STUDY ON TEMPLE WASTE MANAGEMENT AND ITS POTENTIAL FOR REDUCING CARBON EMISSION

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STUDY ON TEMPLE WASTE MANAGEMENT AND ITS POTENTIAL FOR REDUCING CARBON EMISSION

I Gusti Ngurah Made Wiratama[1]
I Made Wahyu Wijaya[2]

ABSTRACT

Objective: This study aims to investigate waste management practices at temple sites in Bali, Indonesia, with the overarching goal of reducing carbon emissions and promoting environmental sustainability amidst increasing waste generation and frequent ceremonial events.

Theoretical Framework: The study relies on key theoretical concepts from environmental science, waste management, tourism studies, and sustainability. These include population dynamics and waste generation, principles of sustainable waste management, and the intersection of cultural tourism with environmental conservation.

Method: This study employs a comprehensive methodology that involves the analysis of waste composition and generation using the Indonesian National Standard (SNI) 19-3964-1994. Additionally, we collected data through interviews and expenditure assessments to evaluate existing waste management practices and understand visitor behaviours.

Results and Discussion: Analysis revealed significant quantities of waste generated at temple sites, with Watu Klotok Temple emerging as the largest contributor, producing 449.87 kg of waste. Other significant contributors included Tanah Kilap Tampel, Saraswati Temple, Mutering Jagat Sidakarya Temple, Jagatnatha Temple, and Pucak Mangu Temple. Predominantly, organic waste accounted for 84.33% of total waste, while plastic and food waste constituted 4.08% and 11.59%, respectively. We observed a strong positive correlation between visitor numbers and waste generation, underscoring the urgent need for sustainable waste management practices to mitigate environmental impact and reduce carbon emissions.

Research Implications: The results of this study have both practical and theoretical implications for waste management strategies and environmental conservation efforts in Bali's cultural landscape. This research's recommendations, such as promoting locally sourced fruits and implementing waste segregation programmes, have broader implications for waste management policies and practices in similar contexts.

Originality/Value: This research contributes to the existing literature by providing empirical evidence on waste management practices at temple sites in Bali and quantifying the potential for carbon emissions reduction. This study's interdisciplinary approach highlights its relevance and value in tackling environmental issues in culturally significant regions and advancing sustainable development practices.

Keywords: Temple Waste, Waste Management, Carbon Emissions, Sustainability.

ESTUDO SOBRE A GESTÃO DE RESÍDUOS DE TEMPLOS E SEU POTENCIAL PARA REDUZIR A EMISSÃO DE CARBONO

RESUMO

Objetivo: Este estudo investiga as práticas de gestão de resíduos nos templos de Bali, Indonésia, visando reduzir as emissões de carbono e promover a sustentabilidade ambiental em meio ao aumento da geração de resíduos e eventos cerimoniais.

[1] Universitas Mahasaraswati, Denpasar City, Bali, Indonesia. E-mail: rahde.wiratama@unmas.ac.id
Orcid: https://orcid.org/0000-0002-9854-1707
[2] Universitas Mahasaraswati, Denpasar City, Bali, Indonesia. E-mail: wijaya@unmas.ac.id
Orcid: https://orcid.org/0000-0002-1847-0081

Referencial Teórico: Fundamentado em conceitos de ciência ambiental, gestão de resíduos, turismo e sustentabilidade, o estudo aborda dinâmicas populacionais, gestão sustentável de resíduos e a interseção entre turismo cultural e conservação ambiental.

Método: A metodologia abrange análise da composição e geração de resíduos conforme o Padrão Nacional da Indonésia (SNI) 19-3964-1994. Dados foram coletados por entrevistas e avaliações de despesas para entender práticas de gestão de resíduos e comportamentos dos visitantes.

Resultados e Discussão: Identificaram-se quantidades expressivas de resíduos nos templos, com o Templo de Watu Klotok como maior gerador, produzindo 449,87 kg. Predominantemente, resíduos orgânicos representaram 84,33%, enquanto plásticos e alimentos totalizaram 4,08% e 11,59%, respectivamente. A correlação positiva entre visitantes e geração de resíduos ressalta a urgência de práticas sustentáveis de gestão.

Implicações da Pesquisa: Os resultados têm implicações práticas e teóricas para estratégias de gestão de resíduos e conservação ambiental em Bali. Recomenda-se promover frutas locais e programas de segregação para políticas de gestão de resíduos.

Originalidade/Valor: Esta pesquisa contribui com evidências empíricas sobre gestão de resíduos em templos de Bali, destacando sua relevância para questões ambientais em regiões culturais e práticas sustentáveis.

Palavras-chave: Resíduos de Templo, Gestão de Resíduos, Emissões de Carbono, Sustentabilidade.

ESTUDIO SOBRE LA GESTIÓN DE LOS RESIDUOS DE LOS TEMPLOS Y SU POTENCIAL PARA REDUCIR LAS EMISIONES DE CARBONO

RESUMEN

Objetivo: Este estudio investiga las prácticas de gestión de residuos en templos de Bali, Indonesia, con el propósito de reducir las emisiones de carbono y promover la sostenibilidad ambiental ante el aumento de la generación de residuos y eventos ceremoniales.

Marco Teórico: Se basa en conceptos de ciencia ambiental, gestión de residuos, turismo y sostenibilidad, como la dinámica poblacional, gestión sostenible de residuos y la intersección del turismo cultural con la conservación ambiental.

Método: La metodología incluye el análisis de composición y generación de residuos según el Estándar Nacional Indonesio (SNI) 19-3964-1994. Se recolectaron datos mediante entrevistas y evaluaciones de gastos para comprender las prácticas de gestión de residuos y los comportamientos de los visitantes.

