Research Article

Solid waste flow and composition determination for sustainable waste management in Gili Trawangan, Indonesia

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Abstract
The aim of this study is to determine the waste flow, solid waste generation rates, and recycling rate in Gili Trawangan, Indonesia, as a case study of small islands in order to propose an appropriate solid waste management strategy. The compost supply and demand balance was estimated to determine the effectiveness of different composting techniques in the reduction of landfill waste on small islands. The hospitality industry contributed to over 70% of the total waste generation; in particular, about 50% was generated by large hotels. This indicates that recovering resources from the waste generated from hospitality-related sources is an effective way of reducing landfill waste. A new solid waste management strategy was proposed to reduce the environmental load and implement a sustainable solid waste management strategy consisting of organic waste composting and zero waste landfilling. As the demand for organic fertilizer was larger than the potential supply, the composting of organic waste from hotels and households would be feasible. Although the estimated cost–benefit ratio of the proposed waste management system was insufficient to operate the proposed system, a charge of only 0.08 USD to tourists is necessary for its implementation. The presented results and conclusions provide support for the decisions of the Lombok Regency and can be a guideline for the implementation of solid waste management strategies on other small islands.

Keywords Small islands · Waste recycling · Composting · Waste generation rate · Gili Trawangan · Waste composition · Cost balance

1 Introduction

Because of the rapid growth of tourism industries worldwide, small islands have become popular destinations and tourism has become an attractive industry for increasing the economy of such countries [8]. However, tourist activities can provoke environmental depletion. One of the biggest associated problems with this industry is solid waste management, with issues of solid waste management on small islands being more complicated than on bigger islands because of their limited land space and remote locations [20]. A higher waste generation rate due to tourism results in a lack of space for landfill sites and an increase in unclean areas from pervasive litter [4]. Waste from the tourism industry may be brought to uncontrolled landfills, although there is a chronic shortage of landfill spaces [6]. Old abandoned objects and illegal dumping pose great threats to the sustainability of both the environment and tourism [2, 18, 20, 23]. Waste is put into open dumping sites on small islands [20, 24], and generally this inadequate waste storage causes the contamination of the surrounding soil, air, and water [13, 15]. These effects may diminish the attractiveness of local resources for both the tourism industry and the local economy. Institutional challenges, however, are typically an issue for small islands where comprehensive and clear policies for solid waste

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management are insufficient [5, 7]. Therefore, planning an effective method of waste reduction for these small islands is important.

Several case studies for solid waste management in small islands such as the Mauritius [12], Langkawi Islands [25], Bahamas [24], Bunaken Islands [28], Maltese Islands [4], and Lavan Islands [10] have been reported. However, few researchers have discussed waste management system proposals that consider quantitative data [9, 27] and waste generation data from all sectors of an island [24]. For example, Chen et al. [5] estimated the waste generation on Green Island using a prediction-based model but not actual field data.

Generally, reliable data regarding waste generation are required for the planning of waste management. In order to formulate a proper option for future waste management in small islands, the determination of waste generation rates and compositions [14] is critical. The proposal should also be established on the basis of quantitative information from the current waste management conditions. Therefore, the determination of waste generators that highly contribute to the total waste generation is required for the effective allocation of financial resources to reduce landfill waste.

Some researchers have recommended composting as an effective food waste recycling method to reduce the amount of landfill waste [11, 19, 24, 27]. Technically, the composting process can reduce food waste volume and contribute to the reduction in waste for landfilling. Furthermore, composting is a more cost-effective treatment method compared with incineration when investment and operating costs are considered [12]; however, the balance of supply and demand for compost on small islands has rarely been discussed. Nevertheless, this balance is important for establishing composting as a realistic waste reduction proposal.

The aim of this study is to determine the waste flow, waste generation rates, and recycling rates in Gili Trawangan, Indonesia, as a case study of small islands to propose an appropriate waste management strategy. The compost supply and demand balance was estimated to determine the effectiveness of the composting technique for the reduction of landfill waste on small islands. Finally, a strategy for waste reduction and the associated costs for establishing a suitable waste management strategy for small islands based on real data were proposed. The results of this study should be applicable to other islands in archipelagic countries.

