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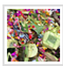
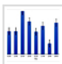
2. Picture1.png (390.32 kB)  Show
3. Graph 1.png (55.3 kB)  Show

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REFUSE DERIVED FUEL POTENTIAL PRODUCTION FROM TEMPLE WASTE AS ENERGY ALTERNATIVE RESOURCE IN BALI ISLAND

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ABSTRACT

The leakage of temple waste in the environment surrounding the temples has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292,36 kg of temple waste is generated from a single ceremonial at a Griya Anyar Tanah Kilap Temple. The temple waste

consists of 90,16% of organic waste (food, leaf and discarded flower) that is easily biodegraded. This research aims to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste are used as RDF material using two different drying

methods, namely natural drying and pyrolysis. The results showed that the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311,7 kcal/kg and 2912,7 kcal/kg, respectively. According to the electrical power potential, pyrolysis RDF has 3856,19 kWh/tons meanwhile natural drying RDF has 3391,59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel (RDF), renewable energy, sustainable waste management, waste recycling, pyrolysis

1. INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3,2 million Balinese Hindus. Temple is an essential part of Balinese culture that vertically connects the society with God and ancestors (1,2). The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature (2).

On another side, the ceremonials conducted at the temples generate waste that need to be managed. The offerings presented by the community are left at the temple and eventually become temple waste. There are many types of offerings depending on the type of festive celebrated. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves (3). Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to incoming visitors. The waste container could be overloaded; some waste is dumped out and damages the environment (4). Improper waste management has damaged the ecosystem aligning with the impact on the living creatures (5).

The problem of temple waste management happens particularly in the temple areas. Improper waste management negatively impacted the environment causing foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, and impairing the visual and aesthetic appearance of the temple as a place for religious activities (6,7). The ritual activities led to a significant increase in temple waste production and the risk of its disposal in the land and water body (8). Waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal. Some temples have implemented the rule to prevent the single-use plastic bag from entering the temple area. The visitors need to remove the plastic bag which is used to bring the offerings before going into the temple. The use of plastic packaging for some components of the offering such as foods, cakes, and even fruits packaged in plastic is still another issue that has not being resolved (9). Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste that is transferred to the landfill. Lack of stringent rules and policy, the need for high financial support, and appropriate technology are some of the factors that contribute to the inefficient management of the temple waste (9).

Temple waste was dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. The types of temple waste components were influenced by visitors because each visitor brings different offerings, according to their socio-economic conditions (10). As with waste generation, the composition of waste is also influenced by several factors:

1. Weather: in areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the

waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes and what will continue to increase is paper and other dry waste that is difficult to degrade.

3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also affect.

The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology (9). The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries such as color extraction, biogas production, vermicomposting, and biochar for agricultural applications (11). Several studies have shown the application of flower waste as a major material for some value-added products. The recycling practice initiatives not only help to preserve the environment through sustainable waste management but also provide work opportunity and generates revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the products have various applications, such as biochar and biocoal. Both use similar production process, namely pyrolysis but have different applications (7). Biochar is used for soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel (12,13). Carbonization, wood distillation, and destructive distillation are other names for pyrolysis processes (14). Refuse Derived Fuel can be produced using several processing techniques by removing most of the biodegradable fractions (e.g., food waste), metals, and glass from the waste. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content (15). The present study examined the potential of temple waste an alternative energy resource by transforming it into RDF.

2. METHODOLOGY

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City Figure, in 2022 (16), the city has a population of 959.237, with 70,51% being Hindus. The study started with an engagement with the temple manager and Pemogan Village Authority to assess the current situation of waste management at the temple.

2.1 Material and Equipment

In the waste collection, some 100 L polypropylene (PP) sacks were used to collect the waste and bring to the separation site.The equipments were used during the waste collection and measurement, such as a 4 x 6 m plastic tarp for separation base, a density box with size of of 1 x 1 x 0,5 meters or 0,5 m^3 for density analysis, digital scale Wei Heng WH-A08 to weigh the waste, and data sheet. All temple waste was moved to the RDF processing place. The temple waste was dried in two ways: (1) Natural drying by sunlight in 4 days and (2) Pyrolisis process. A 200 L of metal drum was used to heat the temple waste for 8 hours. It was placed on a fireplace that was fueled with firewood.

The dried temple waste then proceeds to some machines to produce the RDF. A chaft cutter machine (MCC) series 6-200 with GC-200 Engine and 6,5 horsepower (hp) was used to grind the temple waste into smaller pieces about 2-3 cm. Afterwards, a milling machine FFC

23 with GX 270 engine and 9 hp worked to produce finer temple waste form. Both powders were mixed manually on a tray with common cassava starch of about 10%. The cassava starch has a role as natural binder to make a solid RDF pellet (17). It is also a easy to find material and able to locally processed. The temple waste powder was then pressed into pellet form by using a vertical pellet press machine SLD 150 MPK with JF 180 engine.

2.2 Temple Waste Collection

Temple waste generation and the waste compositions were measured during the full moon ceremonial day. It is one of the ceremonials which have a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 (18). The temple wastes were collected every hour for a period of 12 hours from 11.00 am to 10.00 pm. It was divided into two phases according to the incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.

2.3 Temple Waste Measurement

The temple waste characteristic that was measured were waste generation, waste composition and density. The wastes were collected from the trash bins placed around the temple and weighed. Then the wastes were sorted into several categories, such as food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and compared to the total waste to get the composition percentage. The density (in kg/m^3) was estimated by accommodating the wastes into a box with a size of 1 x 1 x 0,5 meters or 0,5 m^3 in volume. The box was full filled with the waste and weighed. The density represents the waste weight per volume unit. Figure 1 shows the wastes collected during the study.

Figure 1 The temple waste collected from ceremonial activities

2.4 Refused Derived Fuel (RDF) Analysis

The RDFs were prepared and analyzed for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative. Water content was determined by drying a certain of waste amount in an electrical oven at 103 ± 5^0C for one hour until the constant weight was achieved. Water content, dried material, ash content, organic content, volatile, and carbon content was analyzed with gravimetry according to Method Analysis by Association of Efficial Agriculture Chemist. Nitrogen was measured by using semimicro Kjeldhal method, meanwhile the phosphorus and calcium was measured by using spectrophotometry and atomic absorption spectroscopy (AAS). The caloric value was using Gallenkamp Ballistic Bomb Calorimeter. Each sample was weighed into the steel capsule at 0.50 g. To contact the capsule, a 10-cm-long cotton thread was tied to the thermocouple. The device was sealed and charged with up to 30 atoms of oxygen. The bomb was activated by pressing the ignition button, causing the sample to burn in an excess of oxygen. The thermocouple and galvanometer equipment were used to measure the greatest temperature rise in the bomb (19).

3. RESULTS AND DISCUSSION

3.1 Temple Waste Characteristics

The temple waste generation during the ceremonial day is presented in Figure 2.The results showed that the highest waste generation took place between 01.00 and 02.00 pm (phase 1) and between 7.00 and 8.00 pm (phase 2) with 54,91 kg and 47,87 kg, respectively. The minimum waste generation during the ceremony was between 10 to 11 am (phase 1) and between 5 to 6 pm (phase 2). During the 12 hours, it is found that total waste generation during the ceremonial in this temple was 292,36 kg ± 2,48.

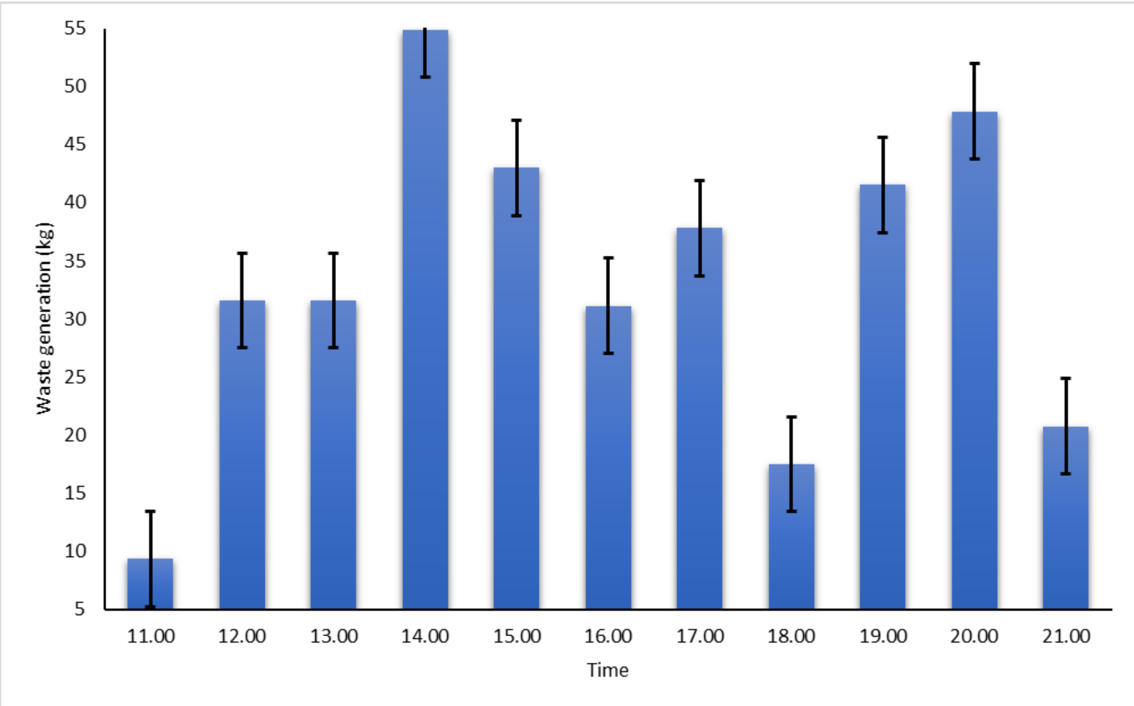

Figure 2 The temple waste generation during full moon ceremonial day

The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community. Those religious and ritual activities lead to significant offerings production and disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them after doing the praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On another side, temple waste can be used as valuable resources through a recycling initiative to make new products (11,20).

Based on the results of density measurements, it was found that the average density of temple waste was 63,56 ± 5,83 kg/m^3. Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. Based on the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is also determined by means of collecting and transporting waste used. When compared to the typical density of domestic household waste, waste in carts, or waste in landfills, the following comparison is obtained:

Table 1. Comparison of waste density based on waste collection conditions

Waste collection conditions	**Density (ton/m^3)**
Waste in household waste containers*	0,01 – 0,20
Waste in waste carts*	0,20 – 0,25
Waste in open trucks*	0,30 – 0,40
Waste in landfills*	0,50 – 0,60
Temple waste (current research)	0,064

* Source: Damanhuri, 2010

Based on the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45,52% dan 33,86% respectively. Meanwhile, other kinds of waste were food waste (10,78%), non-organic waste (3,63%), and hard waste, such as bamboo and wood (9,72%). Table 2 shows the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple obtained during the study period.

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Percentage	Mass (kg)	Volume (m^3)
1	Food waste	10,78%	31,50	0,497
2	Leaf waste	45,52%	133,10	2,100
3	Flower waste	33,86%	98,99	1,562
4	Hard waste	9,72%	28,43	0,449
5	Non-organic waste	3,63%	10,61	0,167

Leaf and flower wastes were the main components of offerings used by Hindus. In this study, food waste, leaf waste and discarded flower are considered as wet waste. It shown that 90,16% the waste at the Griya Tanah Kilap Temple was 90,16% during the ceremonial day. The findings are higher to the one obtained in the previous study at Besakih Temple with the composition of wet waste in normal day was (food waste, flowers, and leaves) 79,13% and in the ceremonial day was 79,19%. Besakih temple is the biggest temple in Bali Island and has daily visitors for praying (21).

The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%). This waste need to be manage immediately as it can produce unpleasant odors including as ammonia, and H_2S. In addition, decomposition products such as methane gas and the like are produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-degradable waste including paper, metal, plastic, and glass should be recycled because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic. Information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique (22,23), biofuel materials (24), biochar (25), natural dyes (26), and natural fertilizers (27).

Jain (22) in his research combined cow dung waste and flower waste generated from traditional ceremonial activities, offerings, or prayers was collected to be used as compost material using vermicomposting with earthworms (*Eisenia foetida*). The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (*Tagetes erecta*) as biofuel was carried out by Khammee *et al.* (24). Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. Thus, the effort to recycle temple waste into products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.

3.2. Refuse Derived Fuel from Temple Waste

The process of making RDF is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material (15).

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid *(char)* (28). The temperature used in the pyrolysis process is classified as low temperature ranging from 400-800^{0}C. According to Ganesh (29), the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. Briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better (30).

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion process of a material per unit mass or per unit volume (31,32), it is necessary to determine the caloric value of the RDF raw material. The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

Table 3. RDF characteristics test results

Parameter	Drying Types	
	Pyrolysis	**Natural Drying**
Dry weight (%)	88,88	85,85
Water content (%)	11,11	14.15
Ash (%)	31,89	7,98
Organic matter (%)	56,98	77.85
Nitrogen (%)	1,69	1,95
Calcium (%)	3,48	5,55
Phosphor (%)	1,38	0,9
Caloric (Kcal/kg)	3311,70	2912,7

Based on the analysis of the characteristics of RDF, the dry weight of the two drying methods did not differ significantly. However, natural drying method took 3-4 days, while pyrolysis took only 8 hours. In term of drying time, pyrolysis is more effective than the natural drying method. Pyrolysis generated lower water content compared to natural drying; however, both met the RDF criteria for water content, which is less than 20% (34). The organic matter content of natural drying RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500^0C and could cause loss of organic matter. Meanwhile, natural drying RDF did not reach extreme temperature and thus, preserved the organic matter.

The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 Kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. Based on the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., (35) showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted as carbon dioxide (CO_2) equivalent, RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

Based on these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials (36). Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) (37), organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) (38). The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

4. CONCLUSION

The temple waste generation in Griya Anyar Tanah Kilap Temple was 292,36 kg ± 2,48 with 90,16% of organic waste during the full moon ceremonial day. The pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311,7 kcal/kg and 2912,7 kcal/kg, respectively. The potential energy of pyrolisis RDF was 3856.19 kWh/tons and 3391.59 kWh/tons for natural drying RDF. These values need to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. The effort to manage temple wastes in all areas on the island of Bali need to be enhances and RDF temple waste can be further developed as an alternative energy resource. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

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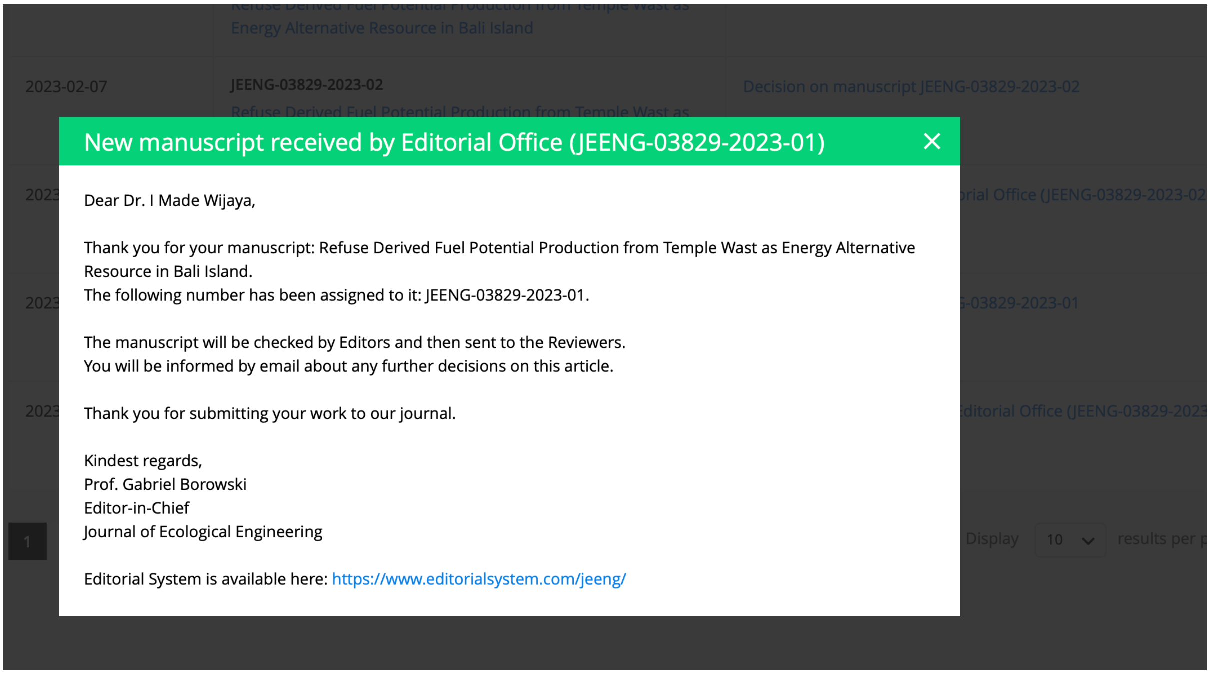

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The leakage of temple waste in the environment surrounding the temples has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292,36 kg of temple waste is generated from a single ceremonial at a Griya Anyar Tanah Kilap Temple. The temple waste consists of 90,16% of organic waste (food, leaf and discarded flower) that is easily biodegraded. This research aims to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste are used as RDF material using two different drying methods, namely natural drying and pyrolysis. The results showed that the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311,7 kcal/kg and 2912,7 kcal/kg, respectively. According to the electrical power potential, pyrolysis RDF has 3856,19 kWh/tons meanwhile natural drying RDF has 3391,59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

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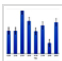
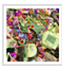
1. Graph 1.png (55.3 kB)  Show
2. Picture1.png (390.32 kB)  Show
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REFUSED DERIVED FUEL POTENTIAL PRODUCTION FROM TEMPLE WASTE AS ENERGY ALTERNATIVE RESOURCE IN BALI ISLAND

Abstract

Improper temple waste management is still a challenge in some Hindu community areas, such as Bali Island, with 3,2 million Balinese Hindus. The leakage of temple waste in the environment surrounding the temple has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292,36 kg of temple waste is generated from a single ceremonial at the temple per day. Those are transported to the regional landfill without any pre-treatments. The temple waste consists of 79,37% of leaf and flower waste that is easily biodegraded. Recycling is an initiative to reduce the temple waste ending up in landfills by making other valuable products. This research aims to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste is used as RDF material with two different ways of drying. The temple waste is recycled to RDF by using traditional and pyrolysis methods. The result shows the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311,7 Cal/gram and 2912,7 Cal/gram, respectively. According to the electrical power potential, pyrolysis RDF has 3856,19 kWh/tons meanwhile natural drying RDF has 3391,59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel (RDF), renewable energy, sustainable waste management, waste recycling,

1.0 INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3,2 million Balinese Hindus. Temple is an essential part of Balinese culture that vertically connects the society with God and ancestors (1,2). The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature (2)

On another side, the ceremonials leave the waste after it has been carried out. The offerings presented by the community are used to be left and therefore become temple waste. There are many types of offerings depending on the current festive day. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves (3). Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to more incoming visitors. The waste container could be overloaded; some waste is dumped out and damages the environment (4). Improper waste management has contaminated the ecosystem aligning with the impact on the living creatures (5).