Resultados y Discusión: El análisis reveló cantidades significativas de residuos en los templos, destacando al Templo de Watu Klotok como el mayor contribuyente con 449.87 kg de residuos. Los residuos orgánicos representaron el 84.33%, seguidos por plásticos (4.08%) y alimentos (11.59%). Se observó una correlación positiva entre visitantes y generación de residuos, resaltando la necesidad de prácticas sostenibles para mitigar el impacto ambiental y reducir emisiones de carbono.

Implicaciones de la Investigación: Los hallazgos tienen implicaciones para la gestión de residuos y la conservación ambiental en Bali, con recomendaciones como promover productos locales y programas de segregación de residuos.

Originalidad/Valor: Este estudio aporta evidencia sobre la gestión de residuos en templos de Bali y cuantifica la reducción potencial de emisiones de carbono, destacando su relevancia para abordar problemas ambientales y avanzar en prácticas sostenibles.

Palabras clave: Residuos de Templo, Gestión de Residuos, Emisiones de Carbono, Sostenibilidad.

1 INTRODUCTION

An increase in the population of a region leads to a rise in the production of garbage (Hariyanto, 2014). Population migration, alongside birth and death rates, significantly influences population growth. The increase in tourist arrivals is evidence that population migration has an impact on the tourism industry. Bali Island is a significant tourist destination in Indonesia, known for its vibrant creative and cultural economy. It draws many tourists annually. Although this situation results in economic advantages, it also leads to an increase in waste production.

To effectively handle the garbage produced from ceremonial offerings, Bali, being an island with numerous sacred temple sites (known as 'pura'), needs to develop a comprehensive management strategy. The waste management strategy is important as it is a crucial part of Bali's comprehensive sustainable island management. Different sectors of community activities necessarily contribute to the development of waste. If Bali's waste management system remains poor, it will be subject to scrutiny as one of Indonesia's and the world's important tourism destinations. The arrival of tourists and the frequent occurrence of ceremonial events add to the buildup of garbage, especially at religious locations. Temples play a crucial role in the lives of the local people and in the tourism industry of Bali due to their spiritual nature. Therefore, factors such as the preservation of culture, pollution of the environment, impact on society, and spirituality, as well as ensuring environmental safety and health, all emphasise the significance of implementing waste management techniques for temples. Therefore, it is crucial to address these elements to effectively manage temple garbage in Bali in a sustainable manner.

Bali Island is widely recognised as a cultural tourism destination that possesses a distinctive charm, particularly due to its temple attractions. Temples in Bali hold significant religious importance for the Hindu community and are also popular tourist destinations, attracting more than six million people annually. Nevertheless, temples also contribute to the accumulation of garbage at waste disposal sites. Wijaya et al. (2021) state that waste in temples originates from the residual materials left behind after religious ceremonies or worship rituals conducted by the Hindu population. Around 3 million Hindu devotees who take part in temple rituals generate waste because of their religious activities. The Hindu population residing on Bali Island directly influences the quantity of ceremonial facilities utilised for religious rituals. With the growth of the population, there is an increase in the number of ceremonial goods being provided, which in turn raises the likelihood of generating more trash from these rites. Approximately 80% of the garbage generated during religious events in Bali comprises readily

biodegradable and compostable materials. The residual garbage generated from these ceremonies typically includes flowers, leaves, fruits, and bamboo. In addition, this garbage is frequently combined with plastic debris and other materials that are also used as objects for religious ceremonies (Yadav et al., 2015). Sugianti and Trihardiningrum (2008) conducted research that shows the average amount of garbage produced at Pura Besakih, the greatest temple in Bali, is 5.06 m^3 per day on normal days and climbs to 46.71 m^3 per day during traditional ceremonial days.

Temples play a crucial role in the religious practices of Balinese Hindus, and it is of paramount significance to ensure their preservation. To prevent dispersion, environmental contamination, and the inconvenience it might cause to the Hindu community, efficient trash management is necessary (Wijaya et al., 2021). Residual garbage from religious ceremonies can be managed using two primary methods: handling and reduction. Waste handling refers to the management of waste produced during ceremonial events, while waste reduction focuses on preventing the development of waste (Jain, 2016; Juneja et al., 2015; Yadav et al., 2015). The objective of this study is to determine the amount and attributes of leftover waste following rituals and to develop waste management techniques for temple locations. Gaining a comprehensive understanding of waste creation is essential for the purpose of efficient waste management planning, particularly in the context of establishing waste infrastructure within temples. The leftover ceremonial waste composition is utilised to assess the feasibility of recycling initiatives, thereby converting garbage into novel goods that possess both practical and economic worth (Singh et al., 2013a; Singh et al., 2018; Singh & Singh, 2016). The residual ceremonial waste management strategy includes the full process of managing waste, from its creation to its removal from the temple grounds. This technique functions as a framework for temple administration to efficiently manage the waste produced during religious activities. This work is unique because it takes a holistic approach to examining the connection between cultural tourism and trash management. It specifically focuses on temple sites on Bali Island. The authors Indawati (2020), Lian et al. (2020), and Obersteiner et al. (2021) have contributed to this research.

2 THEORETICAL FRAMEWORK

The research incorporates fundamental principles from other fields, such as environmental science, waste management, tourism studies, and sustainability. Hariyanto (2014) explains that the fundamental concept revolves around understanding population

dynamics and waste generation, where population growth, including migration, closely correlates with an increase in garbage production. The fundamental principle provides context for understanding the waste management difficulties encountered by areas undergoing demographic changes, as demonstrated by Bali's changing scenery.