2 Materials and methods

2.1 Outline of the waste management system in Gili Trawangan

Indonesia is an archipelagic country with 17,504 islands. Among them, Gili Trawangan, located close to Lombok in West Nusa Tenggara Province (NTB), is one of the most popular small islands for tourists. A summary of waste sources on the island is shown in Table 1. In 2014, 316,000 people visited the islands. The total area of Gili Trawangan is 351 hectares, and it has a shoreline of 7.5 km. The population consists of 1709 residents with 471 households. There were 326 hotels and 31 restaurants on the island in 2015 (obtained from the Tourism Agency of North Lombok Regency by interview), and 63% of the total number of tourists (316,000) in the regency in 2014 visited Gili Trawangan [18]. This number of visitors is dispersed throughout the year. Since the number of tourists is considerably higher than the local population, it is expected that the impact of tourism industries on the environment is severe.

A community-based organization called Forum Masyarakat Peduli Lingkungan (FMPL) was established in 2002. It consists of the village head, the chief of the Gili Trawangan Businessmen Association (APGT), and the island's community and youth leaders. FMPL is in charge of waste management on the island.

Since the local law "Awig-awig" prohibits the use of vehicles powered by fossil fuels on the island, FMPL uses

Table 1 Summary of waste sources in Gili Trawangan

Sources	Remarks
Households	The number of households was 471. The population was 1709
Large hotels	The number of hotels was 71. Total rooms were 1197 and total beds were 1803
	The average number of beds was 26
Small hotels	The number of hotels was 255. Total rooms were 1666 and total beds were 2287
	The average number of beds was 9
Restaurants	The number of restaurants was 31 and total seats were 969
Others	Traditional markets, shore-side public spaces, and a mosque

nine horse-drawn carts to collect waste door to door from households and to transport it to the final disposal site. The original area of the final disposal site was 0.44 ha; however, the waste was overloaded on this site. At the time of this study, ten crews from FMPL have worked on the final disposal site. The Gili Eco Trust (GET), which is a nongovernment organization, supports the waste management of FMPL by distributing waste bins to households along with improving public awareness and education about waste management [29]. The composting of organic waste and recycling of waste glass as a source material for bricks have been implemented by GET. Approximately 600 kg of food waste is composted a day. The food waste is fermented in tanks for two weeks, and the fermented food waste is buried in the ground for another two weeks. The final product is extracted from the ground and is currently used in the garden of the GET offices and sold to hotels in Gili Trawangan.

Apart from FMPL, waste pickers collect recyclable wastes from households and waste containers at waste sources and then sell the recyclable materials to three local collection companies on the island. The collection companies sell the recyclables collected by scavengers to recycling companies on Lombok Island. FMPL also recovers the remaining recyclables at the disposal site and sells them to recycling companies on Lombok Island. In this study, information about the amount of waste collected and the price of recyclables was obtained from the chief of FMLP, GET officers, and the Gili Trawangan Businessmen Association. A waste collection fee is charged to businesses and households who obtain a waste collection service from FMPL.

2.2 Waste generation and composition survey

Surveys of the waste generation rates and waste composition were conducted twice in July and August 2015, as well as in March 2016. Households, hotels, restaurants, and public spaces were considered as sources of waste on the island. Households were selected from approximately a 25 ha area within 1.0 km to the disposal site. Household waste samples from each of the 40 local households were taken for 7 days before collection by FMPL. In this study, hotels on the island were categorized into large hotels and small hotels. Large hotels are those that have a restaurant that provides services not only for guests of the hotel but also for members of the public, while small hotels have either no restaurant or have a restaurant that provides meals only to guests of the hotel. For the survey, ten large hotels and 23 small hotels were selected from east side of the island. In this research, a regular restaurant refers to a restaurant without any lodging service. Waste samples from all public facilities on the island, including a grand mosque, two traditional markets, and seaside public spaces, were taken. All samples were weighed on-site.

The samples obtained from the hotels and households were transported to the landfill site on the island and separated into organics, recyclables [glasses (such as bottles and plates), plastics (such as plastic bags and bottles), paper, and metals (aluminum cans and iron cans)], and others (such as toilet paper, diaper, food wrappers, and coconut shells) manually. The weight of each separated sample was measured. All samples from households, hotels, public spaces, and restaurants were taken after the collection of valuable materials such as plastic bottles, glass bottles, and metals by waste pickers.