The problem of temple waste management happens particularly in the temple areas. Improper waste management makes the temple still the waste contributor at the landfill. The leakage of temple waste may create a bad impact on the environment, such as foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, and impairing the visual and aesthetic appearance of the temple as a place for religious activities (6,7). The ritual activities lead to a significant increase in temple waste production and the risk of its disposal in the land and water body (8). Some temples have implemented the rule to avoid the single-use plastic bag entering the temple area. The visitors need to take out the plastic bag which is used to bring the offerings before going inside the temple. The use of plastic packaging for some components from the offering is still an issue of temple waste, such as foods, cakes, and even fruits packaged in plastic (9). Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste until it is transferred to the landfill.

One of the temple managers at Griya Tanah Kilap Temple in Denpasar City stated that there is no treatment for the temple waste. All the waste is just dumped in the collection place and is waiting to be transferred. The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology (9). The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries such as color extraction, biogas production, vermicomposting, biochar for agricultural applications, and etc (10). Several studies have shown the application of flower waste as a major material for some value-added products. The recycling practice initiative does not only help to preserve the environment through sustainable waste management but also gives the work opportunity and generates revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the product has various applications, such as biochar or biocoal. Both have a similar production process by using pyrolysis but have different utilization (7). Biochar is used to apply to soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel (11,12). Temple waste management has not been addressed properly and has limited research literature, especially on Bali Island. The four major challenges of solid waste management are financial availability, lack of appropriate technologies, improper education, and inappropriate rules and policies. Refuse Derived Fuel (RDF) can be yielded after several processing techniques to convert the composition of raw waste material by removing most of the biodegradable fractions (e.g., food waste), metals, and glass. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content (13). The present study aims to examine the temple waste to be recycled into Refuse Derived Fuel (RDF) and analyze its potential to be an alternative energy resource.

2.0 METHODOLOGY

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. This study was started with an open discussion with the temple manager and Pemogan Village Authority. The interview aimed to get deeper information about the current situation of waste management at the temple.

Temple waste generation and its composition were measured during the full moon ceremonial day. It is one of the ceremonials which lead a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 (14). The temple waste was collected for about 12 hours as the time for people to come to the temple. There were some trash bins placed around the temple to provide the people to put their waste after the praying. Every hour the waste was collected and weighed. The sorting was afterwards done by separating the collected waste into several composition types such as food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and defined its percentage in total waste. The density was measured by using a box with a size of 1 x 1 x 0,5 meters or 0,5 m^3 in volume. Some waste was put in the box and weighed. The density shows the ratio between weight (kg) and volume (m^3).

Figure 1 The temple waste from ceremonial activities

The Refuse Derived Fuel (RDF) pellet was produced in two drying alternatives ways. First, the temple waste was pyrolyzed in a closed burning chamber. After about 8 hours, the waste was ground to yield the powder. Second, the temple waste was dried up directly under the sun for about 4 days and ground to produce the waste powder. Both powders were mixed with cassava starch of about 10%. The cassava starch has a role as natural adhesive material to make a solid RDF pellet. The mix was pelletized by using a molded machine and dried up to get a maximum of 10% moisture. The RDF was prepared and analyzed according to some parameters such as moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative.

3.0 RESULTS AND DISCUSSION

3.1. Temple Waste Characteristic

The temple waste was collected and weighed during the ceremonial day (full moon day) every hour from 11.00 am to 10.00 pm. It was divided into two phases of incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors. The result showed the highest waste generation happened at 02.00 pm (phase 1) and 10.00 pm (phase 2) with 54,91 kg and 47,87 kg, respectively. The waste generation during the ceremonial day is presented in Figure 2.

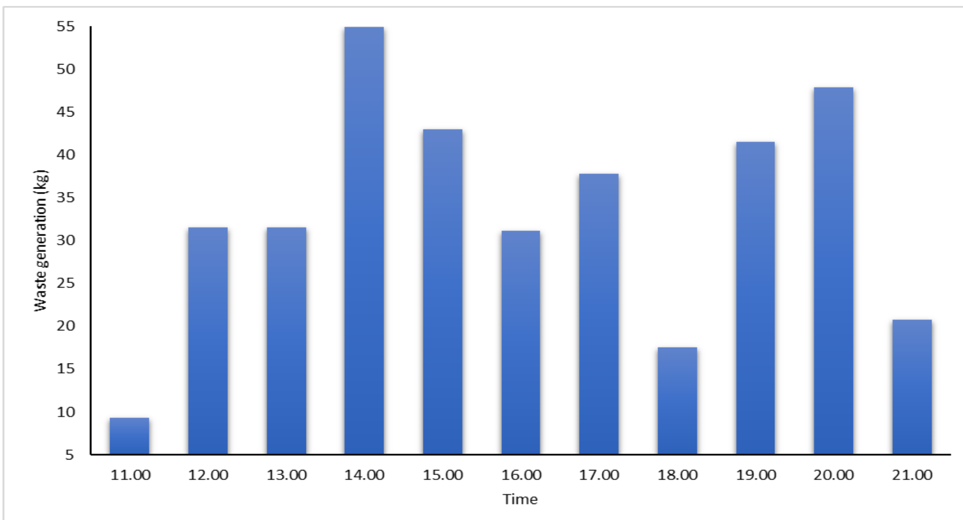

Figure 2 The temple waste generation during full moon ceremonial day

Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City in Figure 2022 (15), the city has a 959.237 population, with 70,51% being Hindus. The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community.

Those religious and ritual activities lead to significant offerings production and disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them after doing the praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On another side, temple waste can be used as valuable resources through a recycling initiative to make new products (10,16).

Waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal.

Based on the results of density measurements, it was found that the average density of temple waste was 63,56 kg/m^3. Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. Based on the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is also determined by means of collecting and transporting waste used. When compared to the typical density of domestic household waste, waste in carts, or waste in landfills, the following comparison is obtained:

Table 1. Comparison of waste density based on waste collection conditions

Waste collection conditions	Density (ton/m^3)
Waste in household waste containers*	0,01 – 0,20
Waste in waste carts*	0,20 – 0,25
Waste in open trucks*	0,30 – 0,40
Waste in landfills*	0,50 – 0,60
Temple waste (current research)	0,064

*) Source: Damanhuri, 2010

Temple waste is dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. As with waste generation, the composition of waste is also influenced by several factors:

1. Weather: in areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes and what will continue to increase is paper and other dry waste that is difficult to degrade.
3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also affect. Developed countries such as America are increasingly using paper as packaging while developing countries such as Indonesia are using plastic packaging.

The types of temple waste components are also influenced by visitors because each visitor brings different offerings, according to their economic conditions. The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%) so waste management must be carried out immediately when it has been collected. Decomposed organic waste (garbage) is one that decomposes easily due to the activity of microorganisms. Therefore, management is urgently needed in the collection, disposal, and transportation process. This waste decomposition can produce unpleasant odors, such as ammonia, H_2S, and other volatile acids. In addition, decomposition products such as methane gas and the like are also produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-decomposing waste generally consists of paper, metal, plastic, glass, and others. Dry waste (refuse) should be recycled because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic.

Based on the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45,52% dan 33,86% respectively. Meanwhile, other kinds of waste were food waste (10,78%), non-organic waste (3,63%), and hard waste, such as bamboo and wood (9,72%). The following is the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple.

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Percentage	Mass (kg)	Volume (m^3)
1	Food waste	10,78%	31,50	0,497
2	Leaf waste	45,52%	133,10	2,100
3	Flower waste	33,86%	98,99	1,562
4	Hard waste	9,72%	28,43	0,449
5	Non-organic waste	3,63%	10,61	0,167

Source: Analysis results

Leaf and flower waste are the main components of offerings used by Hindus. The analysis results are similar to the results of the analysis of the waste composition in the previous study at Besakih Temple with the composition of wet waste of 79,13%. The wet waste consists of food waste, flowers, and leaves. Meanwhile, on the ceremony day, the wet waste at Besakih Temple increases to 79,19%. Things can be done to manage the waste by knowing the composition of the waste at Griya Tanah Kilap Temple. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique (17,18), biofuel materials (19), biochar (20), natural dyes (21), and natural fertilizers (22).

Jain (17) in his research combined cow dung waste and flower waste. Flower waste generated from traditional ceremonial activities, offerings, or prayers is collected to be used as compost material. The composting method used was vermicomposting with earthworms (Eisenia foetida). The results showed the optimum conditions for the bioconversion process in vermicomposting were 50:50 dan 60:40 compositions. Some of the optimum parameters obtained include temperature 25 Figure 2. Flower waste from the temple (left) and aromatherapy incense processed from flower waste C, pH 8.0, particle size 1-2 mm, humidity 60%, black compost results, no odor, and density 0.88. Vermicomposting results also showed low C:N and C:P ratios, as well as increased nitrogen, phosphorus, sodium, magnesium, and sulfur content. Samadhiya et al., (2017) innovated vermicomposting by adding the fungus Trichoderma harzianum to improve the bioconversion process of flower waste and cow dung. The 1:1 ratio between cow dung and earthworm (Eudrilus eugeniae) with the addition of Trichoderma harzianum (0.125%) was the ratio with the best results for vermicomposting. The use of Eudrilus eugeniae was also used by Kohli (2016). The results of vermicompost with the addition of cow dung showed promising results to be developed.

The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (Tagetes erecta) as biofuel was carried out by (19). Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. The fermentation process is carried out with the help of free yeast cells. The highest ethanol results obtained from the 48-hour fermentation process was 11.25 g/L. The increase in fermentation results of *gemitir* flowers can be optimized by performing pretreatment, saccharification, and conditioning of the fermentation reactor. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. This recycling effort aims to prevent and reduce temple waste being transported to landfills. Organic waste collected at the landfill without any prior treatment has the potential to cause negative impacts on the environment, such as the emergence of odors and greenhouse gases, increasing the production of leachate because it has high water content, as well as being a breeding ground for disease vectors. Thus, the effort to recycle temple waste into products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.

3.2. Refuse Derived Fuel from Temple Waste

The process of making Refuse Derived Fuel (RDF) is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material (13).

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. The test was conducted at the Nutrition and Food Laboratory, Faculty of Animal Husbandry, Udayana University. Parameters measured include water content, ash content, organic matter, nitrogen content, calcium content, phosphorus content, and caloric value. A sample of 200 grams was brought to the Nutrition and Food Laboratory to be analyzed for its characteristics. In this study, there were two types of treatment for temple waste before it was used as RDF material. The difference between the two treatments was the drying technique used, namely drying naturally with sunlight and using the pyrolysis technique. Natural drying was done to determine the effective drying time if this activity is carried out by the community later so that it can be easier to apply. Drying by pyrolysis is relatively faster because it uses a closed combustion system to obtain a higher temperature. However, in its application later, machine tools and fuel are required.

The temple waste was dried in the research team's yard by placing some waste on a tarpaulin. Occasionally the garbage is stirred to even out the drying. The drying time of the temple waste carried out in this study was 3-4 days, and the waste had dried, which was indicated by a change in the color of the waste to dark brown with a crunchy texture. The waste was then re-sorted to remove the hard waste, such as incense sticks, wood, or other hard materials. It was done to facilitate the process of grinding temple waste into powder. The dry waste was then ground with a milling machine to become powder. The powder was then mixed with starch glue as an adhesive and formed into pellets.

Unlike the case with natural drying, pyrolysis drying used a metal drum to heat the waste sample. A drum with a capacity of 200 L was used as a pyrolysis reactor. Waste was put into the drum until it filled the volume of the drum. The drum was then tightly closed, and combustion was carried out outside the drum so that the waste material did not come into direct contact with the combustion flame. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid *(char)* (23). The temperature used in the pyrolysis process is classified as low temperature ranging from 400-800^{0}C. According to Ganesh (24), the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. Briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better (25).

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion process of a material per unit mass or per unit volume (26), it is necessary to determine the caloric value of the RDF raw material. The caloric value produced after testing the material can be obtained as Higher Heating Value (HHV) and Lower Heating Value (LHV). The HHV parameter is used to compare the boiler design quality with the coal quality. Meanwhile, the LHV parameter is used to obtain a database in designing the boiler required in the company's manufacturing documents. The difference between HHV and LHV lies in the influence of moisture content of bound hydrogen, which turns into H_2O compounds/latent heat in the combustion process of coal or other fuels (27).

The ultimate analysis was carried out to determine the characteristics of the chemical composition of a fuel material which includes the fractions of carbon (C), nitrogen (N), and sulfur (S) elements. The ultimate test was carried out on a sample basis which was dried at a heating temperature of 105ºC in a moisture-free state and is expressed in wet weight percent or ADB (air-dried basis) (%) material. The value obtained based on the ultimate test will be compared with the fuel requirements of the clinker unit in the cement industry (28). The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

Table 3. RDF characteristics test results

Parameter	**Drying Types**	
	Pyrolysis	**Natural**
Dry weight (%)	88,88	85,85
Water content (%)	11,11	14.15
Ash (%)	31,89	7,98
Organic matter (%)	56,98	77.85
Nitrogen (%)	1,69	1,95
Calcium (%)	3,48	5,55
Phosphor (%)	1,38	0,9
Caloric (Kcal/kg)	3311,70	2912,7

Source: Analysis Result

Based on the analysis of the characteristics of RDF, the dry weight of the two drying methods did not differ significantly. However, drying with natural methods took 3-4 days, while drying by pyrolysis took 8 hours. Thus, of the long drying time factor, the pyrolysis method is more effective than the natural method. It is also supported by the lower water content of the pyrolysis process compared to natural drying. The percentage of the water content of the two RDF briquettes has met the RDF criteria for water content, which is <20% (29). The organic matter content of natural RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500^0C and could cause loss of organic matter. Meanwhile, natural RDF was not heated to extreme temperatures, so the organic matter content was still high.

The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 Kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. Based on the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., (30) showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted as carbon dioxide (CO_2) equivalent, RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

Based on these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials (31). Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) (32), organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) (33). The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

4.0 CONCLUSION

The temple waste recycled into RDF briquettes has a potential of 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). This value needs to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. RDF temple waste can continue to be developed as an alternative energy resource and an effort to handle temple waste in all areas on the island of Bali. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

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4 Februari 2023

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JEENG-05043-2023-01 New manuscript received by Ed

Decision on manuscript JEENG-03829-2023-01

February 04, 2023
JEENG-03829-2023-01
Refuse Derived Fuel Potential Production from Temple Wast as Energy Alternative Resource in Bali Island

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2023-02-07	JEENG-03829-2023-02 Refuse Derived Fuel Potential Production from Temple Wast as Energy Alternative Resource in Bali Island	Publishing fee has been received
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REFUSE~~D~~ DERIVED FUEL POTENTIAL PRODUCTION FROM TEMPLE WASTE AS ENERGY ALTERNATIVE RESOURCE IN BALI ISLAND

Abstract

Improper temple waste management is still a challenge in some Hindu community areas, such as Bali Island, with 3,2 million Balinese Hindus. The leakage of temple waste in the environment surrounding the temple has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292,36 kg of temple waste is generated from a single ceremonial at the temple per day. The~~o~~se are transported to the regional landfill without any pre-treatment~~s~~. The temple waste consists of 79,37% of leaf and flower waste that is easily biodegraded. Recycling is an initiative to reduce the temple waste ending up in landfills by making other valuable products. This research aims to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste ~~is~~ are used as RDF material ~~with~~ using two different ~~ways of~~ drying methods, namely ~~. The temple waste is recycled to RDF by using~~ traditional and pyrolysis ~~methods~~. The results showed that~~s~~ the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311,7 Cal/gram and 2912,7 Cal/gram, respectively. According to the electrical power potential, pyrolysis RDF has 3856,19 kWh/tons meanwhile natural drying RDF has 3391,59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel (RDF), renewable energy, sustainable waste management, waste recycling, pyrolysis~~,~~

1.0 INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3,2 million Balinese Hindus. Temple is an essential part of Balinese culture that vertically connects the society with God and ancestors (1,2). The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature (2).