Millions of tourists visit Bali Island every year due to its thriving creative and cultural economy. This influx of visitors has a significant impact on both the island's economic growth and its environmental sustainability. The relationship between tourism growth and waste accumulation underscores the necessity for well-crafted waste management strategies tailored to the unique conditions of tourist destinations. In this context, the essay explores the importance of temple sites ('pura') in Bali's cultural and religious structure, emphasising their dual function as sacred areas for the Hindu community and popular tourist destinations. This paper, drawing from the research of Wijaya et al. (2021) and other scholars, scrutinizes the significant influence of religious ceremonies and worship rituals on the generation of waste at temple sites. This underscores the cultural importance of temples and the complex issues surrounding trash management, underscoring the need for actions tailored to the unique context.

The study emphasises the significance of creating detailed waste management strategies that are specifically designed for temple sites in Bali, based on the research conducted by Jain (2016), Juneja et al. (2015), and Yadav et al. (2015). This entails not only efficiently managing waste produced at ceremonial occasions, but also taking proactive steps to avoid waste generation, in line with environmental sustainability's wider objectives.

Investigating how more effective waste management procedures might reduce carbon emissions is an essential element of the theoretical framework. The study utilises the IPCC recommendations and relevant literature on greenhouse gas emissions to measure the environmental advantages of waste management initiatives. It provides insights into the possibility of focusing on methods to reduce carbon emissions. This is in line with the wider goals of environmental preservation and emphasises the crucial role of waste management in attaining sustainability objectives.

Furthermore, the study highlights the incorporation of cultural tourism and environmental preservation, showcasing the multidisciplinary aspect of the research. The study emphasises the significance of comprehensive waste management strategies that both protect cultural heritage and encourage sustainable behaviours, drawing on the perspectives of writers like Indawati (2020), Lian et al. (2020), and Obersteiner et al. (2021). By incorporating these abstract principles, the research provides a thorough structure for understanding the intricate interactions of waste management, tourism, and environmental preservation in culturally

important areas such as Bali. It not only adds to theoretical understanding, but also provides practical approaches for tackling environmental issues and supporting sustainable development in tourist locations around the world.

3 METHODOLOGY

The collection of waste samples for this research was conducted at six temples scattered across Bali Province: Tanah Kilap Temple, Jagatnatha Temple, Saraswati Temple, Mutering Jagad Temple, Pucak Mangu Temple, and Watu Klotok Temple. The Hindu community on Bali Island frequently visits these six public temples. The selection of six temples as samples is also based on geographical positions, namely the mountainous and coastal regions. Given that those locations are part of the Bali Province's cleanliness service, the local authority assigned the temples. The locations of each temple are presented in Figure 1.

Figure 1

Sampling points

Source: Google Earth Database (2023)

The quantification of ritualistic waste production was conducted during key religious ceremonies. These events consist of Hari Purnama, which happens during the full moon, and Hari Tilem, which occurs during the dark moon. Additionally, there is a specific festival that takes place every six months at the corresponding temples. The study entailed quantifying the number of individuals visiting the temple, assessing the production and makeup of waste, and examining the correlation between waste production and visitor numbers. The tally of temple visits was conducted using a manual hand counter to record the number of incoming visitors. The category of counted visitors consists exclusively of adults, as children are not included in

the census due to their classification as members of family groupings. The number of visitors is quantified in terms of individuals per hour. Each temple was meticulously scrutinised during the full moon ritual, with the observation time lasting from 1:00 PM to 10:00 PM. Most of the ceremonial activities take place over a span of one or many days. However, there is a specific day that attracts the highest number of people and generates the largest amount of garbage from the temple. The choice of this specific timeframe is derived from the customary behaviour of individuals visiting temples to participate in religious rituals following their daily educational or occupational commitments.

The quantification of waste production and composition adheres to the protocols established by the Indonesian National Standard (SNI) 19-3964-1994, which outline the procedures for sampling and measuring the generation and composition of municipal garbage. The measurement technique encompasses two facets: trash generation quantification and the determination of the percentage composition of different waste categories. The primary constituents of temple waste consist mostly of donations such as coconut leaves, residual flowers, foliage, and various items including food scraps, fruits, bamboo, cloth, and plastic. This is an illustration of the wide range of things and activities related to the worship spaces that temple visitors use.

The quantification of waste generation is achieved by measuring the daily amount of waste. The waste source that has been measured consists of the leftovers resulting from ceremonial activities conducted at each temple. The measurement of waste generation is quantified in kilograms (kg). By measuring the weight of each waste component and dividing it by the total weight of the waste, one can determine the percentage composition of temple waste. The determined composition comprises organic trash, plastic garbage, and food remains. The mathematical formula for determining the percentage composition of temple garbage is as follows:

$$\%\ compotition\ X = \frac{Weight\ X\ (kg)}{Total\ waste\ weight\ (kg)} x100 \qquad (1)$$