The following formulas were applied to estimate the waste generation rates of households (WRh), hotels (WRl), restaurants (WRr), and other facilities (WRf):

$$\mathrm{WRh} = (1/n) \times (\mathrm{WHH}/\mathrm{FM}) \tag{1}$$

where WRh (kg/person/day) is the average household waste generation rate (kg/person/day), WHH is the total amount of waste from the surveyed households during the survey per day (kg/household/day), FM is the total number of family members in a surveyed household i (person/households), i is the identifying number of surveyed households, and n is the number of household samples.

$$\mathrm{WRl} = (1/n) \times (\mathrm{WSHT}/\mathrm{NB}) \tag{2}$$

where WRl (kg/bed/day) is the average waste generation rate of hotels, WSHT is the total amount of waste collected from the hotels during this survey, NB is the total number of beds in the hotels, and n is the number of samples.

$$\mathrm{WRr} = (1/n) \times (\mathrm{WR}/\mathrm{NS}) \tag{3}$$

where WRr (kg/seat/day) is the average waste generation rate of the restaurants, WR is the total amount of waste from the restaurants obtained during this survey, NS is the total number of seats in the restaurants, and n is the number of samples.

The waste generation rate of a public facility [WRf (kg/day/facility)] is directly estimated from the weighed waste from each public facility.

There were 86 horses on the island in 2015; they are used for the transportation of tourists and materials such as solid waste. Horse manure was considered a source of compost even though it was not utilized and is dumped along the street. Since the dumped manure could be a potential source of environmental burden [3], an appropriate treatment such as composting would be required in the future. The manure generation rate has been calculated as 14 kg/day/horse [21].

2.3 Estimation of the supply and demand of organic fertilizer

In this study, products from the windrow composting system were considered as a possible organic fertilizer. The balance of compost demand and potential supply was estimated by the following equation:

$$P = \text{Worg} \times \text{Wcomp} \tag{4}$$

where *P* (kg/day) is the potential amount of compost product produced a day, Worg is the quantity of available organic waste generated in a day, and Wcomp (−) is the mass reduction rate during the composting process. The mass reduction rate of horse manure during composting has been reported by Komar et al. [17] as 38% for the turned pile method. For the mass reduction rate of organic waste from households and hotels during composting, 63% [1] was used. Because the waste generation from restaurants and public spaces was smaller than that from households and hotels in this study, the organic waste from these two sources was excluded.

The demand for organic fertilizer was estimated from the area of agricultural land on the island using Eq. (5). In this study, it was assumed that the compost produced from the waste was utilized as an organic fertilizer for all agricultural crops such as vegetables, tuber crops (cassava and peanut), bananas, and corn on the farmland, as well as in coconut groves. The equation used is defined as follows:

$$D = Sf \times d \tag{5}$$

where *D* (t/day) is the demand for organic fertilizer on the island, *Sf* is the total area of crop farming and coconut farmland (ha), and *d* is the demand of organic fertilizer per area of farming (ton/ha). The Ministry of Agriculture, Indonesia, recommends a value of 20 t/ha of organic fertilizer (BALITSA and JIRCAS, 2016), and we used this value for *d* in Eq. (5).

The area was obtained from satellite images from Google Earth that was calculated using Quantum GIS software (an open source software).

2.4 Material balance and cost estimation of future waste management in Gili Trawangan

Because of the limited space in Gili Trawangan and the demand for environmental conservation, zero waste landfilling as a future waste management strategy is desired. In this study, the cost and material flows in the proposed solid waste management strategy were estimated in the scenario in which all recyclables were fully recovered and sold, organic waste was composted, and only the residue waste was transported to the main island (Lombok) and deposited in a landfill. The waste management fee collected from households and businesses was used as the income of the proposed waste management strategy. The costs of wages, maintenance of horses, electricity, composting, and others were applied at the current cost of the operation fees of FMPL. The current transportation fee from Gili Trawangan to Lombok by boat was used. The transportation fee from the port to the landfill site in Lombok was estimated from the current waste collection fee for households in Lombok. The number of households (930,376) and the number of family members (3.52) in Lombok were obtained from the Statistics of Nusa Tenggara Barat Province. The waste generation rate was adopted from the value in Gili Trawangan found by this study (0.70 kg/person/day). Using these values, it was assumed that one household produces 73.9 kg/month of waste. The collection fee for the waste from one household and the cost of collection were obtained by an interview with the Environmental and Hygiene Services of East Lombok Regency. The collection fee for the waste from one household is 6.8 USD per month (10,000 IDR per month), including the fee for landfilling in Lombok. The cost of collection was estimated as 18.5 USD per ton (135,000 IDR per ton) of waste. The cost of composting the collected waste was obtained from an interview with the project manager of a composting project at the East Lombok Landfill site in 2016. This project composts 3.2 tons/day of the organic waste carried to the landfill site by two employees, and the total cost was 3.4 USD per ton (500,000 IDR per ton) of organic waste, including electricity, fuel, and the packaging of products. This study applied this value for the estimation of composting costs on the island. The sale of compost products and collected recyclables was considered income.

