therefore, if the TOSS has been built, it can undoubtedly help the two existing Biaung Landfills. Previously, the two landfills accommodated 5-7 garbage trucks per day. Apart from household waste, it is also dominated by waste from hotels and restaurants.

The energy potential of solid waste on the island of Nusa Penida can reach 51,933.8 MJ/day for organic waste (Figure 4). This energy potential can be used as an indicator of thermal energy conversion and a source of electrical energy that the community can utilize. In addition, processing waste into energy can help reduce waste in landfills in Nusa Penida. Therefore, organic waste will be processed in TOSS and processed into RDF. Meanwhile, plastic waste will be pressed and then sent to Surabaya. However, for shipping costs, his party will seek subsidies from the government. It was further disclosed, if the TOSS in Nusa Penida has been built, DLHP will also cooperate with the Association of Indonesian Waste Entrepreneurs (APSI) (Fajar Bali, 2021).

The results of the TGA measurement on organic biodegradable waste can be seen in Figure 5. From the results of the mass reduction graph data, it shows that 81.4% of organic biodegradable waste has the highest mass reduction; the first stage is under temperatures above 450°C. This mass reduction is caused by the release of water vapor and several organic compounds that can evaporate at that temperature (Ankona et al., 2021). Water vapor can result from free water; moisture evolution happens at approximately 75-120°C (Lopatina et al., 2020). The temperature of 360–550°C showed an increased mass reduction rate due to the loss of volatile compounds (Nie et al., 2020). The volatile compounds will be depleted at 800°C so that this peak may decrease due to the loss of the remaining volatile compounds. The final heating temperature based on the graph obtained from the measurement results in the 450°C temperature zone until the final heating temperature of 995°C shows that there is still a rate of decline; this can be due to the remaining volatiles.

CONCLUSION

Waste generation from domestic activities on Nusa Penida Island can reach 6364.4 kg/day, and coastal activities can reach 7127.2 kg/day. Of the total waste generated, plastic and metal waste can be sold to collectors for recycling who can cooperate with the Indonesian Waste

Entrepreneurs Association (APSI). Meanwhile, organic waste planned to be processed into RDF has a high chance of around 51,933.8 MJ/day or 14,426 kWh/day. Furthermore, the results of the trial of burning waste with the TGA test obtained residues from the combustion process at the highest temperature of 800ºC, and the residue reached 18.6%. Therefore, processing waste into energy is accommodated to reduce the landfill burden on the island of Nusa Penida. If this effort can be realized, it can be imitated for other regions, and countries that have small tourism islands can have their energy security.

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