Present temple waste management information was collected through interviews with temple management authorities. During the interview phase, inquiries are made to gather data regarding the present condition of temple trash management, the involvement of the community and visitors, and suggestions for waste management. Furthermore, a comprehensive assessment of waste management facility expenditures and waste management costs is carried out at every

temple. The statistical technique used was a basic linear regression analysis. The equation was used to establish a linear correlation between two variables: variable X (representing the number of visitors) as the dependent variable and variable Y (representing the amount of waste generated at the peak of the celebration every day) as the independent variable. The analysis of carbon emissions from ritual waste is conducted using greenhouse gas (GHG) calculations. The emission calculations adhere to the IPCC GHG Inventory Guidelines of 2006 (IPCC, 2006) as specified in the Ministry of Environment and Forestry Indonesia (KLH, 2013) with regards to air pollution originating from landfill sites. The specific greenhouse gas under consideration is methane gas (CH_4), which is generated from the accumulation of ceremonial waste. The calculation of the potential methane gas (CH_4) generated from the accumulation process is determined using the following equation:

$$Lo = DDOCm \,.\, F \,.\frac{16}{12} \qquad (2)$$

Lo = potential CH_4 gas generated (Gg CH_4)
DDOCm = mass of degraded and decomposed organic carbon (kg)
F = fraction of CH_4 gas produced from landfill gas
16/12 = ratio of CH_4/C

Where:

DDOCm = degraded and decomposed organic carbon (kg)
W = mass of wet waste disposed of (kg)
DOC = fraction of degraded organic carbon
DOCf = fraction of decomposed organic carbon
MCF = CH_4 correction factor for aerobic decomposition

4 RESULTS AND DISCUSSIONS

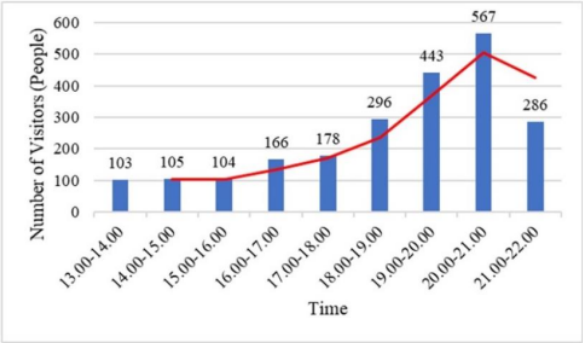
4.1 TEMPLE VISITORS

The term "number of temple visitors" denotes the total count of those who visit the temple with the intention of engaging in religious devotion. These guests usually bring offerings and aromatic substances for worship. The quantification of temple attendees is carried out during the pinnacle of the festivity, which occurs over a span of one day. Every six months,

each chosen temple has a celebration as part of the research sample. Figure 2 displays the mean number of visits to the temples at the study sites.

Figure 2

Fluctuation of temple visitors in Bali



Source: Author (2023)

According to the measurements conducted, it has been noted that the peak visitor activity during the full moon ceremony takes place between 8:00 p.m. and 9:00 p.m. Examining the visitation patterns across the computation period indicates that the number of visitors rises as the day advances towards the evening. This behaviour is attributed to the culmination of job and family engagements. In addition, evenings are less impacted by the high temperatures, enabling temple guests to participate in worship with greater ease. The fluctuation in visitor numbers has ramifications for predicting the quantity of garbage produced from ceremonial relics.

Therefore, it is crucial for temple staff to closely monitor visitor trends and adjust their waste management strategies accordingly. By understanding when peak visitor activity occurs, the temple can allocate resources more efficiently and ensure that the sacred grounds remain clean and respected. Additionally, this data can be used to plan for future events and ceremonies, ensuring that the temple can accommodate the influx of visitors and maintain a high level of cleanliness and sustainability. The correlation between visitor numbers and waste production highlights the importance of implementing sustainable practices and educating guests on the importance of responsible waste disposal. Through careful observation and analysis of visitor patterns, the temple can continue to uphold its traditions while also promoting environmental stewardship. The data collected can also inform decision-making processes when it comes to waste management and resource allocation within the temple grounds. By

understanding the relationship between visitor numbers and waste production, temple staff can proactively implement measures to minimise environmental impact and promote a culture of sustainability among visitors. This proactive approach will not only benefit the temple in terms of maintaining its pristine grounds but will also set an example for other religious and cultural sites to follow suit in promoting responsible waste disposal practices. Ultimately, by utilising data to inform decision-making and promote sustainable practices, the temple can continue to thrive as a sacred and environmentally conscious destination for all who visit.

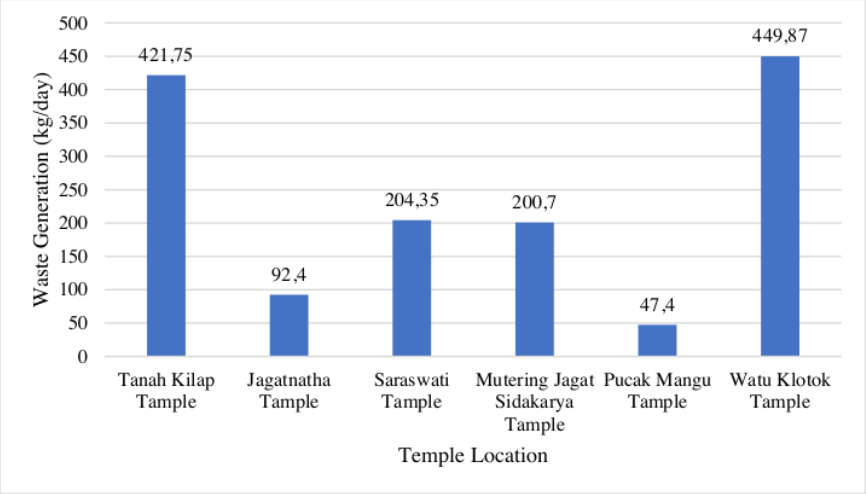
4.2 TEMPEL WASTE GENERATION AND CHARACTERISTICS

The average garbage generation is measured during a 24-hour period at the height of the full moon celebration. Out of the 6 temples chosen for the study, it was observed that the Watu Klotok Temple in the Klungkung Regency produces the most amount of garbage, with a total of 449.87 kg each day during ceremonies. The lack of a waste management system in this temple is to blame for the increased trash production, as the temple administration continues to collect, accumulate, and burn trash in nearby locations. In addition, temple visitors have not been instructed to contribute to the cleanliness of the temple by appropriately gathering the remains of their ceremonial offerings.