On another side, the ceremonials conducted at the temples generate waste that need to be ~~leave the waste after it has been carried out~~managed. The offerings presented by the community are ~~used to be~~ left at the temple and ~~therefore~~ eventually become temple waste. There are many types of offerings depending on the ~~current~~ type of festive~~-~~ celebrated~~day~~. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves (3). Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to ~~more~~ incoming visitors. The waste container could be overloaded; some waste is dumped out and

Commented [A1]: Does this refer to a single temple or many temples?

Commented [A2]: Same question as above damages the environment (4). Improper waste management has ~~contaminated~~ damaged the ecosystem aligning with the impact on the living creatures (5).

The problem of temple waste management happens particularly in the temple areas. Improper waste management ~~makes the temple still the waste contributor at the landfill. The leakage of temple waste may create a bad~~negatively impacted ~~on~~ the environment ~~, such as~~causing foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, and impairing the visual and aesthetic appearance of the temple as a place for religious activities (6,7). The ritual activities lead to a significant increase in temple waste production and the risk of its disposal in the land and water body (8). Some temples have implemented the rule to ~~avoid~~ prevent the single-use plastic bag from entering the temple area. The visitors need to ~~take out~~remove the plastic bag which is used to bring the offerings before going in~~side~~to the temple. The use of plastic packaging for some components ~~from~~ of the offering ~~is still an issue of temple waste,~~ such as foods, cakes, and even fruits packaged in plastic is still another issue that has not being resolved (9). Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste ~~until it~~ that is transferred to the landfill. Lack of stringent rules and policy, the need for high financial support, and appropriate technology are some of the factors that contribute to the inefficient management of the temple waste (9).

One of the temple managers at Griya Tanah Kilap Temple in Denpasar City stated that there is no treatment for the temple waste. All the waste is just dumped in the collection place and is waiting to be transferred. The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology (9). The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries such as color extraction, biogas production, vermicomposting, and biochar for agricultural applications~~, and etc~~ (10). Several studies have shown the application of flower waste as a major material for some value-added products (reference?). The recycling practice initiatives ~~does~~ not only help to preserve the environment through sustainable waste management but also ~~gives the~~provide work opportunity and generate~~s~~ revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the products ha~~s~~ve~~s~~ various applications, such as biochar ~~or~~ and biocoal. Both ~~have~~ use ~~a~~ similar production process, namely ~~by using~~ pyrolysis but have different ~~utilization~~ applications (7). Biochar is used ~~to apply to~~for soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel (11,12). ~~Temple waste management has not been addressed properly and has limited research literature, especially on Bali Island. The four major challenges of solid waste management are financial availability, lack of appropriate technologies, improper education, and inappropriate rules and policies.~~ Refuse Derived Fuel ~~(RDF)~~ can be ~~yielded~~ produced ~~after~~ using several processing techniques ~~to~~ by ~~convert the composition of raw waste material by~~ removing most of the biodegradable fractions (e.g., food waste), metals, and glass from the waste. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content (13). The present study ~~aims to~~ examined the potential of temple

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waste an alternative energy resource ~~to be recycled~~by transforming it into ~~Refuse Derived Fuel (~~RDF~~)~~. ~~and analyze its potential to be an alternative energy resource.~~

2.0 METHODOLOGY

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2.1 Waste collection

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City, in 2022 (15), the city has a population of 959.237, with 70,51% being Hindus. Th~~is~~e study ~~was~~ started with an ~~open discussion~~engagement with the temple manager and Pemogan Village Authority ~~. The interview aimed to get deeper information about~~to assess the current situation of waste management at the temple.

Temple waste generation and ~~its~~ the waste compositions were measured during the full moon ceremonial day. It is one of the ceremonials which ~~lead~~have a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 (14). The temple wastes w~~as~~ere collected every hour for ~~about~~ a period of 12 hours from 11.00 am to 10.00 pm. ~~The temple waste was collected and weighed during the ceremonial day (full moon day) every hour from 11.00 am to 10.00 pm.~~ It was divided into two phases of incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.

~~as the time for people to come to the temple.~~ The wastes ~~re~~ were collected from ~~some~~ the trash bins placed around the temple ~~to provide the people to put their waste after the praying. Every hour the waste was collected~~ and weighed. Then the wastes were sorted ~~ing was afterwards done by separating the collected waste~~ into several ~~composition types such~~categories, ~~namely~~viz. ~~as~~ food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and its percentage in total waste was then determined~~fined its percentage in total waste~~. The density (in kg/m^3) was ~~measured~~ estimated by accommodating the wastes ~~using~~ into a box with a size of 1 x 1 x 0,5 meters or 0,5 m^3 in volume. Figure 1 shows the type of wastes collected during the study.~~Some waste was put in the box and weighed. The density shows the ratio between weight (kg) and volume (m^3).~~

Figure 1 The temple waste from ceremonial activities

2.2 Refuse Derived Fuel production

The ~~Refuse Derived Fuel (~~RDF~~)~~ pellet was produced ~~in~~ using two drying ~~alternatives ways~~methods that are pyrolysis and natural drying. ~~First~~In pyrolysis method, the temple wastes ~~was~~ were pyrolyzed in a closed burning chamber at a temperature of xx°C~~.~~ ~~After~~ for ~~about~~ 8 hours. ~~, the waste was ground to yield the powder.~~Alternatively, ~~Second,~~ the temple wastes ~~was~~ were dried ~~up~~ directly under the sun for about 4 days. ~~and~~ The dried wastes were ground to produce the waste powder. Both powders were mixed with cassava starch of about 10%. The cassava starch has a role as natural adhesive material to make a solid RDF pellet. The mix was pelletized by using a molded machine (brand and model) and dried up to get a maximum of 10% moisture. The RDFs ~~was~~ were prepared and analyzed ~~according to some parameters such as~~for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative.

Commented [A7]: How do you mix it?

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Commented [A9]: Need to explain what methods were used for the analysis.

Commented [A10]: Discuss how you determine the caloric value?

3.0 RESULTS AND DISCUSSION

3.1. Temple Waste Characteristics

The temple waste generation during the ceremonial day is presented in Figure 2.~~The temple waste was collected and weighed during the ceremonial day (full moon day) every hour from 11.00 am to 10.00 pm. It was divided into two phases of incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.~~ The results showed that the highest waste generation ~~happened~~ took place ~~at~~ between 1.00 and 02.00 pm (phase 1) and between 7.00 and 8~~10~~.00 pm (phase 2) with 54,91 kg and 47,87 kg, respectively. The minimum waste generation during the ceremony was between 10 to 11 am (phase 1) and between 5 to 6 pm (phase 2). (Comment: Any reason for such observation? Please discuss)~~The waste generation during the ceremonial day is presented in Figure 2.~~

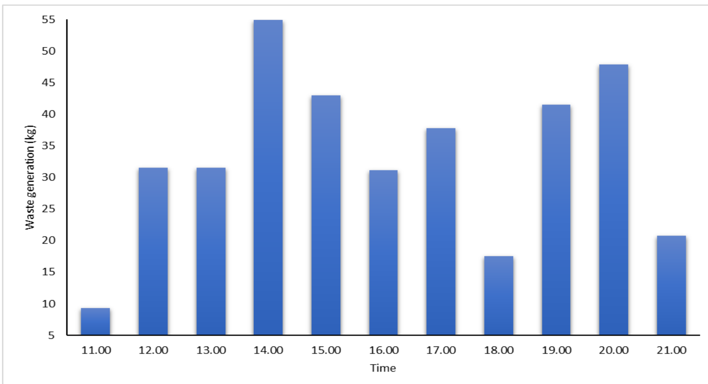

Figure 2 The temple waste generation during full moon ceremonial day

~~Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City in Figure 2022 (15), the city has a 959.237 population, with 70,51% being Hindus. The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community.~~

~~Those religious and ritual activities lead to significant offerings production and disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them after doing the praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On another side, temple waste can be used as valuable resources through a recycling initiative to make new products (10,16).~~

~~Waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal.~~

Based on the results of density measurements, it was found that the average density of temple waste was 63,56 kg/m^3. ~~Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. Based on the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is~~

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Commented [A12]: Any range value? How about the std. dev.? Table 1 is for domestic solid waste? Can you change the density to the same unit between your results and Damanhuri, 2010? This is for better comparison. Better to also discuss on the reason for the difference value.

~~also determined by means of collecting and transporting waste used. When compared to the typical density of domestic household waste, waste in carts, or waste in landfills, the following comparison is obtained:~~

Table 1. Comparison of waste density based on waste collection conditions

Waste collection conditions	Density (ton/m^3)
Waste in household waste containers*	0,01 – 0,20
Waste in waste carts*	0,20 – 0,25
Waste in open trucks*	0,30 – 0,40
Waste in landfills*	0,50 – 0,60
Temple waste (current research)	0,064

*~~)~~ Source: Damanhuri, 2010

Temple waste wa~~i~~s dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. The types of temple waste components were influenced by visitors because each visitor brings different offerings, according to their socio-economic conditions. As with waste generation, the composition of waste is also influenced by several factors:

1. Weather: in areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes and what will continue to increase is paper and other dry waste that is difficult to degrade.
3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also affect. Developed countries such as America are increasingly using paper as packaging while developing countries such as Indonesia are using plastic packaging.

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~~The types of temple waste components are also influenced by visitors because each visitor brings different offerings, according to their economic conditions. The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%) so waste management must be carried out immediately when it has been collected. Decomposed organic waste (garbage) is one that decomposes easily due to the activity of microorganisms. Therefore, management is urgently needed in the collection, disposal, and transportation process. This waste decomposition can produce unpleasant odors, such as ammonia, H_2S, and other volatile acids. In addition, decomposition products such as methane gas and the like are also produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-decomposing waste generally consists of paper, metal, plastic, glass, and others. Dry waste (refuse) should be recycled because otherwise, other processes are needed, such as combustion.~~

~~However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic.~~

Based on the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45,52% dan 33,86% respectively. Meanwhile, other kinds of waste were food waste (10,78%), non-organic waste (3,63%), and hard waste, such as bamboo and wood (9,72%). ~~The following is~~Table 2 shows the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple obtained during the study period.

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Percentage	Mass (kg)	Volume (m^3)
1	Food waste	10,78%	31,50	0,497
2	Leaf waste	45,52%	133,10	2,100
3	Flower waste	33,86%	98,99	1,562
4	Hard waste	9,72%	28,43	0,449
5	Non-organic waste	3,63%	10,61	0,167

Source: Analysis results

Leaf and flower wastes ~~are~~ were the main components of offerings used by Hindus. The ~~analysis results~~findings are similar to the ~~results of the analysis of the waste composition~~one obtained in the previous study at Besakih Temple with the composition of wet waste (food waste, flowers, and leaves) of 79,13% (Reference). ~~The wet waste consists of food waste, flowers, and leaves.~~ Meanwhile, on the ceremony day, the wet waste at Besakih Temple increases to 79,19%.

The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%). This waste need to be manage immediately as it can produce unpleasant odors including as ammonia, and H_2S. In addition, decomposition products such as methane gas and the like are produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-degradable waste including paper, metal, plastic, and glass should be recycled ~~because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic~~.

~~Things can be done to manage the waste by knowing the composition of the waste at Griya Tanah Kilap Temple~~Information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique (17,18), biofuel materials (19), biochar (20), natural dyes (21), and natural fertilizers (22).

Jain (17) in his research combined cow dung waste and flower waste ~~. Flower waste~~ generated from traditional ceremonial activities, offerings, or prayers ~~wa~~is collected to be used as compost material ~~. The composting method~~ us~~ed was~~ing vermicomposting with earthworms (Eisenia foetida). The results showed the optimum conditions for the bioconversion process in vermicomposting were 50:50 dan 60:40 compositions. Some of the optimum parameters obtained

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include temperature 25 Figure 2. Flower waste from the temple (left) and aromatherapy incense processed from flower waste C, pH 8.0, particle size 1-2 mm, humidity 60%, black compost results, no odor, and density 0.88. Vermicomposting results also showed low C:N and C:P ratios, as well as increased nitrogen, phosphorus, sodium, magnesium, and sulfur content. Samadhiya et al., (2017) innovated vermicomposting by adding the fungus Trichoderma harzianum to improve the bioconversion process of flower waste and cow dung. The 1:1 ratio between cow dung and earthworm (Eudrilus eugeniae) with the addition of Trichoderma harzianum (0.125%) was the ratio with the best results for vermicomposting. The use of Eudrilus eugeniae was also used by Kohli (2016). The results of vermicompost with the addition of cow dung showed promising results to be developed.

The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (Tagetes erecta) as biofuel was carried out by Khammee *et al.* ~~-~~(19). Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. The fermentation process wa~~i~~s carried out with the help of free yeast cells. The highest ethanol results obtained from the 48-hour fermentation process was 11.25 g/L. The increase in fermentation results of *gemitir* flowers can be optimized by performing pretreatment, saccharification, and conditioning of the fermentation reactor. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. ~~This recycling effort aims to prevent and reduce temple waste being transported to landfills. Organic waste collected at the landfill without any prior treatment has the potential to cause negative impacts on the environment, such as the emergence of odors and greenhouse gases, increasing the production of leachate because it has high water content, as well as being a breeding ground for disease vectors. Thus, the effort to recycle temple waste into products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.~~

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Commented [A16]: Since this is not that related to your work, I suggest you only discuss this in brief.

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3.2. *Refuse Derived Fuel from Temple Waste*

The process of making ~~Refuse Derived Fuel (~~RDF~~)~~ is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material (13).

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. The test was conducted at the Nutrition and Food Laboratory, Faculty of Animal Husbandry, Udayana University. Parameters measured include water content, ash content, organic matter, nitrogen content, calcium content, phosphorus content, and caloric value. A sample of 200 grams was brought to the Nutrition and Food Laboratory to be analyzed for its characteristics. In this study, there were two types of treatment for temple waste before it was used as RDF material. The difference between the two treatments was the drying technique used, namely drying naturally with sunlight and using the pyrolysis technique. Natural drying was done to determine the effective drying time if this activity is carried out by the community later so that it can be easier to apply. Drying by pyrolysis is relatively faster because it uses a closed combustion system to obtain a higher temperature. However, in its application later, machine tools and fuel are required.

The temple waste was dried in the research team's yard by placing some waste on a tarpaulin. Occasionally the garbage is stirred to even out the drying. The drying time of the temple waste carried out in this study was 3-4 days, and the waste had dried, which was indicated by a change in the color of the waste to dark brown with a crunchy texture. The waste was then re-sorted to remove the hard waste, such as incense sticks, wood, or other hard materials. It was done to facilitate the process of grinding temple waste into powder. The dry waste was then ground with a milling machine to become powder. The powder was then mixed with starch glue as an adhesive and formed into pellets.

Unlike the case with natural drying, pyrolysis drying used a metal drum to heat the waste sample. A drum with a capacity of 200 L was used as a pyrolysis reactor. Waste was put into the drum until it filled the volume of the drum. The drum was then tightly closed, and combustion was carried out outside the drum so that the waste material did not come into direct contact with the combustion flame. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid *(char)* (23). The temperature used in the pyrolysis process is classified as low temperature ranging from 400-800^{0}C. According to Ganesh (24), the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. Briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better (25).

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion process of a material per unit mass or per unit volume (26), it is necessary to determine the caloric value of the RDF raw material. The caloric value produced after testing the material can be obtained as Higher Heating Value (HHV) and Lower Heating Value (LHV). The HHV parameter is used to compare the boiler design quality with the coal quality. Meanwhile, the LHV parameter is used to obtain a database in designing the boiler required in the company's manufacturing documents. The difference between HHV and LHV lies in the influence of moisture content of bound hydrogen, which turns into H_2O compounds/latent heat in the combustion process of coal or other fuels (27).