3 Results

3.1 Waste generation rates and waste stream on the Island

Table 2 shows the average waste generation rates of households and businesses on the island. The average waste generation rate of households (WRh) was 0.70 kg/person/day. The waste generation rates (WRl) of small and large hotels were 0.65 kg/bed/day (0.89 kg/room/day) and 3.27 kg/bed/day (4.93 kg/room/day), respectively. Pirani and Arafat [22] found that the range of waste generated by hotels in the USA varied from 0.45 to 0.91 kg/day/room, and the WRl of small hotels in this study was within this range. However, the WRl of large hotels was over five times higher than the WRl of small hotels. The waste from large hotels included the waste from their restaurants; therefore, the waste generation rate of the large hotels was much higher than that of the small hotels. The average waste generation rate of regular restaurants (WRr) was 0.53 kg/seat/day (4.4%). The waste generation rates of the public facilities varied between 18.9 and 766 kg/day; 0.8 tons of waste (6.7%) was generated in one day. It was found that the hospitality industry, including hotels and restaurants, contributed over 70% of the total waste generation. In particular, about 50% of the waste was generated from large hotels.

Figure 1 shows the estimated waste flow on the island. The total solid waste generation was calculated as 11.8 tons a day. FMPL collected 9.3 tons/day (79%) of waste and transported it to the disposal site. Resources recovered by the recycling companies from containers in front of hotels, public spaces, and households totaled 1.86 tons/day (16.1%). Table 3 shows the types of recyclables collected and the average price of recyclable materials sold to the collection companies. These average prices were obtained from the collection companies by survey. The dominant recyclable materials were beer bottles (33%) from hotels and restaurants, as well as cardboards (31%). At the landfill site, FMPL drivers and workers also recovered recyclables (0.3 tons/day) such as plastics and metals, and the recyclables were sold to the

Table 2 Waste generation rates and quantity for households and businesses in Gili Trawangan

Waste source	Waste generation rate	Quantity ton/day	%
Households	0.70 kg/person/day	1.20	10.2
Large hotels	3.27 (4.93) kg/bed/day (kg/room/day)	5.90	50.1
Small hotels	0.65 (0.89) kg/bed/day (kg/room/day)	1.49	12.6
Restaurants	0.53 kg/seat/day	0.51	4.4
Traditional markets	559 kg/day	0.56	0.56
Shore-side public spaces and harbor	188 kg/day	0.19	0.19
Mosque	17.9 kg/day	0.018	0.02
Recovered waste by waste pickers		1.86	16.1
Total	6.9 kg/day/person	11.8	100

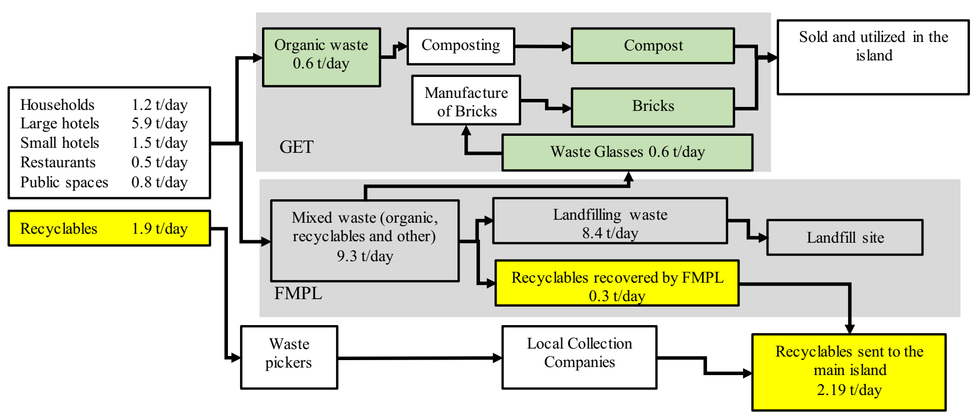

Fig. 1 Waste flow in Gili Trawangan

Table 3 Average composition of recyclables collected by recycling businesses and FMPL

	Waste pickers quantity (kg/day)	(%)	FMPL quantity (kg/day)	(%)	Total quantity (kg/day)	(%)	Average price Rp/kg
Plastics	321	17	128	38	449	20	1700
Cardboards	579	31	117	35	696	32	1400
Beer bottles	621	33	71	21	692	32	869
Scrap metals	193	10	–	–	193	9	12,700
Aluminum mans	75	4	16	5	91	4	12,700
Metal cans	73	4	–	–	73	3	700
Total	1862	100	332	100	2194	100	

recycling companies on the main island. Finally, 8.4 tons of waste was landfilled (71% of the total waste).