This has led to a significant environmental impact on the surrounding area, as the burning of trash releases harmful toxins into the air and soil. The temple administration must take immediate action to implement a proper waste management system, educate visitors on the importance of cleanliness, and work towards reducing the amount of waste generated during ceremonies. Failure to address these issues could result in further damage to the environment and tarnish the reputation of the temple as a sacred place of worship. It is crucial for all stakeholders to come together and find sustainable solutions to ensure the preservation of the temple and its surroundings for future generations. For example, the temple could collaborate with local waste management companies to properly dispose of hazardous materials and explore ways to recycle or reduce waste. Additionally, they could hold workshops and seminars for visitors on proper disposal methods and the impact of pollution on the environment to promote a culture of responsibility and sustainability among worshippers. Figure 3 displays the waste generated from ceremonial activities that has been gathered at each temple.

Figure 3

Average waste generation at temple



Source: Author (2023)

The Pucak Mangu Temple in Badung Regency has the lowest waste creation, specifically 47.4 kg/day during rituals. The minimum waste production at Pucak Mangu Temple can be credited to the proactive involvement of temple management in consistently encouraging temple visitors to uphold cleanliness within the temple premises. In addition, guests must gather the remains of their offerings and place them in specified garbage containers. Significantly, temple authorities actively promote the practice of retrieving one's ceremonial contributions following the completion of the rituals. The waste composition data for each temple is provided in Table 1, while the overall composition percentages are displayed in Figure 4.

Table 1

Temple waste composition

No	Location	Organic Waste (kg)	Plastic Waste (kg)	Food Waste (kg)	Total (kg)
1	Tanah Kilap Temple	317,75	24,7	79,3	421,75
2	Jagatnatha Temple	81	2,4	9	92,4
3	Saraswati Temple	175,05	5,9	23,4	204,35
4	Mutering Jagat Sidakarya Temple	144,4	16,8	39,5	200,7
5	Pucak Mangu Temple	40,4	4	3	47,4
6	Watu Klotok Temple	435,88	4,04	9,95	449,87
	Total (kg)	**1194,48**	**57,84**	**164,15**	**1416,47**
	Average (kg)	199,08	9,64	27,36	236,08

Source: Author (2023)

Figure 4

Average temple waste composition (kg)

Source: Author (2023)

Table 1 displays the waste composition of six different temples, showing the amount of organic waste, plastic waste, food waste, and total waste produced in kkilogrammes. The combined waste from all six temples is 1416.47 kg, with an average waste composition of 199.08 kg organic waste, 9.64 kg plastic waste, and 27.36 kg food waste per temple. The information gives insight into the types and quantities of waste these temples produce, allowing for further analysis and potential waste management practise improvement. The variation in waste composition among the six temples suggests different consumption patterns and waste generation practices within these religious institutions. The average total waste generated per temple is 236.08 kg, indicating a significant amount of waste being produced collectively. This data underscores the importance of implementing effective waste management strategies to reduce the environmental impact of temple activities and promote sustainability in their operations. Further research and monitoring could help identify specific areas for waste reduction and recycling initiatives within these temples.

The research findings provide a percentage breakdown of the composition of total temple garbage as follows: The quantity of organic garbage is 1,194.48 kg, which makes up 84.33% of the total. This waste includes substances such as flowers, leaves, and incense. The total weight of plastic garbage is 57.84 kg, which accounts for 4.08% of the total waste. This includes various products such as plastic bags, food packaging, and incense wrapping. The amount of food waste is 164.15 kg, which accounts for 11.59% of the total. This trash includes products such as fruits and bread. The amount of organic waste produced has significant potential that should be utilised. The amount of organic waste produced has significant potential that should be utilised for composting or energy generation. This can help reduce greenhouse

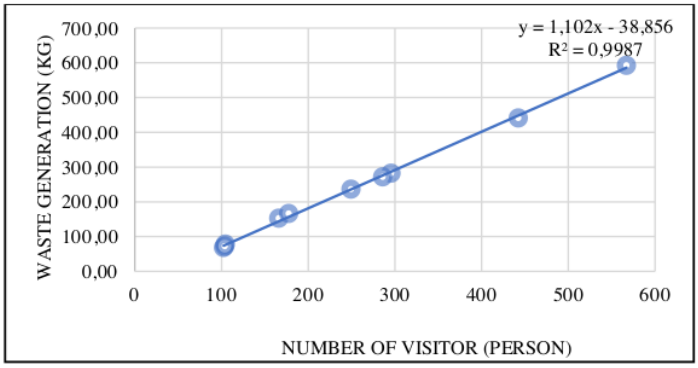
gas emissions and create valuable resources. Several studies have highlighted that organic waste holds the potential to be utilised as an alternative fuel source (Wijaya et al., 2023), biogas (Butar-Butar et al., 2020), compost fertiliser (Butar-Butar et al., 2020) (Policastro & Cesaro, 2023), and aggregate mix for concrete materials. Plastic waste can be used as a source of energy and recycled products that hold economic potential (Ridwan et al., 2022; Wamba et al., 2023). Additionally, food waste can be used as animal feed (Nath et al., 2023).