The ultimate analysis was carried out to determine the characteristics of the chemical composition of a fuel material which includes the fractions of carbon (C), nitrogen (N), and sulfur (S) elements. The ultimate test was carried out on a sample basis which was dried at a heating temperature of 105ºC in a moisture-free state and is expressed in wet weight percent or ADB (air-dried basis) (%) material. The value obtained based on the ultimate test will be compared with the fuel requirements of the clinker unit in the cement industry (28). The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

Table 3. RDF characteristics test results

Parameter	Drying Types	
	Pyrolysis	**Natural Drying**
Dry weight (%)	88,88	85,85
Water content (%)	11,11	14.15
Ash (%)	31,89	7,98
Organic matter (%)	56,98	77.85
Nitrogen (%)	1,69	1,95
Calcium (%)	3,48	5,55
Phosphor (%)	1,38	0,9
Caloric (Kcal/kg)	3311,70	2912,7

Source: Analysis Result

Based on the analysis of the characteristics of RDF, the dry weight of the two drying methods did not differ significantly. However, natural drying ~~with natural~~ method~~s~~ took 3-4 days, while ~~drying by~~ pyrolysis took only 8 hours. ~~Thus, of the long~~In term of drying time~~ factor~~, ~~the~~ pyrolysis ~~method~~ is more effective than the natural drying method. Pyrolysis generated ~~It is also supported by the~~ lower water content ~~of the pyrolysis process~~ compared to natural drying~~.~~ ; however, ~~The percentage of~~both ~~the water content of the two RDF briquettes has~~ met the RDF criteria for water content, which is less than ~~<~~20% (29). The organic matter content of natural drying RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500^0C and could cause loss of organic matter. Meanwhile, natural drying RDF ~~was not heated to~~did not reach extreme temperature and thus, ~~so the~~preserved the organic matter~~ content was still high~~.

Commented [A18]: Are there equations to determine HHV and LHV. If there are, you need to discuss them in your METHODOLOGY

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The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 Kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. Based on the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., (30) showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted as carbon dioxide (CO_2) equivalent, RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

Based on these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials (31). Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) (32), organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) (33). The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

4.0 CONCLUSION

Commented [A22]: Besides the caloric values, you may want to add on the waste collected during the ceremonial and also waste composition obtained.

The temple waste recycled into RDF briquettes has a potential of 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). Th~~e~~ise values need~~s~~ to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. The effort to manage temple wastes in all areas on the island of Bali need to be enhances and RDF temple waste can ~~continue to~~ be further developed as an alternative energy resource~~ and an effort to handle temple waste in all areas on the island of Bali~~. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

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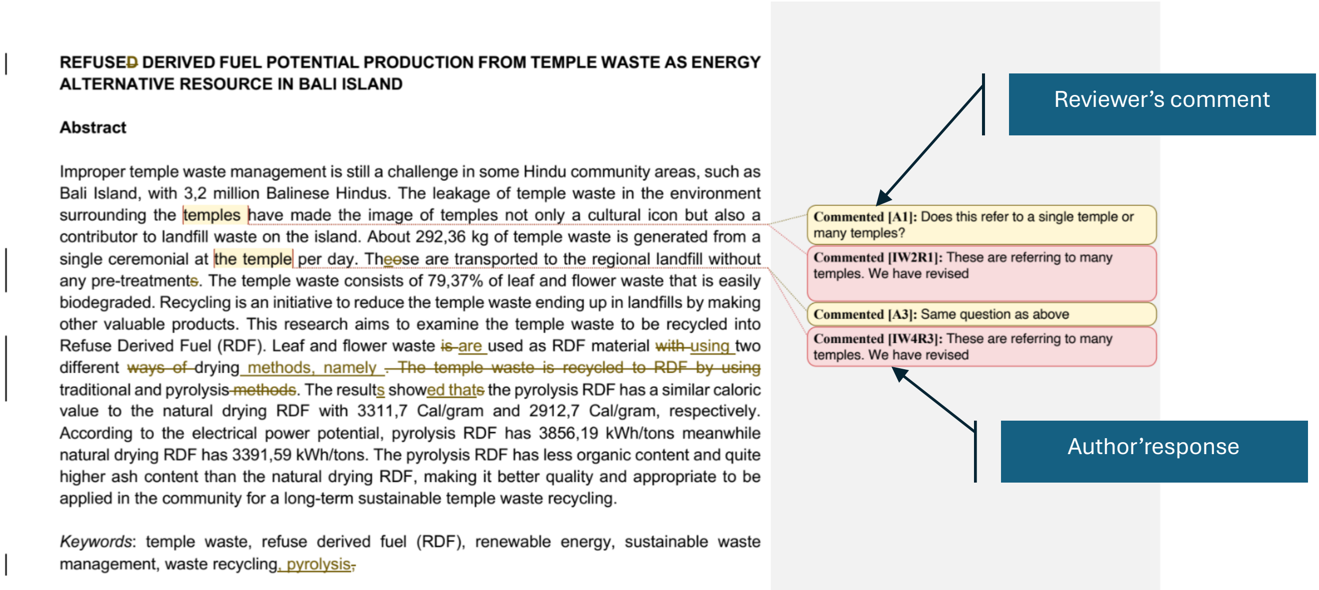
BUKTI RESPON PENULIS
(*AUTHOR'S RESPONSES*)
5 Februari 2023

RESPON PENULIS TERHADAP REVIEWER

Respon penulis terhadap setiap komentar penelaah (reviewer) dapat dilihat pada manuskrip bagian review track changes



REFUSE~~D~~ DERIVED FUEL POTENTIAL PRODUCTION FROM TEMPLE WASTE AS ENERGY ALTERNATIVE RESOURCE IN BALI ISLAND

Abstract

Improper temple waste management is still a challenge in some Hindu community areas, such as Bali Island, with 3,2 million Balinese Hindus. The leakage of temple waste in the environment surrounding the temples have made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292,36 kg of temple waste is generated from a single ceremonial at the temple per day. Th~~e~~ese are transported to the regional landfill without any pre-treatment~~s~~. The temple waste consists of 79,37% of leaf and flower waste that is easily biodegraded. Recycling is an initiative to reduce the temple waste ending up in landfills by making other valuable products. This research aims to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste ~~is~~ are used as RDF material ~~with~~ using two different ~~ways of~~ drying methods, namely ~~. The temple waste is recycled to RDF by using~~ traditional and pyrolysis ~~methods~~. The results showed that~~s~~ the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311,7 Cal/gram and 2912,7 Cal/gram, respectively. According to the electrical power potential, pyrolysis RDF has 3856,19 kWh/tons meanwhile natural drying RDF has 3391,59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel (RDF), renewable energy, sustainable waste management, waste recycling, pyrolysis~~.~~

Author's Responses to the Reviewer's Comment

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Keywords: temple waste, refuse derived fuel (RDF), renewable energy, sustainable waste management, waste recycling, pyrolysis~~,~~

Commented [A1]: Does this refer to a single temple or many temples?

Commented [IW2R1]: These are referring to many temples. We have revised

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1.0 INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3,2 million Balinese Hindus. Temple is an essential part of Balinese culture that vertically connects the society with God and ancestors (1,2). The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature (2).

On another side, the ceremonials conducted at the temples generate waste that need to be ~~leave the waste after it has been carried out~~managed. The offerings presented by the community are ~~used to be~~ left at the temple and ~~therefore~~ eventually become temple waste. There are many types of offerings depending on the ~~current~~ type of festive~~-~~ celebrated~~day~~. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves (3). Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to ~~more~~ incoming visitors. The waste container could be overloaded; some waste is dumped out and damages the environment (4). Improper waste management has ~~contaminated~~ damaged the ecosystem aligning with the impact on the living creatures (5).

The problem of temple waste management happens particularly in the temple areas. Improper waste management ~~makes the temple still the waste contributor at the landfill. The leakage of temple waste may create a bad~~negatively impacted ~~on~~ the environment, ~~, such as~~causing foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, and impairing the visual and aesthetic appearance of the temple as a place for religious activities (6,7). The ritual activities lead to a significant increase in temple waste production and the risk of its disposal in the land and water body (8). Some temples have implemented the rule to ~~avoid~~ prevent the single-use plastic bag from entering the temple area. The visitors need to ~~take out~~remove the plastic bag which is used to bring the offerings before going into~~side~~ the temple. The use of plastic packaging for some components ~~from~~ of the offering ~~is still an issue of temple waste,~~ such as foods, cakes, and even fruits packaged in plastic is still another issue that has not being resolved (9). Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste ~~until it~~ that is transferred to the landfill. Lack of stringent rules and policy, the need for high financial support, and appropriate technology are some of the factors that contribute to the inefficient management of the temple waste (9).

One of the temple managers at Griya Tanah Kilap Temple in Denpasar City stated that there is no treatment for the temple waste. All the waste is just dumped in the collection place and is waiting to be transferred. The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology (9). The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries such as color extraction, biogas production, vermicomposting, and biochar for agricultural applications~~, and etc~~ (10). Several studies have shown the application of flower waste as a major material for some value-added products (reference?). The recycling practice initiatives ~~does~~ not only help to preserve the environment through sustainable waste management but also ~~gives the~~provide work opportunity and generate~~s~~ revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the products ha~~s~~ves various applications, such as biochar ~~or~~ and biocoal. Both ~~have~~ use ~~a~~ similar production process, namely ~~by using~~ pyrolysis but have different ~~utilization~~ applications (7). Biochar is used ~~to apply to~~for soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel (11,12). ~~Temple waste management has not been addressed properly and has limited research literature, especially on Bali Island. The four major challenges of solid waste management are financial availability, lack of appropriate technologies, improper education, and inappropriate rules and policies.~~ Refuse Derived Fuel ~~(RDF)~~ can be ~~yielded~~ produced ~~after~~ using several processing techniques ~~to~~ by ~~convert the composition of raw waste material by~~ removing most of the biodegradable fractions (e.g., food waste), metals, and glass from the waste. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content (13). The present study ~~aims to~~ examined the potential of temple

Commented [A5]: I suggest this paragraph is removed due to redundancy of explanation. Furthermore, using the statement from temple manager is inappropriate reference in jurnal publication.

Commented [IW6R5]: We are agreed to remove this paragraph as reviewer's suggestion

Commented [A7]: When "such as" is used, "and etc." should not be used

Commented [IW8]: We have added the reference

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waste an alternative energy resource ~~to be recycled~~by transforming it into ~~Refuse Derived Fuel (~~RDF). ~~and analyze its potential to be an alternative energy resource.~~

2.0 METHODOLOGY

2.1 Waste collection

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City, in 2022 (15), the city has a population of 959.237, with 70,51% being Hindus. Th~~e~~is study ~~was~~ started with an ~~open discussion~~engagement with the temple manager and Pemogan Village Authority ~~. The interview aimed to get deeper information about~~to assess the current situation of waste management at the temple.

Temple waste generation and ~~its~~ the waste compositions were measured during the full moon ceremonial day. It is one of the ceremonials which ~~lead~~have a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 (14). The temple wastes w~~ere~~as collected every hour for ~~about~~ a period of 12 hours from 11.00 am to 10.00 pm. ~~The temple waste was collected and weighed during the ceremonial day (full moon day) every hour from 11.00 am to 10.00 pm.~~ It was divided into two phases of incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.

~~as the time for people to come to the temple.~~ The wastes ~~re~~ were collected from ~~some~~ the trash bins placed around the temple ~~to provide the people to put their waste after the praying. Every hour the waste was collected~~ and weighed. Then the wastes were sorted ~~ing was afterwards done by separating the collected waste~~ into several ~~composition types such~~categories, ~~namely~~viz. ~~as~~ food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and its percentage in total waste was then determined~~fined its percentage in total waste~~. The density (in kg/m^3) was ~~measured~~ estimated by accommodating the wastes ~~using~~ into a box with a size of 1 x 1 x 0,5 meters or 0,5 m^3 in volume. Figure 1 shows the type of wastes collected during the study.~~Some waste was put in the box and weighed. The density shows the ratio between weight (kg) and volume (m^3).~~

Commented [A10]: METHODOLOGY should include sub-section for MATERIAL AND EQUIPMENT, ANALYTICAL METHOD, and PROCEDURES.

Commented [IW11R10]: We have revised the methodology structure according to reviewer's suggestion. We have added the sub-section of Material and equipment with describing the method of waste collection and measurement and procedure for data collection, also we added the analysis for the RDF characteristic.

Figure 1 The temple waste from ceremonial activities

2.2 Refuse Derived Fuel production

The ~~Refuse Derived Fuel (~~RDF~~)~~ pellet was produced ~~in~~ using two drying ~~alternatives ways~~methods that are pyrolysis and natural drying. ~~First~~In pyrolysis method, the temple wastes ~~was~~ were pyrolyzed in a closed burning chamber at a temperature of xx°C~~.~~ ~~After~~ for ~~about~~ 8 hours. ~~, the waste was ground to yield the powder.~~Alternatively, ~~Second,~~ the temple wastes ~~was~~ were dried ~~up~~ directly under the sun for about 4 days. ~~and~~ The dried wastes were ground to produce the waste powder. Both powders were mixed with cassava starch of about 10%. The cassava starch has a role as natural adhesive material to make a solid RDF pellet. The mix was pelletized by using a molded machine (brand and model) and dried up to get a maximum of 10% moisture. The RDFs ~~was~~ were prepared and analyzed ~~according to some parameters such as~~for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative.

3.0 RESULTS AND DISCUSSION

3.1. Temple Waste Characteristics

The temple waste generation during the ceremonial day is presented in Figure 2.~~The temple waste was collected and weighed during the ceremonial day (full moon day) every hour from 11.00 am to 10.00 pm. It was divided into two phases of incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.~~ The results showed that the highest waste generation ~~happened~~ took place ~~at~~ between 1.00 and 02.00 pm (phase 1) and between 7.00 and 8~~10~~.00 pm (phase 2) with 54,91 kg and 47,87 kg, respectively. The minimum waste generation during the ceremony was between 10 to 11 am (phase 1) and between 5 to 6 pm (phase 2). (Comment: Any reason for such observation? Please discuss)~~The waste generation during the ceremonial day is presented in Figure 2.~~

Commented [A12]: How do you mix it?

Commented [IW13R12]: We have added more explanation for this: Both powders were mixed manually on a tray with common cassava starch about 10%. The cassava strach has a role as natural binder to make a solid RDF pellet.

Commented [A14]: How do you produce it? Or bought? Quality?

Commented [IW15R14]: In the revised version, we have added an explanation about the cassava starch which is: It is a material that is locally produced and easy to find in the market

Commented [A16]: Need to explain what methods were used for the analysis.

Commented [IW17R16]: In the revised versian, we have added more detail explanation on this issue:

The RDFs were prepared and analyzed for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO2 equivalent to define its potential as an energy alternative. Water content was determined by drying a certain amount of waste in an electrical oven at 103 ± 5 °C for one hour until the constant weight was achieved. Water content, dried material, ash content, organic content, volatile, and carbon content were analyzed with gravimetry according to Method Analysis by Association of Official Agriculture Chemist. Nitrogen was measured by using semimicro Kjeldhal method, meanwhile the phosphorus and calcium was measured by using spectrophotometry and atomic absorption spectroscopy (AAS).

Commented [A18]: Discuss how you determine the caloric value?

Commented [IW19R18]: The caloric value measured by using Gallenkamp Ballistic Bomb Calorimeter. Each sample was weighed into the steel capsule at 0.50 g. To coact the capsule, a 10-cm-long cotton thread was tied to the thermocouple. The device was sealed and charged with up to 30 atoms of oxygen. The bomb was activated by pressing the ignition button, causing the sample to burn in an excess of oxygen. The thermocouple and galvanometer equipment were used to measure the greatest temperature rise in the bomb

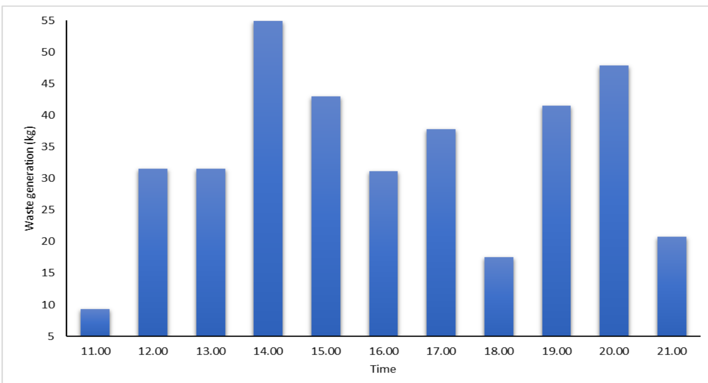

Figure 2 The temple waste generation during full moon ceremonial day

~~Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City in Figure 2022 (15), the city has a 959.237 population, with 70,51% being Hindus. The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community.~~

~~Those religious and ritual activities lead to significant offerings production and disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them after doing the praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On another side, temple waste can be used as valuable resources through a recycling initiative to make new products (10,16).~~

~~Waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal.~~

Commented [IW20]: We have made revision for this paragraph to be more appropriate

Commented [IW21]: We have made correction for these paragraph to be more appropriate with the article context.

Commented [A22]: I suggest this discussion is removed as they are not relevant to the results that you presented. It is better if you can compare this with other previous studies conducted by other researchers, even at different temples

Based on the results of density measurements, it was found that the average density of temple waste was 63,56 kg/m^3. ~~Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. Based on the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is also determined by means of collecting and transporting waste used. When compared to the typical density of domestic household waste, waste in carts, or waste in landfills, the following comparison is obtained:~~

Table 1. Comparison of waste density based on waste collection conditions

Waste collection conditions	Density (ton/m^3)
Waste in household waste containers*	0,01 – 0,20
Waste in waste carts*	0,20 – 0,25
Waste in open trucks*	0,30 – 0,40
Waste in landfills*	0,50 – 0,60
Temple waste (current research)	0,064

*~~)~~ Source: Damanhuri, 2010

Temple waste wa~~i~~s dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. The types of temple waste components were influenced by visitors because each visitor brings different offerings, according to their socio-economic conditions. As with waste generation, the composition of waste is also influenced by several factors:

1. Weather: in areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes and what will continue to increase is paper and other dry waste that is difficult to degrade.
3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also affect. Developed countries such as America are increasingly using paper as packaging while developing countries such as Indonesia are using plastic packaging.