The GET recovered 0.6 tons/day (5%) of separated food waste from hotels and restaurants and composted this waste as a pilot project. The composting product was used in the yard of the GET offices. The GET recovered waste glass (0.6 tons/day) from the landfill site and used it as a material for construction bricks. The bricks fabricated from waste glass were sold by the GET on the island. A total of 2.19 tons of recyclables was collected and recycled each day, and this was 19% of the total waste generated on the island (Table 3). The main sources of waste were found to be the hotels and restaurants, and the composition and amount of waste were constant. It is therefore easy for waste pickers to collect a large amount of resources.

3.2 Waste composition

The results of the waste composition survey are shown in Table 4. The percentage of organic waste in the waste from small hotels (52.8%) was smaller than that of the large hotels and households (66.1%) because the restaurants in small hotels are only for their guests. On the other hand, the waste from large hotels included the food waste from restaurants serving not only their guests, but also customers from outside the hotels. Waste from the large hotels contained 12.2% coconut shells, while coconut shells only amounted to 1.3% of the waste from small hotels as the restaurants in large hotels sell coconut water that is popular with tourists. In this study, coconut shells were excluded from the compostable organics because of their slow biodegradation. Compostable waste comprised 63.7% of the total waste, amounting to 5.48 t/day. This amount was almost equivalent to 50% of all waste on the island. Landfilling of the organic waste causes greenhouse gas generation [26] and leachate generation with a high concentration of organic pollutants. The composting of organic wastes is one of the most useful methods for preventing environmental stresses resulting from landfill sites. Notably, the percentage of glass, such as bottles, in the waste of small hotels was 21.9%, and this was larger than that of large hotels. This is because waste glass from large hotels would have already been picked up by waste pickers before the composition survey. Despite the recycling activities performed by waste pickers, 1.87 tons/day of recyclable wastes was still transported to the landfill site. If the recyclable waste is separated from the waste discharged from hotels and households, further reduction in the landfilling waste could be achieved.

4 Discussion

The percentage of compostable organic waste comprised a large portion of the landfilling waste; therefore, the recycling of this waste by composting is an effective method of reducing the landfilling waste. In order to assess this method, the balance of the compost produced from the compostable waste and the demand for compost on the island were first estimated. In this estimation, waste from hotels and households also in addition to manure from horses was considered sources of compost. Currently, it was calculated that approximately 1.20 tons/day of manure was generated. Table 5 shows the potential area

Table 4 Composition of waste generated by hotels and households

	Large hotels (%)	Small hotels (%)	Households (%)	Quantity (t/day)
Compostable organics (kitchen waste, fruits, vegetables, and yard waste)	**66.1**	**52.8**	**65.7**	**5.48**
Recyclables	**16.7**	**39.4**	**24.2**	**1.87**
Glass (bottles, plates, etc.)	5.1	21.9	1.3	
Plastic (plastic bags, snack wrappers, etc.)	3.7	5.4	11	
Plastic (bottles, micas, buckets, etc.)	2.4	3.9	6.5	
Paper	3.1	4.4	4.9	
Paper cup	1.1	1.8	–	
Can (aluminum and iron)	1.3	2.0	0.5	
Residues	**17.2**	**7.8**	**10.1**	**1.25**
Paper not suitable for recycling	2.9	5.1	–	
Diapers	–	0.1	6.6	
Young coconut shells	12.2	1.3	–	
Others	2.05	1.2	–	
Total	**100**	**100**	**100**	
Quantity (t/day)	5.9	1.5	1.2	8.60