4.3 TRENDS IN TEMPLE WASTE GENERATION

Waste creation at the temple pertains to the quantity of waste generated during ceremonial events, specifically measured at the height of the ceremony. Figure 5 displays a linear equation that can be observed based on the computation results. According to the straightforward linear regression equation, Figure 5 clearly shows a correlation between the quantity of temple visitors and garbage production. The equation demonstrates a functional correlation, where an augmentation in visitors results in a corresponding augmentation in trash production. For example, if the number of visitors were to increase to 100, the projected trash production (Y) would similarly rise. It indicates that the independent variable could provide an explanation, while the remaining factors are influenced by other variables. Plant growth within the temple premises could potentially be another component contributing to temple waste. In addition to analysing the correlation between the two previously mentioned characteristics, it is crucial to consider the current state of the temple, which may be assessed based on socio-cultural factors.

Figure 5

Waste Generation vs Visitors



Source: Author (2023)

These components encompass the understanding of temple administration and visitors regarding trash, the consciousness of both parties regarding appropriate waste disposal, perceptions of the cleanliness of the temple environment, and the waste management regulations established by the temple management. Wardhana and Sudiarawan (2021) state that there are now no regulations in place, either by the local government or the traditional village, regarding the advice, management, and sanctions for maintaining the temple environment after religious events (upakara yadnya). This situation unequivocally reinforces the idea that an increase in temple visitation leads to a proportional rise in temple garbage production. Moreover, it is presumed that individuals who visit the temple are not required to take responsibility for the preservation of the temple surroundings.

4.4 STRATEGIES FOR TEMPLE WASTE MANAGEMENT

Tri Hita Karana is a fundamental aspect of Balinese civilisation that showcases its inherent native brilliance. The concept of Tri Hita Karana encompasses the essence of three factors that contribute to harmony (Suhardita et al., 2020). The three elements encompass the harmonious interconnection between humans and God, humans and their peers, and humans and the natural world. Temples, known as Pura, are sacred sites in Balinese culture where people worship and symbolise the harmonious connection between humanity and the divine. Moreover, temples are widely recognised as prominent symbols of cultural tourism.

Religious ceremonies in Bali are conducted without interruption, resulting in the continual and indirect production of temple garbage. Based on the extensive research undertaken, it is recommended that temple garbage be efficiently utilised to prevent the notion that temples are contributing to waste, considering the significant amount of waste generated and its composition. Multiple studies in the literature suggest that both organic and inorganic trash can be used to produce economically valuable commodities.

Organic waste has the potential to be used as an alternative fuel source, compost fertiliser, and as an ingredient in building materials like bricks or roof tiles. Wijaya et al. (2023) state that organic waste from temples can serve as a viable substitute for electricity. Plastic garbage can be repurposed for creating handicrafts and recyclable goods, offering significant economic opportunities. According to Wahyudi et al. (2018), there is a processing method that can turn plastic trash into plastic pyrolysis oil. This oil can serve as a substitute energy source due to its comparable characteristics to kerosene and diesel fuel. Pyrolysis oil quality is inferior to kerosene but superior to diesel fuel when considering indications such as density, combustion

duration, water temperature, and water volume lost while cooking. Plastic trash possesses substantial economic potential. Jati and Azzaki (2021) state that the total economic potential generated within a year from major cafés, small cafes, canteens, and futsal establishments amounts to Rp. 915,468.00. An escalation in the production of plastic garbage will lead to a corresponding rise in the monetary worth of plastic waste, ultimately leading to an augmented economic value. The economic potential is contingent upon both the nature of the activity and the specific type of plastic trash produced. By organising, gathering, and marketing plastic garbage based on its category, the community and temple administration may foster a self-contained circular economic system within the temple premises.

Food waste also possesses equivalent potential for use. Food waste can be used as a viable source of animal feed. The food waste produced during temple events can provide nourishment for maggots. Maggots possess the ability to rapidly break down food waste and effectively eradicate any unpleasant smells. According to Trishuta et al. (2020), maggots can break down food waste at a rate of up to 100 mg per larva each day. Undoubtedly, this situation offers a noteworthy prospect, especially considering that temple food waste is presently disposed of, resulting in disagreeable smells.

The temple trash management system is an essential component of the broader temple waste management framework. According to the interview results, waste management related to religious events is currently lacking in terms of facilities, infrastructure, and human resources. The temple management must build a waste management system that comprises preparing human resources, defining environmental governance regulations (awig-awig) for the temple region, and planning the waste management system. Temple management can accomplish human resource preparedness by conducting training sessions. Engaging in training activities would improve their comprehension of the significance of waste management and environmental conservation inside the temple grounds. According to Balachander (2015) and Singh et al. (2013), achieving a sustainable environment at the regional level requires the active participation of the local population, in addition to temple management. Undoubtedly, this strategy facilitates the conversion of the temple perimeter area into an environment that is completely free of garbage.

Currently, the restrictions established at a temple only specify the criteria for individuals who are allowed to enter the temple. The scope of this legislation might be broadened to particularly target environmental governance. Community-based norms, also known as customary law, can be implemented to set rules for temple environmental stewardship. Regulations that are based on the community in Indonesia have a more powerful impact since

they directly pertain to the psychology and behaviours of the local community in that specific setting. Furthermore, in Indonesia, customary law is acknowledged as a domestic law and carries legal importance when such laws are enacted (Siti Romlah, 2017). The customary law that can be established consists of three elements: 1) Proposal to utilise indigenous materials in ceremonial structures; 2) Analysis of the conduct of temple attendees pre- and post-worship; and 3) Implementation of environmental stewardship inside the temple grounds.