~~The types of temple waste components are also influenced by visitors because each visitor brings different offerings, according to their economic conditions. The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%) so waste management must be carried out immediately when it has been collected. Decomposed organic waste (garbage) is one that decomposes easily due to the activity of microorganisms. Therefore, management is~~

Commented [A23]: Any range value? How about the std. dev.? Table 1 is for domestic solid waste? Can you change the density to the same unit between your results and Damanhuri, 2010? This is for better comparison. Better to also discuss on the reason for the difference value.

Commented [IW24R23]: In the revised version, the have added the std.dev to the value of waste density. The table which is referring to Damanhuri 2010 was for domestic solid waste and has been compared to the result.

Commented [A25]: In the discussion section, you need to relate this information with the results that you obtained. If there is no relationship provide, they are not supposed to be written here. It should be in Introduction section.

Commented [IW26R25]: We have realized that this part of discussion is lack of information and very general. In the revised version, we have changed to be more appropriate, as reviewer's suggestion. We have added more related discussion

~~urgently needed in the collection, disposal, and transportation process. This waste decomposition can produce unpleasant odors, such as ammonia, H_2S, and other volatile acids. In addition, decomposition products such as methane gas and the like are also produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-decomposing waste generally consists of paper, metal, plastic, glass, and others. Dry waste (refuse) should be recycled because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic.~~

Based on the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45,52% dan 33,86% respectively. Meanwhile, other kinds of waste were food waste (10,78%), non-organic waste (3,63%), and hard waste, such as bamboo and wood (9,72%). ~~The following is~~Table 2 shows the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple obtained during the study period.

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Percentage	Mass (kg)	Volume (m^3)
1	Food waste	10,78%	31,50	0,497
2	Leaf waste	45,52%	133,10	2,100
3	Flower waste	33,86%	98,99	1,562
4	Hard waste	9,72%	28,43	0,449
5	Non-organic waste	3,63%	10,61	0,167

Source: Analysis results

Leaf and flower wastes ~~are~~ were the main components of offerings used by Hindus. The ~~analysis results~~findings are similar to the ~~results of the analysis of the waste composition~~one obtained in the previous study at Besakih Temple with the composition of wet waste (food waste, flowers, and leaves) of 79,13% (Reference). ~~The wet waste consists of food waste, flowers, and leaves.~~ Meanwhile, on the ceremony day, the wet waste at Besakih Temple increases to 79,19%.

The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%). This waste need to be manage immediately as it can produce unpleasant odors including as ammonia, and H_2S. In addition, decomposition products such as methane gas and the like are produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-degradable waste including paper, metal, plastic, and glass should be recycled ~~because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic~~.

~~Things can be done to manage the waste by knowing the composition of the waste at Griya Tanah Kilap Temple~~Information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as

Commented [A27]: This is a little bit confusing. What is the different between 79,13 and 79,19%? Are they from Besakih Temple but on different days? How about the value of wet waste for your study? It is better to calculate yours and compare it with Besakih Temple. Yours seem to be around 88%? Are they comparable with Besakih? Compare and justify the different values - why? Different socio-economic status? Different ceremonial event?

Commented [IW28R27]: The values are showing the composition of wet waste in Besakih Temple form previous study which is 79,13% in the normal day, and increases to 79,19% in the ceremonial day. We have made clear explanation in the revised version.

We also have added the comparison between our result to the previous study, which were higher with 90,16% of wet waste in the ceremonial day.. We have explained in the revised version that the differents caused by the visitors and products recycling flower waste into compost through the vermicomposting technique (17,18), biofuel materials (19), biochar (20), natural dyes (21), and natural fertilizers (22).

Jain (17) in his research combined cow dung waste and flower waste ~~. Flower waste~~ generated from traditional ceremonial activities, offerings, or prayers wa~~i~~s collected to be used as compost material ~~. The composting method~~ us~~ed was~~ing vermicomposting with earthworms (Eisenia foetida). The results showed the optimum conditions for the bioconversion process in vermicomposting were 50:50 dan 60:40 compositions. Some of the optimum parameters obtained include temperature 25 Figure 2. Flower waste from the temple (left) and aromatherapy incense processed from flower waste C, pH 8.0, particle size 1-2 mm, humidity 60%, black compost results, no odor, and density 0.88. Vermicomposting results also showed low C:N and C:P ratios, as well as increased nitrogen, phosphorus, sodium, magnesium, and sulfur content. Samadhiya et al., (2017) innovated vermicomposting by adding the fungus Trichoderma harzianum to improve the bioconversion process of flower waste and cow dung. The 1:1 ratio between cow dung and earthworm (Eudrilus eugeniae) with the addition of Trichoderma harzianum (0.125%) was the ratio with the best results for vermicomposting. The use of Eudrilus eugeniae was also used by Kohli (2016). The results of vermicompost with the addition of cow dung showed promising results to be developed.

Commented [A29]: Since your work is related more to RFD, I don't think you should discuss vermicomposting in lenghty. You may want to discuss other techniques mentioned in previous paragraph in general to be fair.

Commented [IW30R29]: In the revised version, I have changed this part of discussion following the reviewer's suggestion. I have added more explanation about the RDF and temple waste technology

The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (Tagetes erecta) as biofuel was carried out by Khammee *et al.* (19). Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. The fermentation process wa~~i~~s carried out with the help of free yeast cells. The highest ethanol results obtained from the 48-hour fermentation process was 11.25 g/L. The increase in fermentation results of *gemitir* flowers can be optimized by performing pretreatment, saccharification, and conditioning of the fermentation reactor. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

Commented [A31]: Since this is not that related to your work, I suggest you only discuss this in brief.

Commented [IW32R31]: In the revised version, I have changed this part to be more brief as reviewer's suggestion

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. ~~This recycling effort aims to prevent and reduce temple waste being transported to landfills. Organic waste collected at the landfill without any prior treatment has the potential to cause negative impacts on the environment, such as the emergence of odors and greenhouse gases, increasing the production of leachate because it has high water content, as well as being a breeding ground for disease vectors. Thus, the effort to recycle temple waste into products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.~~

Commented [A33]: This is repetition from what has been discussed in Introduction section. Some of not relevant to what you want to highlight from your study.

3.2. Refuse Derived Fuel from Temple Waste

The process of making ~~Refuse Derived Fuel (~~RDF~~)~~ is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material (13).

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. The test was conducted at the Nutrition and Food Laboratory, Faculty of Animal Husbandry, Udayana University. Parameters measured include water content, ash content, organic matter, nitrogen content, calcium content, phosphorus content, and caloric value. A sample of 200 grams was brought to the Nutrition and Food Laboratory to be analyzed for its characteristics. In this study, there were two types of treatment for temple waste before it was used as RDF material. The difference between the two treatments was the drying technique used, namely drying naturally with sunlight and using the pyrolysis technique. Natural drying was done to determine the effective drying time if this activity is carried out by the community later so that it can be easier to apply. Drying by pyrolysis is relatively faster because it uses a closed combustion system to obtain a higher temperature. However, in its application later, machine tools and fuel are required.

The temple waste was dried in the research team's yard by placing some waste on a tarpaulin. Occasionally the garbage is stirred to even out the drying. The drying time of the temple waste carried out in this study was 3-4 days, and the waste had dried, which was indicated by a change in the color of the waste to dark brown with a crunchy texture. The waste was then re-sorted to remove the hard waste, such as incense sticks, wood, or other hard materials. It was done to facilitate the process of grinding temple waste into powder. The dry waste was then ground with a milling machine to become powder. The powder was then mixed with starch glue as an adhesive and formed into pellets.

Unlike the case with natural drying, pyrolysis drying used a metal drum to heat the waste sample. A drum with a capacity of 200 L was used as a pyrolysis reactor. Waste was put into the drum until it filled the volume of the drum. The drum was then tightly closed, and combustion was carried out outside the drum so that the waste material did not come into direct contact with the combustion flame. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid *(char)* (23). The temperature used in the pyrolysis process is classified as low temperature ranging from 400-800^{0}C. According to Ganesh (24), the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. Briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better (25).

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion process of a material per unit mass or per unit volume (26), it is necessary to determine the caloric value of the RDF raw material. The caloric value produced after testing the material can be obtained as Higher Heating Value (HHV) and Lower Heating Value (LHV). The HHV parameter is used to compare the boiler design quality with the coal quality. Meanwhile, the LHV parameter is used to obtain a database in designing the boiler required in the company's manufacturing documents. The difference between HHV and LHV lies in the influence of moisture content of bound hydrogen, which turns into H_2O compounds/latent heat in the combustion process of coal or other fuels (27).

The ultimate analysis was carried out to determine the characteristics of the chemical composition of a fuel material which includes the fractions of carbon (C), nitrogen (N), and sulfur (S) elements. The ultimate test was carried out on a sample basis which was dried at a heating temperature of 105ºC in a moisture-free state and is expressed in wet weight percent or ADB (air-dried basis) (%) material. The value obtained based on the ultimate test will be compared with the fuel requirements of the clinker unit in the cement industry (28). The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

Table 3. RDF characteristics test results

Parameter	Drying Types	
	Pyrolysis	**Natural Drying**
Dry weight (%)	88,88	85,85
Water content (%)	11,11	14.15
Ash (%)	31,89	7,98
Organic matter (%)	56,98	77.85
Nitrogen (%)	1,69	1,95
Calcium (%)	3,48	5,55
Phosphor (%)	1,38	0,9
Caloric (Kcal/kg)	3311,70	2912,7

Source: Analysis Result

Based on the analysis of the characteristics of RDF, the dry weight of the two drying methods did not differ significantly. However, natural drying ~~with natural~~ method~~s~~ took 3-4 days, while ~~drying by~~ pyrolysis took only 8 hours. ~~Thus, of the long~~In term of drying time~~ factor~~, ~~the~~ pyrolysis ~~method~~ is more effective than the natural drying method. Pyrolysis generated ~~It is also supported by the~~ lower water content ~~of the pyrolysis process~~ compared to natural drying~~.~~ ; however, ~~The percentage of~~both ~~the water content of the two RDF briquettes has~~ met the RDF

Commented [A34]: Are there equations to determine HHV and LHV. If there are, you need to discuss them in your METHODOLOGY

Commented [IW35R34]: We have removed the discussion part about HHV and LHV for further study. Thus, we have changed and corrected it as reviewer's suggestion

Commented [A36]: I found this part to be a mixture of METHODOLOGY and LITERATURE REVIEW and not suitable to be put under RESULTS AND DISCUSSION. Some are repetition from what that has been discussed earlier.

Commented [IW37R36]: We have reviewed this part of discussion and made correction according to reviewer's comment to get better explanation and avoid the repetition.

Commented [A38]: How did you do this? Explain it under METHODOLOGY.

Commented [IW39R38]: We have added the explanation for these analysis in the Methodology

Commented [A40]: Why this comparison is needed?

Commented [IW41R40]: We compare this result to some requirement standard for the use of RDF to give more explanation for the further application of the RDF. We also add more comparison of the RDF quality to the national standard of briquette to extend the information about the RDF and its classification.

criteria for water content, which is less than ~~<~~20% (29). The organic matter content of natural drying RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500^0C and could cause loss of organic matter. Meanwhile, natural drying RDF ~~was not heated to~~did not reach extreme temperature and thus, ~~so the~~preserved the organic matter~~ content was still high~~.

The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 Kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. Based on the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., (30) showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted as carbon dioxide (CO_2) equivalent, RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

Based on these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials (31). Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) (32), organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) (33). The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

4.0 CONCLUSION

The temple waste recycled into RDF briquettes has a potential of 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). The~~i~~se values need~~s~~ to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. The effort to manage temple wastes in all areas on the island of Bali need to be enhances and RDF temple waste can ~~continue to~~ be further developed as an alternative energy resource~~ and an effort to handle temple waste in all areas on the island of Bali~~. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

Commented [A42]: Besides the caloric values, you may want to add on the waste collected during the ceremonial and also waste composition obtained.

Commented [IW43R42]: In the revised version, we have added the waste characteristic including waste generation and its composition as reviewer's suggestion

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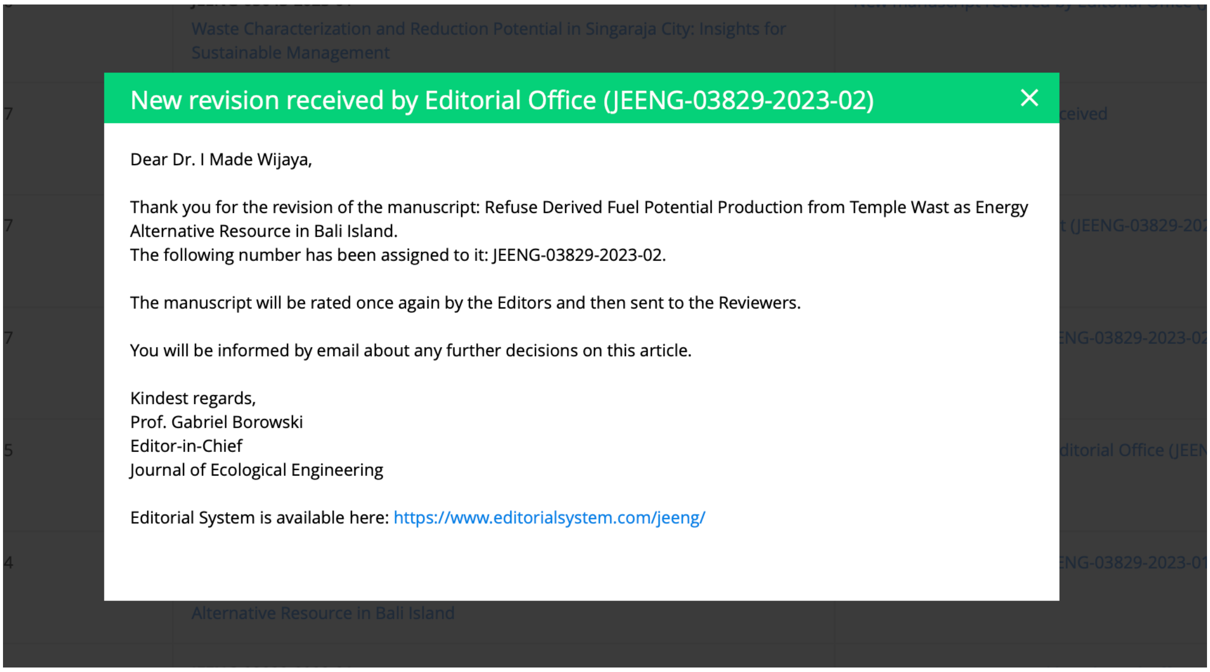

New revision received by Editorial Office (JEENG-03829-2023-02)

Dear Dr. I Made Wijaya,

Thank you for the revision of the manuscript: Refuse Derived Fuel Potential Production from Temple Wast as Energy Alternative Resource in Bali Island.
The following number has been assigned to it: JEENG-03829-2023-02.

The manuscript will be rated once again by the Editors and then sent to the Reviewers.

You will be informed by email about any further decisions on this article.

Kindest regards,
Prof. Gabriel Borowski
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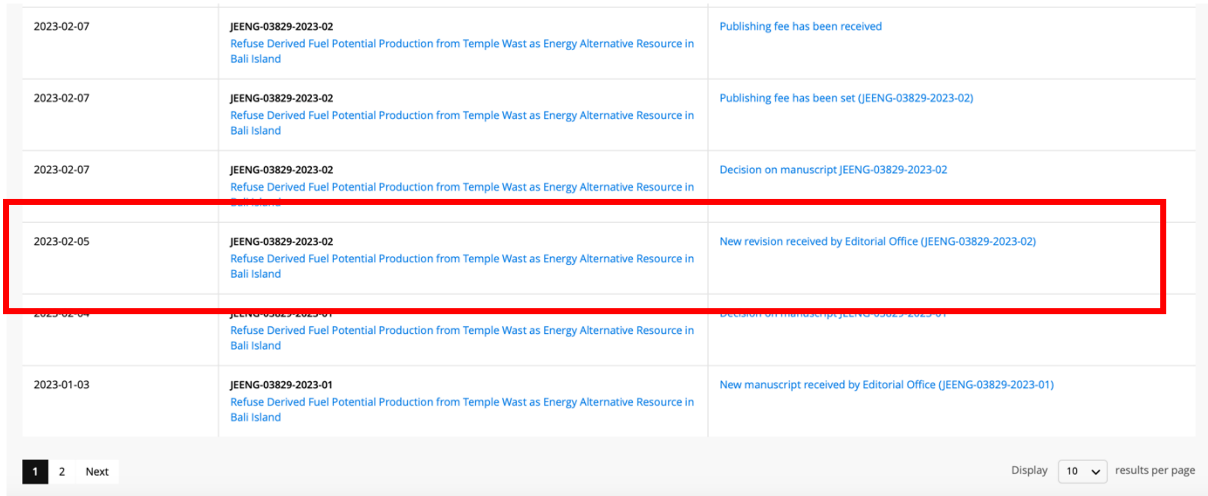

2023-02-07	**JEENG-03829-2023-02** Refuse Derived Fuel Potential Production from Temple Wast as Energy Alternative Resource in Bali Island	Publishing fee has been received
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REFUSE DERIVED FUEL POTENTIAL PRODUCTION FROM TEMPLE WASTE AS ENERGY ALTERNATIVE RESOURCE IN BALI ISLAND

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ABSTRACT

The leakage of temple waste in the environment surrounding the temples has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292.36 kg of temple waste is generated from a single ceremonial at Griya Anyar Tanah Kilap Temple. The temple waste consists of 90,16% of organic waste (food, leaf and discarded flower) that is easily biodegraded. This research aimed to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste are used as RDF material using two different drying methods, namely natural drying and pyrolysis. The results showed that the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. According to the electrical power potential, pyrolysis RDF has 3856.19 kWh/tons, meanwhile natural drying RDF has 3391.59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel (RDF), renewable energy, sustainable waste management, waste recycling, pyrolysis

1. INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3.2 million Balinese Hindus. Temples are an essential part of Balinese culture that vertically connects the society with God and ancestors [1,2]. The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature [2].

