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

I Made Wahyu Wijaya[1,2,*], I Gusti Ngurah Made Wiratama[2], I Kadek Ardi Putra[2], Azmi Aris[3]

[1] Regional Development Planning and Environmental Management, Postgraduate Program, Universitas Mahasaraswati Denpasar, Denpasar, Bali, Indonesia

[2] Environmental Engineering Department, Faculty of Engineering, Universitas Mahasaraswati Denpasar, Denpasar, Bali, Indonesia

[3] Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Sustainable Environment (RISE), Universiti Teknologi Malaysia, Johor Bahru, Malaysia

* Corresponding author: wijaya@unmas.ac.id

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

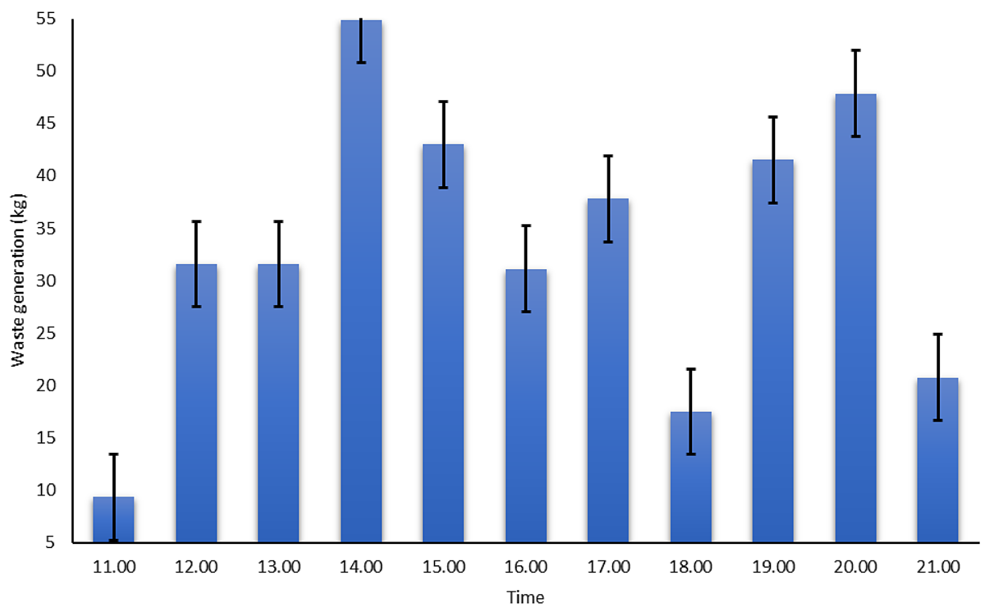

Figure 2. The temple waste generation during full moon ceremonial day

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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