The utilisation of local materials is intended to adhere to the concepts of a circular economy and to support Bali Governor Regulation No. 99 of 2018, which pertains to the marketing and utilisation of agricultural, fisheries, and local industry products in Bali. Local fruits are also more affordable, which eliminates any idea that religious ceremonies burden the faithful. The behaviour of temple visitors during worship can be discerned by observing their use of disposable plastic goods. Following the worship, temple visitors must personally transport and handle their worship-related garbage at their own residences. The environmental stewards within the temple precinct are responsible for upholding its cleanliness. The recommendations for trash management in temples are presented in Table 2.

Table 2

Temple waste management recommendations

No	Problem	Recommendations
1	Lack of waste handling information and regulation regarding the temple waste management	1. Temple visitors are required to use local Balinese fruits or products for their offerings. 2. Temple visitors are prohibited from using single-use plastics for their offerings. 3. Temple visitors are prohibited from smoking during religious activities. 4. Temple visitors are responsible for bringing back the leftover offering waste.
2	Low cleanliness awareness around temple environment	1. Supervisor inform temple visitors about the regulations. 2. Supervisor conducting control checks on offering" facilities, including local fruits and single-use plastics. 3. Supervisor collectects used single-use plastics.
3	No provision of temple waste management system	1. Visitors are required to separation of organic and inorganic waste. 2. Temple managers must manage of organic waste into 2 products such as: a. RDF briquettes made by shredding, drying, milling, and pelletitation. b. Compost made by shredding, fermentation, and screening.

Source: Author (2023)

The collection and sorting activities are conducted repeatedly due to the recurring nature of ceremonial events, which occur at least every six months. Meanwhile, the products derived from the processing of organic waste can serve as a source of income for the temple management.

4.5 POTENTIAL REDUCTION OF CARBON EMISSIONS FROM TEMPLE WASTE MANAGEMENT

The mean waste produced per temple in this investigation was 236.08 kg/temple. The temple wastes are classified into three distinct categories: organic garbage, plastic waste, and food waste. According to the research findings, the temple garbage is composed of the following: organic waste makes up 1,194.48 kg (84.33%), plastic waste weighs 57.84 kg (4.08%), and food waste totals 164.15 kg (11.59%). According to the IPCC (2006), the quantity of organic waste can be measured in terms of its emissions of gases such as CH_4 or CO_2. This suggests that proper waste management practices in temples could potentially lead to a significant reduction in carbon emissions. By properly segregating and disposing of organic waste, temples could minimize their environmental impact and contribute to the overall reduction of greenhouse gases. Implementing sustainable waste management practices in temples could not only benefit the environment but also set a positive example for the community and inspire others to follow suit. Tables 3 and 4 show the calculated and presented emission gas equivalent for the temple's garbage.

Table 3

Estimated emissions from organic temple waste

No	Lokasi	Organic Waste	DOC	DOCf	MCF	DDOCm (kg/day)	F	CH_4 (kg/day)	eq CO_2 (kg/day)
1	Tanah Kilap Tample	317,75	0,15	0,7	0,5	16,68	0,50	11,12	378,12
2	Jagatnatha Tample	81	0,15	0,7	0,5	4,25	0,50	2,84	96,39
3	Saraswati Tample	175,05	0,15	0,7	0,5	9,19	0,50	6,13	208,31
4	Mutering Jagat Sidakarya Tample	144,4	0,15	0,7	0,5	7,58	0,50	5,05	171,84
5	Pucak Mangu Tample	40,4	0,15	0,7	0,5	2,12	0,50	1,41	48,08
6	Watu Klotok Tample	435,88	0,15	0,7	0,5	22,88	0,50	15,26	518,70
	Total	**1194,48**				62,71		41,81	1421,43
	Average	199,08				10,45		6,97	236,91

Source: Author (2023)

Table 4

Estimated emissions from food waste

No	Lokasi	Organic Waste	DOC	DOCf	MCF	DDOCm (kg/day)	F	CH_4 (kg/day)	eq CO_2 (kg/day)
1	Tanah Kilap Tample	79,3	0,15	0,7	0,5	4,16	0,50	2,78	94,37
2	Jagatnatha Tample	9	0,15	0,7	0,5	0,47	0,50	0,32	10,71
3	Saraswati Tample	23,4	0,15	0,7	0,5	1,23	0,50	0,82	27,85
4	Mutering Jagat Sidakarya Tample	39,5	0,15	0,7	0,5	2,07	0,50	1,38	47,01
5	Pucak Mangu Tample	3	0,15	0,7	0,5	0,16	0,50	0,11	3,57
6	Watu Klotok Tample	9,95	0,15	0,7	0,5	0,52	0,50	0,35	11,84
	Total	**164,15**				8,62		5,75	195,34
	Average	27,36				1,44		0,96	32,56

Source: Author (2023)

If the trash generated from ceremonial events is not effectively managed and disposed of in a controlled manner, it will surely lead to a rise in greenhouse gas emissions. According to the data in Table 3, effective management of trash at Watu Klotok Temple has the potential to decrease carbon emissions by 15.26 kg/day of CH_4 or 518.70 kg/day of CO_2 equivalent. According to Table 4, the estimated emissions from food waste at Tanah Kilap Temple were 2.78 kg/day of methane (CH_4) or 94.37 kg/day of carbon dioxide equivalent (CO_2eq). According to a study by Tuti et al. (2014), the emission factor for CH_4 from organic waste ranges between 0.07 and 0.11 kg CH_4 per dry weight or 0.42 and 0.47 kg CH_4 per wet weight. Furthermore, Anifah et al. (2021) emphasise that organic and paper waste play a significant role in generating greenhouse gas emissions during landfilling procedures. By recycling paper, plastic, metal, glass, vegetables, and food waste, the emission of CH_4 will be reduced from 4.9 g/year to 1.5 g/year, and the emission of CO_2 will fall from 237.21 g/year to -48.17 g/year (Indawati, 2020). Thus, it may be inferred that inadequate management of ceremonial waste can lead to a rise in carbon emissions.