On the other hand, the ceremonials conducted at the temples generate waste that needs to be managed. The offerings presented by the community are left at the temple and eventually become temple waste. There are many types of offerings depending on the type of festival celebrated. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves [3]. Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to incoming visitors. The waste container could be overloaded; some waste is dumped out and damages the environment [4]. Improper waste management has damaged the ecosystem aligning with the impact on the living creatures [5].

The problem of temple waste management happens particularly in the temple areas. Improper waste management negatively impacted the environment causing foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, as well as impairing the visual and aesthetic appearance of the temple as a place for religious activities [6–8]. The ritual activities led to a significant increase in temple waste production and the risk of its disposal in the land and water body [9–12]. The waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal. Some temples have implemented the rule to prevent the single-use plastic bag from entering the temple area. The visitors need to remove the plastic bag which is used to bring the offerings before going into the temple. The use of plastic packaging for some components of the offering such as foods, cakes, and even fruits packaged in plastic is still another issue that has not being resolved [13]. Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste that is transferred to the landfill. Lack of stringent rules and policy, the need for high financial support, and appropriate technology are some of the factors that contribute to the inefficient management of the temple waste [13,14].

Temple waste was dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. The types of temple waste components were influenced by visitors, because each visitor brings different offerings, according to their socio-economic conditions [15]. As with waste generation, the composition of waste is also influenced by several factors:

1. Weather: in the areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the

waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes and what will continue to increase is paper and other dry waste that is difficult to degrade.

3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: the communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to the areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also affect.

The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology [13]. The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries, such as color extraction, biogas production, vermicomposting, and biochar for agricultural applications [16]. Several studies have shown the application of flower waste as a major material for some value-added products. The recycling practice initiatives not only help to preserve the environment through sustainable waste management but also provide work opportunities and generate revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the products have various applications, such as biochar and biocoal. Both use similar production process, namely pyrolysis, but have different applications [7]. Biochar is used for soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel [17,18]. Carbonization, wood distillation, and destructive distillation are other names for pyrolysis processes [19]. Refuse Derived Fuel can be produced using several processing techniques by removing most of the biodegradable fractions (e.g., food waste), metals, and glass from the waste. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content [20]. The present study examined the potential of temple waste an alternative energy resource by transforming it into RDF.

2. METHODOLOGY

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City Figure, in 2022 [21], the city has a population of 959.237, with 70.51% being Hindus. The study started with an engagement with the temple manager and Pemogan Village Authority to assess the current situation of waste management at the temple.

2.1 Material and Equipment

In the waste collection, some 100 L polypropylene (PP) sacks were used to collect the waste and bring to the separation site.The equipments were used during the waste collection and measurement, included a 4 x 6 m plastic tarp for separation base, a density box with size of of 1 x 1 x 0.5 meters or 0.5 m^3 for density analysis, Wei Heng WH-A08 digital scale to weigh the waste, and data sheet. All temple waste was moved to the RDF processing place. The temple waste was dried in two ways: (1) Natural drying by sunlight in 4 days and (2) Pyrolisis process. A 200 L of metal drum was used to heat the temple waste for 8 hours. It was placed on a fireplace that was fueled with firewood.

The dried temple waste then proceeds to some machines to produce the RDF. A chaft cutter machine (MCC) series 6-200 with GC-200 Engine and 6.5 horsepower (hp) was used to grind the temple waste into smaller pieces about 2-3 cm. Afterwards, a milling machine FFC

23 with GX 270 engine and 9 hp worked to produce finer temple waste form. Both powders were mixed manually on a tray with common cassava starch of about 10%. The cassava starch has a role as natural binder to make a solid RDF pellet [22]. It is also a material which is easy to find material and able to locally processed. The temple waste powder was then pressed into pellet form by using a vertical pellet press machine SLD 150 MPK with JF 180 engine.

2.2 Temple Waste Collection

Temple waste generation and the waste compositions were measured during the full moon ceremonial day. It is one of the ceremonies which have a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 [23]. The temple wastes were collected every hour for a period of 12 hours from 11.00 am to 10.00 pm. It was divided into two phases according to the incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.

2.3 Temple Waste Measurement

The temple waste characteristic that was measured included waste generation, waste composition and density. Then, the wastes were collected from the trash bins placed around the temple and weighed. Then the wastes were sorted into several categories, such as food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and compared to the total waste to obtain the composition percentage. The density (in kg/m^3) was estimated by accommodating the wastes into a box with a size of 1 x 1 x 0.5 meters or 0.5 m^3 in volume. The box was full filled with the waste and weighed. The density represents the waste weight per volume unit. Figure 1 shows the wastes collected during the study.

Figure 1 The temple waste collected from ceremonial activities

2.4 Refused Derived Fuel (RDF) Analysis

The RDFs were prepared and analyzed for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative. Water content was determined by drying a certain of waste amount in an electrical oven at 103 ± 5°C for one hour until the constant weight was achieved. Water content, dried material, ash content, organic content, volatile, and carbon content were analyzed with gravimetry according to Method Analysis by Association of Efficial Agriculture Chemist. Nitrogen was measured by using semimicro Kjeldhal method, meanwhile the phosphorus and calcium was measured by using spectrophotometry and atomic absorption spectroscopy (AAS). The caloric value was using Gallenkamp Ballistic Bomb Calorimeter. Each sample was weighed into the steel capsule at 0.50 g. To contact the capsule, a 10-cm-long cotton thread was tied to the thermocouple. The device was sealed and charged with up to 30 atoms of oxygen. The bomb was activated by pressing the ignition button, causing the sample to burn in an excess of oxygen. The thermocouple and galvanometer equipment were used to measure the greatest temperature rise in the bomb [24].

3. RESULTS AND DISCUSSION

3.1 Temple Waste Characteristics

The temple waste generation during the ceremonial day is presented in Figure 2. The results showed that the highest waste generation took place between 01.00 and 02.00 pm (phase 1) and between 7.00 and 8.00 pm (phase 2) with 54.91 kg and 47.87 kg, respectively. The minimum waste generation during the ceremony was between 10 to 11 am (phase 1) and between 5 to 6 pm (phase 2). During the 12 hours, it was found that total waste generation during the ceremonial in this temple was 292.36 kg ± 2.48.

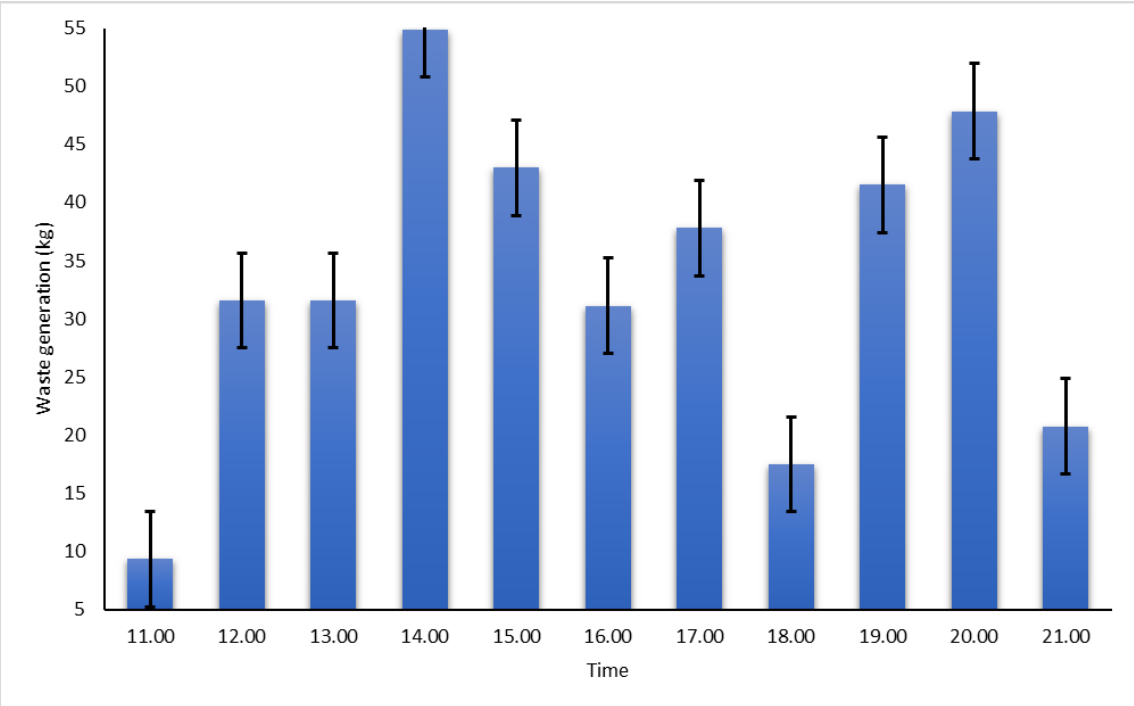

Figure 2 The temple waste generation during full moon ceremonial day

The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community. Those religious and ritual activities lead to significant production of offerings and their disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them after praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On the other hand, temple waste can be used as valuable resources through a recycling initiative to make new products [16,25].

On the basis of the results of density measurements, it was found that the average density of temple waste was 63.56 ± 5.83 kg/m^3. Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. On the basis of the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is also determined by means of collecting and transporting waste used. The comparison between the typical density of waste in the household, waste carts, open trucks, landfill waste and current research can be seen on Table 1.

Table 1. Comparison of waste density based on waste collection conditions

Waste collection conditions	**Density (ton/m^3)**
Waste in household waste containers*	0.01 – 0.20
Waste in waste carts*	0.20 – 0.25
Waste in open trucks*	0.30 – 040
Waste in landfills*	0.50 – 0.60
Temple waste (current research)	0.064

* Source: Damanhuri, 2010

On the basis of the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45.52% dan 33.86% respectively. Meanwhile, other kinds of waste were food waste (10.78%), non-organic waste (3.63%), and hard waste, such as bamboo and wood (9.72%). Table 2 shows the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple obtained during the study period.

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Percentage	Mass (kg)	Volume (m^3)
1	Food waste	10.78%	31.50	0.49
2	Leaf waste	45.52%	133.10	2.10
3	Flower waste	33.86%	98.99	1.56
4	Hard waste	9.72%	28.43	0.45
5	Non-organic waste	3.63%	10.61	0.17

Leaf and flower wastes were the main components of offerings used by Hindus. In this study, food waste, leaf waste and discarded flower are considered as wet waste. It shown that 90.16% the waste at the Griya Tanah Kilap Temple was 90.16% during the ceremonial day. The findings are higher than the one obtained in the previous study at Besakih Temple with the composition of wet waste in normal day was (food waste, flowers, and leaves) 79.13% and in the ceremonial day was 79.19%. Besakih temple is the largest temple in Bali Island and has daily visitors for praying [26].

The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%). This waste needs to be managed immediately, as it can produce unpleasant odors including as ammonia, and H_2S. In addition, decomposition products such as methane gas and the like are produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-degradable waste including paper, metal, plastic, and glass should be recycled because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic. The information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique [27,28], biofuel materials [29], biochar [30], natural dyes [31], and natural fertilizers [32].

Jain [27] in his research combined cow dung waste and flower waste generated from traditional ceremonial activities, offerings, or prayers was collected to be used as compost material using vermicomposting with earthworms (*Eisenia foetida*). The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (*Tagetes erecta*) as biofuel was carried out by Khammee *et al.* [29]. Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. Thus, the effort to recycle temple waste into the products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.

3.2. Refuse Derived Fuel from Temple Waste

The process of making RDF is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material [20].

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid *(char)* [33]. The temperature used in the pyrolysis process is classified as low temperature ranging from 400 to 800°C. According to Ganesh [34], the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. Briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better [35].

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are the components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion process of a material per unit mass or per unit volume [36,37], it is necessary to determine the caloric value of the RDF raw material. The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

Table 3. RDF characteristics test results

Parameter	**Drying Types**	
	Pyrolysis	**Natural Drying**
Dry weight (%)	88.88	85.85
Water content (%)	11.11	14.15
Ash (%)	31.89	7.98
Organic matter (%)	56.98	77.85
Nitrogen (%)	1.69	1.95
Calcium (%)	3.48	5.55
Phosphor (%)	1.38	0.9
Caloric (Kcal/kg)	3311.70	2912.7

On the basis of the analysis of the characteristics, of RDF, the dry weight of the two drying methods did not differ significantly. However, natural drying method took 3-4 days, while pyrolysis took only 8 hours. In terms of drying time, pyrolysis is more effective than the natural drying method. Pyrolysis generated lower water content compared to natural drying; however, both met the RDF criteria for water content, which is less than 20% [38]. The organic matter content of natural drying RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500°C and could cause loss of organic matter. Meanwhile, natural drying RDF did not reach extreme temperature and thus, preserved the organic matter.

The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 Kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. On the basis of the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., [39] showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the values of estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted to carbon dioxide (CO_2) equivalent, the RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

On the basis of these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials [40]. Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) [41], organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) [42]. The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

4. CONCLUSION

The temple waste generation in Griya Anyar Tanah Kilap Temple was 292.36 kg ± 2.48 with 90.16% of organic waste during the full moon ceremonial day. The pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. The potential energy of pyrolysis RDF was 3856.19 kWh/tons and 3391.59 kWh/tons for natural drying RDF. These values need to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. The effort to manage temple wastes in all areas on the island of Bali need to be enhanced and RDF temple waste can be further developed as an alternative energy resource. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

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Refuse Derived Fuel Potential Production from Temple Waste as Energy Alternative Resource in Bali Island

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ABSTRACT

The leakage of temple waste in the environment surrounding the temples has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292.36 kg of temple waste is generated from a single ceremonial at Griya Anyar Tanah Kilap Temple. The temple waste consists of 90,16% of organic waste (food, leaf and discarded flower) that is easily biodegraded. This research aimed to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste are used as RDF material using two different drying methods, namely natural drying and pyrolysis. The results showed that the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. According to the electrical power potential, pyrolysis RDF has 3856.19 kWh/tons, meanwhile natural drying RDF has 3391.59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel, renewable energy, sustainable waste management, waste recycling, pyrolysis.

INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3.2 million Balinese Hindus. Temples are an essential part of Balinese culture that vertically connects the society with God and ancestors [1, 2]. The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature [2].

On the other hand, the ceremonials conducted at the temples generate waste that needs to be managed. The offerings presented by the community are left at the temple and eventually become temple waste. There are many types of offerings depending on the type of festival celebrated. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves [3]. Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to incoming visitors. The waste container could be overloaded; some waste is dumped out and damages the environment [4]. Improper waste management has damaged the ecosystem aligning with the impact on the living creatures [5].

The problem of temple waste management happens particularly in the temple areas. Improper waste management negatively impacted the environment causing foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, as well as impairing the visual and aesthetic appearance of the temple as a place for religious activities [6–8]. The ritual activities led to a significant increase in temple waste production and the risk of its disposal in the land and water body [9–12]. The waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal. Some temples have implemented the rule to prevent the single-use plastic bag from entering the temple area. The visitors need to remove the plastic bag which is used to bring the offerings before going into the temple. The use of plastic packaging for some components of the offering such as foods, cakes, and even fruits packaged in plastic is still another issue that has not being resolved [13]. Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste that is transferred to the landfill. Lack of stringent rules and policy, the need for high financial support, and appropriate technology are some of the factors that contribute to the inefficient management of the temple waste [13, 14].

Temple waste was dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. The types of temple waste components were influenced by visitors, because each visitor brings different offerings, according to their socio-economic conditions [15]. As with waste generation, the composition of waste is also influenced by several factors:

1. Weather: in the areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes, whereas paper and other dry waste that is difficult to degrade will continue to increase.
3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: the communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to the areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also have an impact.

The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology [13]. The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries, such as color extraction, biogas production, vermicomposting, and biochar for agricultural applications [16]. Several studies have shown the application of flower waste as a major material for some value-added products. The recycling practice initiatives not only help to preserve the environment through sustainable waste management but also provide work opportunities and generate revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the products have various applications, such as biochar and biocoal. Both use a similar production process, namely pyrolysis, but have different applications [7]. Biochar is used for soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel [17, 18]. Carbonization, wood distillation, and destructive distillation are other names for pyrolysis processes [19]. Refuse Derived Fuel can be produced using several processing techniques by removing most of the biodegradable fractions (e.g., food waste), metals, and glass from the waste. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content [20]. The present study examined the potential of temple waste an alternative energy resource by transforming it into RDF.