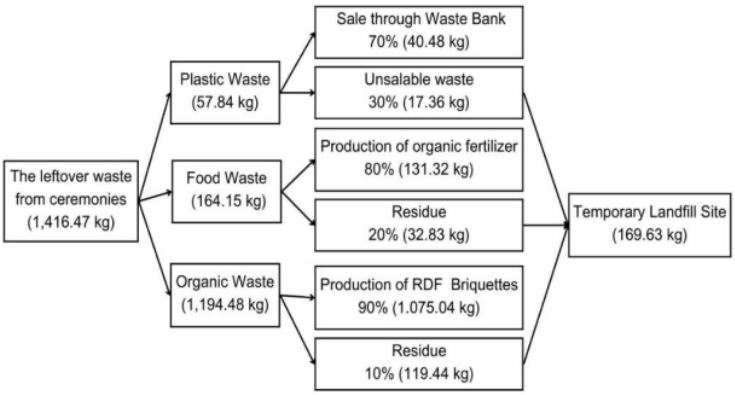
According to the data presented in Table 3 and Table 4, the quantity of organic waste is 1,194.48 kg and the quantity of food waste is 164.15 kg. If properly managed, this trash has the capacity to decrease emissions. Properly handling organic waste can result in a reduction of 41.81 kg/day of CH_4 emissions or 1,421.43 kg/day of CO_2eq emissions. Proper management of food waste can result in a reduction in emissions by 5.75 kilogrammes per day of CH_4 or 195.34 kilogrammes per day of CO_2eq. Figure 6's mass balance estimates indicate the possibility of

decreasing carbon emissions from plastic waste by a maximum of 70%, food waste by a maximum of 80%, and organic waste by 90%. The mass balance simulation computation is adjusted based on the prior studies conducted by Albizzati et al. (2024), Sandhi & Rosenlund (2024), Tihin et al. (2023), and Zafar et al. (2024). Carbon emissions can be lowered by reusing garbage. Plastic waste can be used as an energy source and recycled into economically valuable products (Ridwan et al., 2022; Wamba et al., 2023). Food waste can be repurposed as organic fertiliser (Butar-Butar et al., 2020) and used as animal feed (Nath et al., 2023). Organic waste can be transformed into RDF briquettes (Wijaya et al., 2023) and biogas (Butar-Butar et al., 2020). This suggests that implementing waste management practices in temples has the capacity to decrease carbon emissions and alleviate the strain on landfill sites.

Efficient temple trash management is crucial for preserving the environmental integrity of the temple sanctuary. The significance of facilities and infrastructure in processing and controlling trash generated from Upakara activities is significant. To ascertain the elements of waste management activities, a mass balance analysis is required, including the inflow and outflow of waste produced within the temple premises. This analysis helps to understand the influx and efflux of trash production, hence facilitating decision-making processes about waste treatment and recycling. This analysis enhances the ability to make well-informed judgements on waste management and the possibility of reusing garbage by comprehending the patterns of waste input and outflow (Consonni et al., 2005). The core idea of mass balance is rooted in the concept of mass conservation, which asserts that mass cannot be generated or eliminated but can only undergo transformation from one condition to another. Within the realm of solid waste management, the mass balance equation considers the materials that enter, leave, and undergo changes within waste management facilities and infrastructure (Dangi et al., 2023). Figure 6 presents the analysis of the estimated mass balance resulting from waste management in the sacred temple's environment.

Figure 6

Estimated mass balance for the temple waste



Source: Author (2023)

5 CONCLUSION

The research findings suggest that the optimal time for visiting is from 8:00 p.m. to 9:00 p.m. The Watu Klotok Temple had the highest trash generation, amounting to 449.87 kg. Following it were Tanah Kilap Tampel with 421.75 kg, Saraswati Temple with 204.35 kg, Mutering Jagat Sidakarya Temple with 200.7 kg, Jagatnatha Temple with 92.4 kg, and Pucak Mangu Temple with 47.4 kg. The predominant type of garbage is organic waste, accounting for 84.33%, or 1,194.48 kg. Plastic waste constitutes 4.08%, or 57.84 kg, while food waste makes up 11.59%, or 164.15 kg. There is a strong positive correlation between the number of temple visits and the amount of rubbish generated, as indicated by an R-squared value of 0.9987. Suggestions for addressing the issue of temple waste include: (1) mandating the use of locally sourced fruits, promoting the use of reusable bags, enforcing a ban on smoking, and encouraging individuals to take responsibility for their own waste; (2) implementing a comprehensive improvement campaign and conducting regular monitoring; (3) establishing a system for collecting and disposing of single-use plastics; (4) implementing a waste segregation programmeme to separate organic and inorganic waste; and (5) initiating a waste recycling ram. The carbon emissions reduction potential in organic waste is 41.81 kg/day of methane (CH_4) or 1,421.43 kg/day of carbon dioxide equivalent (CO_2eq). In comparison, the carbon emissions reduction potential in food waste is 5.75 kg/day of methane (CH_4) or 195.34 kg/day of carbon dioxide equivalent (CO_2eq).

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