METHODOLOGY

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City Figure, in 2022 [21], the city has a population of 959.237, with 70.51% being Hindus. The study started with an engagement with the temple manager and Pemogan Village Authority to assess the current situation of waste management at the temple.

Material and equipment

In the waste collection, some 100 L polypropylene (PP) sacks were used to collect the waste and bring to the separation site.The equipments were used during the waste collection and measurement, included a 4 x 6 m plastic tarp for separation base, a density box with size of of 1 x 1 x 0.5 meters or 0.5 m^3 for density analysis, Wei Heng WH-A08 digital scale to weigh the waste, and data sheet. All temple waste was moved to the RDF processing place. The temple waste was dried in two ways: (1) Natural drying by sunlight in 4 days and (2) Pyrolisis process. A 200 L of metal drum was used to heat the temple waste for 8 hours. It was placed on a fireplace that was fueled with firewood.

The dried temple waste then proceeds to some machines to produce the RDF. A chaft cutter machine (MCC) series 6-200 with GC-200 Engine and 6.5 horsepower (hp) was used to grind the temple waste into smaller pieces about 2-3 cm. Afterwards, a milling machine FFC 23 with GX 270 engine and 9 hp worked to produce finer temple waste form. Both powders were mixed manually on a tray with common cassava starch of about 10%. The cassava starch has a role as natural binder to make a solid RDF pellet [22]. It is also a material which is easy to find material which can be locally processed. The temple waste powder was then pressed into pellet form by using a vertical pellet press machine SLD 150 MPK with JF 180 engine.

Temple waste collection

Temple waste generation and the waste compositions were measured during the full moon ceremonial day. It is one of the ceremonies which have a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 [23]. The temple wastes were collected every hour for a period of 12 hours from 11.00 am to 10.00 pm. It was divided into two phases according to the incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.

Temple waste measurement

The temple waste characteristic that was measured included waste generation, waste composition and density. Then, the wastes were collected from the trash bins placed around the temple and weighed. Then the wastes were sorted into several categories, such as food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and compared to the total waste to obtain the composition percentage. The density

a)

b)

Figure 1. The temple waste collected from ceremonial activities

(in kg/m^3) was estimated by accommodating the wastes into a box with a size of 1×1×0.5 meters or 0.5 m^3 in volume. The box was full filled with the waste and weighed. The density represents the waste weight per volume unit. Figure 1 shows the wastes collected during the study.

Refused derived fuel analysis

The RDFs were prepared and analyzed for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative. Water content was determined by drying a certain amount of waste in an electrical oven at 103 ± 5 °C for one hour until the constant weight was achieved. Water content, dried material, ash content, organic content, volatile, and carbon content were analyzed with gravimetry according to Method Analysis by Association of Efficial Agriculture Chemist. Nitrogen was measured by using semi-micro Kjeldhal method, meanwhile the phosphorus and calcium was measured by using spectrophotometry and atomic absorption spectroscopy (AAS). The caloric value was using Gallenkamp Ballistic Bomb Calorimeter. Each sample was weighed into the steel capsule at 0.50 g. To contact the capsule, a 10-cm-long cotton thread was tied to the thermocouple. The device was sealed and charged with up to 30 atoms of oxygen. The bomb was activated by pressing the ignition button, causing the sample to burn in an excess of oxygen. The thermocouple and galvanometer equipment were used to measure the greatest temperature rise in the bomb [24].

RESULTS AND DISCUSSION

Temple waste characteristics

The temple waste generation during the ceremonial day is presented in Figure 2. The results showed that the highest waste generation took place between 1.00 and 2.00 pm (phase 1) and between 7.00 and 8.00 pm (phase 2) with 54.91 kg and 47.87 kg, respectively. The minimum waste generation during the ceremony was between 10 to 11 am (phase 1) and between 5 to 6 pm (phase 2). During the 12 hours, it was found that total waste generation during the ceremonial in this temple was 292.36 kg ± 2.48.

The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community. Those religious and ritual activities lead to significant production of offerings and their disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them

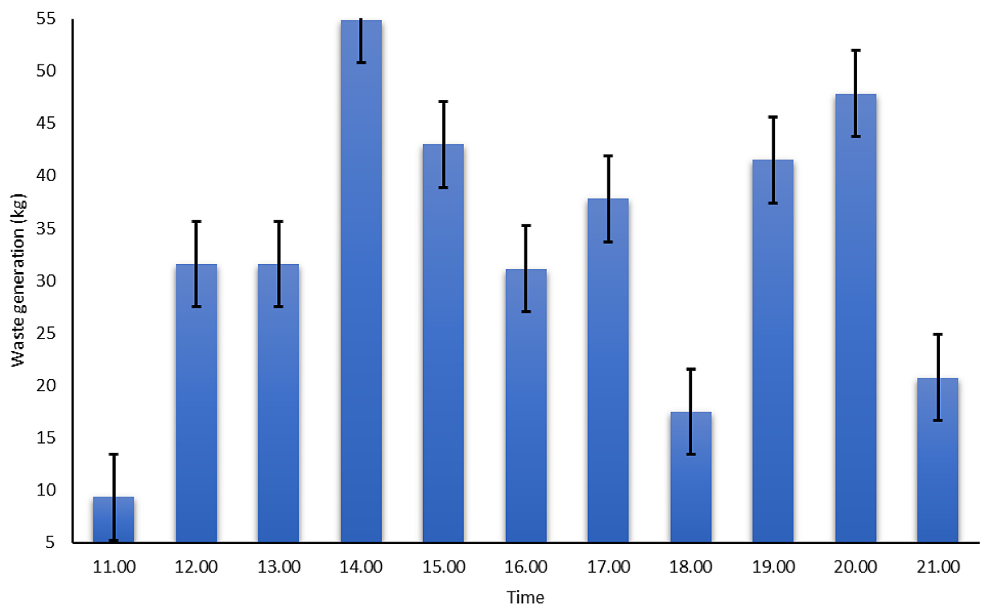

Figure 2. The temple waste generation during full moon ceremonial day

Table 1. Comparison of waste density based on waste collection conditions [Damanhuri, 2010]

Waste collection conditions	Density (ton/m^3)
Waste in household waste containers*	0.01 – 0.20
Waste in waste carts*	0.20 – 0.25
Waste in open trucks*	0.30 – 0.40
Waste in landfills*	0.50 – 0.60
Temple waste (current research)	0.064

after praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On the other hand, temple waste can be used as valuable resources through a recycling initiative to make new products [16, 25].

On the basis of the results of density measurements, it was found that the average density of temple waste was 63.56 ± 5.83 kg/m^3. Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. On the basis of the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is also determined by means of collecting and transporting waste used. The comparison between the typical density of waste in the household, waste carts, open trucks, landfill waste and current research can be seen on Table 1.

On the basis of the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45.52% dan 33.86% respectively. Meanwhile, other kinds of waste were food waste (10.78%), non-organic waste (3.63%), and hard waste, such as bamboo and wood (9.72%). Table 2 shows the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple obtained during the study period.

Leaf and flower wastes were the main components of offerings used by Hindus. In this study, food waste, leaf waste and discarded flower are considered as wet waste. It shown that 90.16% the waste at the Griya Tanah Kilap Temple was 90.16% during the ceremonial day. The findings are higher than the one obtained in the previous study at Besakih Temple with the composition of wet waste in normal day was (food waste, flowers, and leaves) 79.13% and in the ceremonial day was 79.19%. Besakih temple is the largest temple in Bali Island and has daily visitors for praying [26].

The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%). This waste needs to be managed immediately, as it can produce unpleasant odors including as ammonia, and H_2S. In addition, decomposition products such as methane gas and the like are produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-degradable waste including paper, metal, plastic, and glass should be recycled because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic. The information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique [27,28], biofuel materials [29], biochar [30], natural dyes [31], and natural fertilizers [32].

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Share (%)	Mass (kg)	Volume (m^3)
1	Food waste	10.78	31.50	0.497
2	Leaf waste	45.52	133.10	2.100
3	Flower waste	33.86	98.99	1.562
4	Hard waste	9.72	28.43	0.449
5	Non-organic waste	3.63	10.61	0.167

Jain [27] in his research combined cow dung waste and flower waste generated from traditional ceremonial activities, offerings, or prayers was collected to be used as compost material using vermicomposting with earthworms (*Eisenia foetida*). The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (*Tagetes erecta*) as biofuel was carried out by Khammee et al. [29]. Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. Thus, the effort to recycle temple waste into the products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.

Refuse derived fuel from temple waste

The process of making RDF is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material [20].

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid (*char*) [33]. The temperature used in the pyrolysis process is classified as low temperature ranging from 400 to 800 °C. According to Ganesh [34], the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. The briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better [35].

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are the components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion

Table 3. RDF characteristics test results

Parameter	Drying types	
	Pyrolysis	Natural drying
Dry weight (%)	88.88	85.85
Water content (%)	11.11	14.15
Ash (%)	31.89	7.98
Organic matter (%)	56.98	77.85
Nitrogen (%)	1.69	1.95
Calcium (%)	3.48	5.55
Phosphor (%)	1.38	0.9
Caloric (kcal/kg)	3311.70	2912.7

process of a material per unit mass or per unit volume [36, 37], it is necessary to determine the caloric value of the RDF raw material. The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

On the basis of the analysis of the characteristics, of RDF, the dry weight of the two drying methods did not differ significantly. However, natural drying method took 3-4 days, while pyrolysis took only 8 hours. In terms of drying time, pyrolysis is more effective than the natural drying method. Pyrolysis generated lower water content compared to natural drying; however, both met the RDF criteria for water content, which is less than 20% [38]. The organic matter content of natural drying RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500°C and could cause loss of organic matter. Meanwhile, natural drying RDF did not reach extreme temperature and thus, preserved the organic matter.

The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. On the basis of the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., [39] showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the values of estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted to carbon dioxide (CO_2) equivalent, the RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

On the basis of these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials [40]. Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) [41], organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) [42]. The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

CONCLUSIONS

The temple waste generation in Griya Anyar Tanah Kilap Temple was 292.36 kg ± 2.48 with 90.16% of organic waste during the full moon ceremonial day. The pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. The potential energy of pyrolysis RDF was 3856.19 kWh/tons and 3391.59 kWh/tons for natural drying RDF. These values need to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. The effort to manage temple wastes in all areas on the island of Bali need to be enhanced and RDF temple waste can be further developed as an alternative energy resource. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

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KEYWORDS

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ABSTRACT

The leakage of temple waste in the environment surrounding the temples has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292.36 kg of temple waste is generated from a single ceremonial at Griya Anyar Tanah Kilap Temple. The temple waste consists of 90,16% of organic waste (food, leaf and discarded flower) that is easily biodegraded. This research aimed to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste are used as RDF material using two different drying methods, namely natural drying and pyrolysis. The results showed that the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. According to the electrical power potential, pyrolysis RDF has 3856.19 kWh/tons, meanwhile natural drying RDF has 3391.59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

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Refuse Derived Fuel Potential Production from Temple Waste as Energy Alternative Resource in Bali Island

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ABSTRACT

The leakage of temple waste in the environment surrounding the temples has made the image of temples not only a cultural icon but also a contributor to landfill waste on the island. About 292.36 kg of temple waste is generated from a single ceremonial at Griya Anyar Tanah Kilap Temple. The temple waste consists of 90,16% of organic waste (food, leaf and discarded flower) that is easily biodegraded. This research aimed to examine the temple waste to be recycled into Refuse Derived Fuel (RDF). Leaf and flower waste are used as RDF material using two different drying methods, namely natural drying and pyrolysis. The results showed that the pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. According to the electrical power potential, pyrolysis RDF has 3856.19 kWh/tons, meanwhile natural drying RDF has 3391.59 kWh/tons. The pyrolysis RDF has less organic content and quite higher ash content than the natural drying RDF, making it better quality and appropriate to be applied in the community for a long-term sustainable temple waste recycling.

Keywords: temple waste, refuse derived fuel, renewable energy, sustainable waste management, waste recycling, pyrolysis.

INTRODUCTION

Bali is well known as an island of a thousand temples, with about 5000 temples around the island, not counting the household's temple. The Balinese temple is a sacred and holy place to carry out any religious ceremonials for the 3.2 million Balinese Hindus. Temples are an essential part of Balinese culture that vertically connects the society with God and ancestors [1, 2]. The community believes that a Balinese temple is where the almighty Gods descend on important ceremonial days. Most Balinese temples have a written charter consisting of rules and obligations for the member to follow. It defines the aspects of social life, worshipping, and nature [2].

On the other hand, the ceremonials conducted at the temples generate waste that needs to be managed. The offerings presented by the community are left at the temple and eventually become temple waste. There are many types of offerings depending on the type of festival celebrated. The complete offering consists of food, fruits, flowers, leaves, cake, and drink. The simple offering could consist of only flowers and leaves [3]. Currently, the temple waste is collected from the trash bin around the temple. Afterwards, all the waste will be picked up and transported to the landfill without any pre-treatment. During the ceremonial day, the temple waste significantly increases due to incoming visitors. The waste container could be overloaded; some waste is dumped out and damages the environment [4]. Improper waste management has damaged the ecosystem aligning with the impact on the living creatures [5].

The problem of temple waste management happens particularly in the temple areas. Improper waste management negatively impacted the environment causing foul odor, soil contamination, water pollution due to its nutrient richness and leaching, breeding center of diseases, as well as impairing the visual and aesthetic appearance of the temple as a place for religious activities [6–8]. The ritual activities led to a significant increase in temple waste production and the risk of its disposal in the land and water body [9–12]. The waste thrown away by visitors is generally still mixed with plastic waste used to wrap *banten* or offerings. Although it has been advised to separate plastic waste from the rest of the offerings, there are still several visitors who do not comply with the appeal. Some temples have implemented the rule to prevent the single-use plastic bag from entering the temple area. The visitors need to remove the plastic bag which is used to bring the offerings before going into the temple. The use of plastic packaging for some components of the offering such as foods, cakes, and even fruits packaged in plastic is still another issue that has not being resolved [13]. Additionally, the separation practice of temple waste does not run very well and ends up being mixed waste that is transferred to the landfill. Lack of stringent rules and policy, the need for high financial support, and appropriate technology are some of the factors that contribute to the inefficient management of the temple waste [13, 14].

Temple waste was dominated by offerings waste, flowers, leaves, and other waste in the form of leftover food, fruit, bamboo, cloth, and plastic. The types of temple waste components were influenced by visitors, because each visitor brings different offerings, according to their socio-economic conditions [15]. As with waste generation, the composition of waste is also influenced by several factors:
1. Weather: in the areas with high water content, the humidity of the waste will also be quite high
2. Frequency of collection: the more often waste is collected, the higher the pile of the waste. However, if the waste is not transported and left in landfills, the organic waste will decrease because it decomposes, whereas paper and other dry waste that is difficult to degrade will continue to increase.
3. Season: waste types will be determined by the current fruit season.
4. Socio-economic level: the communities or regions with a higher economy produce waste with a higher paper and plastic component and lower organic waste compared to the areas with a lower economy.
5. Product packaging: packaging of daily necessities products will also have an impact.

The insufficient waste management facility and unskilled human resources become the obstacles in managing the temple waste. There is no separation, proper collection, and management system due to the lack of stringent rules and policy, the need for high financial support, and appropriate technology [13]. The temple waste will be mixed with the municipal waste and boost the leachate production that can infiltrate the groundwater.

Proper waste management is urgently needed to handle the waste problem at the temple. Recycling initiatives could be an alternative to reduce the temple waste ending up in landfills. Flower and leaf waste could be the major resource material for industries, such as color extraction, biogas production, vermicomposting, and biochar for agricultural applications [16]. Several studies have shown the application of flower waste as a major material for some value-added products. The recycling practice initiatives not only help to preserve the environment through sustainable waste management but also provide work opportunities and generate revenue for the low-income community around the temple.

Recently, the conversion of lignocellulosic biomass has been gaining the attention as the products have various applications, such as biochar and biocoal. Both use a similar production process, namely pyrolysis, but have different applications [7]. Biochar is used for soil amendment, while biocoal or Refuse Derived Fuel (RDF) is used as an alternative fuel [17, 18]. Carbonization, wood distillation, and destructive distillation are other names for pyrolysis processes [19]. Refuse Derived Fuel can be produced using several processing techniques by removing most of the biodegradable fractions (e.g., food waste), metals, and glass from the waste. It gives a mixture of organic materials with a low number of inorganic materials and lower moisture content [20]. The present study examined the potential of temple waste an alternative energy resource by transforming it into RDF.

METHODOLOGY

The study was conducted at the Griya Tanah Kilap Temple, located around 10 kilometers from the city center. It has a 2300 m^2 area and is one of the well-known temples in the city, managed by the Pemogan Village Authority. Griya Tanah Kilap Temple is a public temple visited by the Hindus Community living in Denpasar City. According to Denpasar City Figure, in 2022 [21], the city has a population of 959.237, with 70.51% being Hindus. The study started with an engagement with the temple manager and Pemogan Village Authority to assess the current situation of waste management at the temple.

Material and equipment

In the waste collection, some 100 L polypropylene (PP) sacks were used to collect the waste and bring to the separation site.The equipments were used during the waste collection and measurement, included a 4 x 6 m plastic tarp for separation base, a density box with size of of 1 x 1 x 0.5 meters or 0.5 m^3 for density analysis, Wei Heng WH-A08 digital scale to weigh the waste, and data sheet. All temple waste was moved to the RDF processing place. The temple waste was dried in two ways: (1) Natural drying by sunlight in 4 days and (2) Pyrolisis process. A 200 L of metal drum was used to heat the temple waste for 8 hours. It was placed on a fireplace that was fueled with firewood.

The dried temple waste then proceeds to some machines to produce the RDF. A chaft cutter machine (MCC) series 6-200 with GC-200 Engine and 6.5 horsepower (hp) was used to grind the temple waste into smaller pieces about 2-3 cm. Afterwards, a milling machine FFC 23 with GX 270 engine and 9 hp worked to produce finer temple waste form. Both powders were mixed manually on a tray with common cassava starch of about 10%. The cassava starch has a role as natural binder to make a solid RDF pellet [22]. It is also a material which is easy to find material which can be locally processed. The temple waste powder was then pressed into pellet form by using a vertical pellet press machine SLD 150 MPK with JF 180 engine.

Temple waste collection

Temple waste generation and the waste compositions were measured during the full moon ceremonial day. It is one of the ceremonies which have a huge number of visitors to come to pray at the temple. The temple waste generation rate, composition, and density were measured according to the SNI 19-3964-1994 [23]. The temple wastes were collected every hour for a period of 12 hours from 11.00 am to 10.00 pm. It was divided into two phases according to the incoming visitors. Phase one was from 11.00 am to 3.00 pm representing the non-employee visitors. Phase two was from 3.00 pm to 10.00 pm, which mostly represented the employee visitors.

Temple waste measurement

The temple waste characteristic that was measured included waste generation, waste composition and density. Then, the wastes were collected from the trash bins placed around the temple and weighed. Then the wastes were sorted into several categories, such as food waste, leaves, flowers, bulk waste, and inorganic waste. Each composition was weighed and compared to the total waste to obtain the composition percentage. The density

a)

b)

Figure 1. The temple waste collected from ceremonial activities

(in kg/m^3) was estimated by accommodating the wastes into a box with a size of 1×1×0.5 meters or 0.5 m^3 in volume. The box was full filled with the waste and weighed. The density represents the waste weight per volume unit. Figure 1 shows the wastes collected during the study.

Refused derived fuel analysis

The RDFs were prepared and analyzed for their moisture, ash content, organic content, nitrogen, calcium, phosphorus, and caloric value. The result of caloric value was converted into electrical power potential and CO_2 equivalent to define its potential as an energy alternative. Water content was determined by drying a certain amount of waste in an electrical oven at 103 ± 5 °C for one hour until the constant weight was achieved. Water content, dried material, ash content, organic content, volatile, and carbon content were analyzed with gravimetry according to Method Analysis by Association of Efficial Agriculture Chemist. Nitrogen was measured by using semi-micro Kjeldhal method, meanwhile the phosphorus and calcium was measured by using spectrophotometry and atomic absorption spectroscopy (AAS). The caloric value was using Gallenkamp Ballistic Bomb Calorimeter. Each sample was weighed into the steel capsule at 0.50 g. To contact the capsule, a 10-cm-long cotton thread was tied to the thermocouple. The device was sealed and charged with up to 30 atoms of oxygen. The bomb was activated by pressing the ignition button, causing the sample to burn in an excess of oxygen. The thermocouple and galvanometer equipment were used to measure the greatest temperature rise in the bomb [24].

RESULTS AND DISCUSSION

Temple waste characteristics

The temple waste generation during the ceremonial day is presented in Figure 2. The results showed that the highest waste generation took place between 1.00 and 2.00 pm (phase 1) and between 7.00 and 8.00 pm (phase 2) with 54.91 kg and 47.87 kg, respectively. The minimum waste generation during the ceremony was between 10 to 11 am (phase 1) and between 5 to 6 pm (phase 2). During the 12 hours, it was found that total waste generation during the ceremonial in this temple was 292.36 kg ± 2.48.

The Hindus Community usually goes to the public temple on ceremonial days, such as the full moon (*Purnama*) and new moon (*Tilem*), which regularly come every 15 days, the day of knowledge (*Saraswati*) every 6 months, or other ceremonials for a certain community. Those religious and ritual activities lead to significant production of offerings and their disposal as waste to the environment. It results in various social and environmental impacts because of the high organic content in the temple waste. The community usually brings the offerings and leaves them

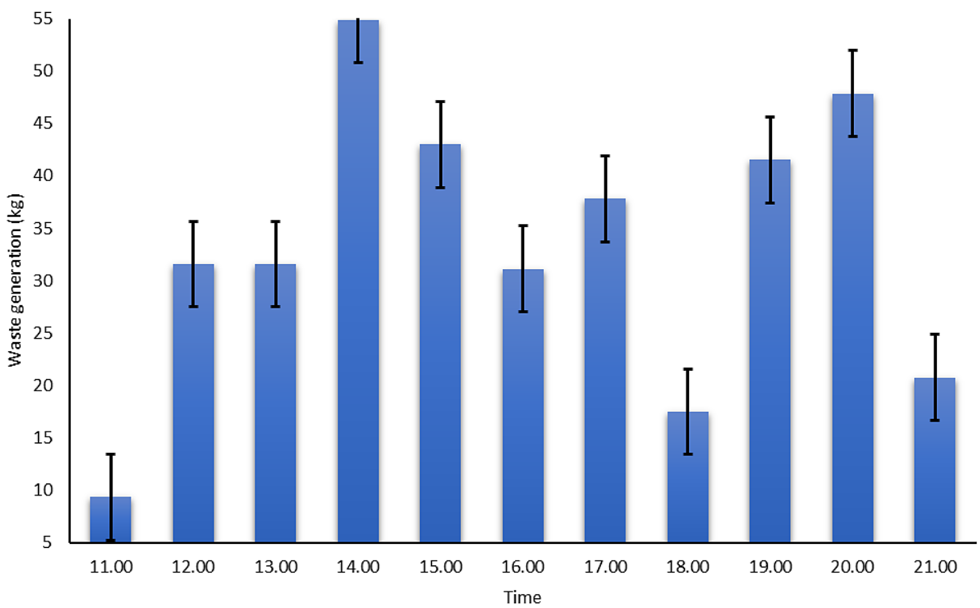

Figure 2. The temple waste generation during full moon ceremonial day

Table 1. Comparison of waste density based on waste collection conditions [Damanhuri, 2010]

Waste collection conditions	Density (ton/m^3)
Waste in household waste containers*	0.01 – 0.20
Waste in waste carts*	0.20 – 0.25
Waste in open trucks*	0.30 – 0.40
Waste in landfills*	0.50 – 0.60
Temple waste (current research)	0.064

after praying. Every hour, the cleaning staff of the temple will clean the area and collect all the temple waste. All waste is still mixed and stored in a temporary waste station for the next morning and will be collected by the government waste collection service to dispose of at the landfill. On the other hand, temple waste can be used as valuable resources through a recycling initiative to make new products [16, 25].

On the basis of the results of density measurements, it was found that the average density of temple waste was 63.56 ± 5.83 kg/m^3. Thus, the volume of waste generated at the Griya Tanah Kilap Temple can be determined by dividing the weight by the density of the waste. On the basis of the density and the weight, the volume of waste from Griya Tanah Kilap Temple was 4.61 m^3/day. Waste density data could be used to estimate the weight and volume of waste transported to a waste processing site or landfill. Besides, the density value is used to determine the volume of waste containers needed to accommodate the generation of waste in a place. Waste density is also determined by means of collecting and transporting waste used. The comparison between the typical density of waste in the household, waste carts, open trucks, landfill waste and current research can be seen on Table 1.

On the basis of the analysis of the composition of temple waste, leaf and flower waste became the largest component of waste compared to other types of waste, which were 45.52% dan 33.86% respectively. Meanwhile, other kinds of waste were food waste (10.78%), non-organic waste (3.63%), and hard waste, such as bamboo and wood (9.72%). Table 2 shows the contribution of each waste composition to the total waste at Griya Tanah Kilap Temple obtained during the study period.

Leaf and flower wastes were the main components of offerings used by Hindus. In this study, food waste, leaf waste and discarded flower are considered as wet waste. It shown that 90.16% the waste at the Griya Tanah Kilap Temple was 90.16% during the ceremonial day. The findings are higher than the one obtained in the previous study at Besakih Temple with the composition of wet waste in normal day was (food waste, flowers, and leaves) 79.13% and in the ceremonial day was 79.19%. Besakih temple is the largest temple in Bali Island and has daily visitors for praying [26].

The waste composition can describe the diversity of activities and products used by temple visitors. In general, waste in Indonesia is dominated by organic or compostable types (70-80%). This waste needs to be managed immediately, as it can produce unpleasant odors including as ammonia, and H_2S. In addition, decomposition products such as methane gas and the like are produced, which can be a safety hazard if not handled properly. The accumulation of waste that decomposes quickly needs to be avoided, especially in the area of holy places as it can interfere with prayer activities. Non-degradable waste including paper, metal, plastic, and glass should be recycled because otherwise, other processes are needed, such as combustion. However, this combustion also requires further handling, and has the potential as a source of problematic air pollution, especially if it contains PVC plastic. The information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique [27,28], biofuel materials [29], biochar [30], natural dyes [31], and natural fertilizers [32].

Table 2. Mass and volume of each type of waste composition

No.	Type of waste	Share (%)	Mass (kg)	Volume (m^3)
1	Food waste	10.78	31.50	0.497
2	Leaf waste	45.52	133.10	2.100
3	Flower waste	33.86	98.99	1.562
4	Hard waste	9.72	28.43	0.449
5	Non-organic waste	3.63	10.61	0.167

Jain [27] in his research combined cow dung waste and flower waste generated from traditional ceremonial activities, offerings, or prayers was collected to be used as compost material using vermicomposting with earthworms (*Eisenia foetida*). The lignin content in flower waste can be a source of material for making biofuels. The utilization of *gemitir* flower (*Tagetes erecta*) as biofuel was carried out by Khammee et al. [29]. Fresh *gemitir* flowers have a water content of 80% and can be processed as biofuel material at 20% moisture content. However, this research can initiate the use of flowers from the remains of traditional ceremonies to produce biofuels.

With a composition of organic waste that reaches 80%, the ceremonial waste at the Griya Tanah Kilap Temple certainly has the potential to be developed into RDF, which can be reused for ceremonial activities as *pasepan* material. Before being processed into RDF, it is necessary to analyze the quality of the RDF material so it can be processed and developed. Thus, the effort to recycle temple waste into the products that have use-value is expected to be able to change the image of the temple from a waste contributor in the landfill to a cultural icon of Bali Island that pays attention to cultural, environmental, and social sustainability.

Refuse derived fuel from temple waste

The process of making RDF is carried out through several processes first to select the components of waste composition that can be used. Waste components such as food waste, metal, and glass are separated from the garbage collection, leaving a mixture of organic and inorganic waste. A good waste component to use is to have a low water content to improve the thermochemical properties of the material [20].

The characteristic test of RDF material was done to determine the condition of the temple waste, which would be used as RDF material. In this pyrolysis combustion, the heating of the waste material was carried out without contact with oxygen. Pyrolysis is a process of thermal degradation of solid material in the absence of oxygen. In this process, it is possible to have several thermochemical conversion pathways so that the solid becomes a gas (permanent gasses), liquid (pyrolytic liquid), and solid (*char*) [33]. The temperature used in the pyrolysis process is classified as low temperature ranging from 400 to 800 °C. According to Ganesh [34], the process of making RDF from waste has five important steps, namely initial separation, size screening, counting, separating magnetic materials, and making pellets.

Briquettes can be made from a variety of raw materials, such as bagasse, rice husks, wood sawdust, and agricultural waste materials. The main ingredient contained in the raw material is cellulose. The higher the cellulose content, the better the quality of the briquettes. The briquettes containing too many wasted substances tend to emit smoke and unpleasant odors. An adhesive is needed to glue the particles of raw material substances in the process of making briquettes, so that a compact briquette is produced. The use of adhesive materials is intended to hold water and form a dense texture or bond two glued substrates. With the presence of adhesive material, the arrangement of the particles is better, more regular, and denser so that in the compression process, the pressure of the briquettes will be better [35].

The physical characteristics of the material include the amount of water content, ash content, volatile content, and fixed carbon content contained in the material. In general, to determine the four physical characteristics, proximate analysis is used. Proximate analysis of a fuel material will be beneficial to evaluate the flame rate at the combustion stage, databases for designing boilers, and classifying fuels. In general, the fixed carbon and volatile matter content from the proximate analysis will affect the energy content of the biomass. The greater the ratio between fixed carbon and volatile matter in the material, the greater the chemical energy that can be released in the heating process. Meanwhile, water content and ash content in the material are the components that can affect fuel quality.

In determining the maximum amount of heat energy released from the complete combustion

Table 3. RDF characteristics test results

Parameter	Drying types	
	Pyrolysis	Natural drying
Dry weight (%)	88.88	85.85
Water content (%)	11.11	14.15
Ash (%)	31.89	7.98
Organic matter (%)	56.98	77.85
Nitrogen (%)	1.69	1.95
Calcium (%)	3.48	5.55
Phosphor (%)	1.38	0.9
Caloric (kcal/kg)	3311.70	2912.7

process of a material per unit mass or per unit volume [36, 37], it is necessary to determine the caloric value of the RDF raw material. The results of the analysis of the characteristic test of RDF products using natural drying and pyrolysis methods are presented in Table 3.

On the basis of the analysis of the characteristics, of RDF, the dry weight of the two drying methods did not differ significantly. However, natural drying method took 3-4 days, while pyrolysis took only 8 hours. In terms of drying time, pyrolysis is more effective than the natural drying method. Pyrolysis generated lower water content compared to natural drying; however, both met the RDF criteria for water content, which is less than 20% [38]. The organic matter content of natural drying RDF was higher than that of pyrolysis RDF, which was 77.85% and 56.98%, respectively. The higher the organic content of a material, the better the quality to be used as fuel. The amount of organic matter in pyrolysis RDF was lower than natural RDF due to the combustion temperature in the RDF reactor, which might be very high and reached 500˚C and could cause loss of organic matter. Meanwhile, natural drying RDF did not reach extreme temperature and thus, preserved the organic matter.

The caloric value of both types of RDF is close to the minimum caloric value required for combustion needs in the cement industry sector, which is 3000 kcal/kg. The drying method certainly has a crucial role in increasing the caloric value of RDF. On the basis of the Regulation of the Minister of Energy and Mineral Resources No. 47 of 2006 concerning Guidelines for the Manufacture and Utilization of Coal Briquettes and Coal-Based Solid Fuels, RDF in this study is classified as bio-coal briquettes with a maximum humidity standard of 15% and a minimum caloric value of 4400 kcal/kg. Research by Widyatmoko et al., [39] showed that RDF briquettes from organic matter and residue that had been carbonized first gave a caloric value of 8,051.25 cal/gr, which is equivalent to 9,357.34 kWh/tons. With 1 calorie equivalent to 1.1622E-6 kWh, the values of estimated potential electrical energy that can be generated from the RDF of temple waste in this study are 3856.19 kWh/tons (pyrolysis drying) and 3391.59 kWh/tons (natural drying). If converted to carbon dioxide (CO_2) equivalent, the RDF from temple waste is equivalent to producing 184 tons CO_2 equivalent (pyrolysis drying) and 162 tons CO_2 equivalent (natural drying).

On the basis of these results, it is necessary to increase the caloric value of the temple waste RDF, for example, by increasing the drying efficiency and adding other flammable materials [40]. Some materials that can be added to the RDF mixture are plastic, which has a caloric value of around 11,113.76 cal/gr, paper (3776.29 cal/gr), wood (5066.92 cal/gr) [41], organic mud (1199 cal/gr) and coconut shell (5721 cal/gr) [42]. The results of these characteristic tests need to be studied further by comparing the characteristics of the RDF from this study with the RDF from previous studies. RDF briquettes can certainly be an alternative fuel used for domestic or industrial needs. This temple waste recycling research is an initial study to determine the potential of temple waste RDF. Thus, it is hoped that this recycling effort can be one of the solutions to handling temple waste and developing renewable energy resources.

CONCLUSIONS

The temple waste generation in Griya Anyar Tanah Kilap Temple was 292.36 kg ± 2.48 with 90.16% of organic waste during the full moon ceremonial day. The pyrolysis RDF has a similar caloric value to the natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg, respectively. The potential energy of pyrolysis RDF was 3856.19 kWh/tons and 3391.59 kWh/tons for natural drying RDF. These values need to be increased to meet the criteria for using RDF, both through increasing drying efficiency and adding other materials with a high caloric value, such as plastic, paper, or wood. The effort to manage temple wastes in all areas on the island of Bali need to be enhanced and RDF temple waste can be further developed as an alternative energy resource. This recycling effort is also one of the implementations of the circular economy concept in temple waste management.

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