Table 5 Potential compost demand in Gili Trawangan

Land	Area (ha)	Compost demand (t/day)	Remarks
Farmland	93.3	5.11	Coconut fields 80.6 ha, crops 12.7 ha
Raw material of compost	**Waste generation (t/day)**	**Compost production (t/day)**	**Remarks**
Organic waste from households	0.7896	0.292	The decomposition rate of organic waste from households was 63%
Organic waste from hotels	4.691	1.736	The decomposition rate of organic waste from households was 63%. Generation includes 0.6 ton organics, which is collected by GET currently
Horse manure	1.204	0.746	The decomposition rate of horse manure was 52.5% [16]. The number of horses in the island was 86. Manure production rate was 14 kg/cap/day
Total	6.685	2.77	

for the compost usage and demand on the island. The estimated total area for the potential compost usage was 93.3 ha, including 80.6 ha of coconut groves and 12.7 ha of crop farmlands. When this estimated potential area is in need of the standard amount of compost as an organic fertilizer, 5.11 tons/day of compost can be used. On the other hand, the potential compost production from horse manure and organic waste from households and hotels was 2.77 tons/day. This result indicates that all of the organic fertilizers produced on the island could be used on the island.

Figure 2 shows the proposed waste flow including the composting of organic waste and transportation of the residue waste to the main island. Table 6 shows the estimated monthly cost balance of waste management on the island including the composting of organic waste. The revenue from households and businesses was obtained from an interview with FMPL. The revenue from households and businesses varied from 2.1 to 3.4 USD per month (30,000–50,000 IDR per month) and from 3.4 to 239 USD per month (50,000–3,500,000 IDR per month), respectively, according to the location and amount of waste generated. The total revenue was around 6360 USD per day (93 million IDR per day). The potential income from landfilled recyclables was estimated from the results of the composition survey from hotels and households, and the revenue was 198 USD per month (2.9 million IDR per month). The prices of recyclables were adopted from the data obtained from a survey of the three collection companies (Table 3). The total wages of the employees and administrators (73% of the total cost) were estimated using a current FMPL worker's salary (obtained by interview from FMPL) and calculated as 3283 USD per month (48 million IDR per month) for 20 workers. The income from selling compost was estimated as 5461 USD per month (79.2 million IDR per month) using the current selling price of compost (1000 IDR per kg) obtained by interview from FMPL. The total income was estimated as 11,974 USD per

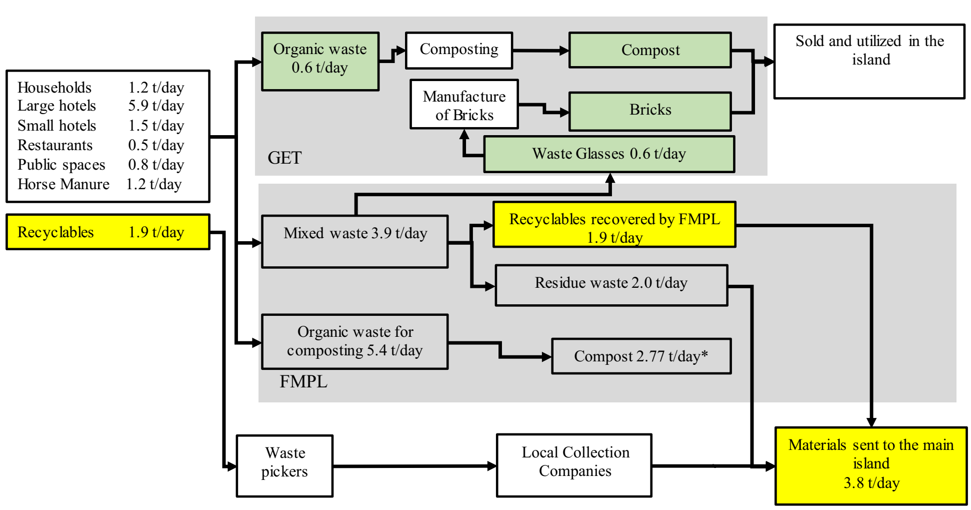

Fig. 2 Proposed waste flow. * Including compost from horse manure

Table 6 Cost balance of the proposed waste management strategy

Cost		USD/month	Remarks
Solid waste management	Monthly wage for workers[a]	3283	20 people including composting operators, 164 USD per month (2,400,000 IDR per month)
	Wages for administrators[a]	752	Four people, 188 USD per month (2,750,000 IDR per month)
	Feed and shoes of horses[a]	82	
	Others[a]	815	Electricity, meeting cost, office suppliers, and so on.
Composting		6811	The organic waste for composting is 5.4 t/day, and the cost is 34.2 USD per ton (500,000 IDR per ton[b]), including electricity fuel and packaging of products.
Transportation of the residue waste from the landfill site to the port in Gili Trawangan		615	Transportation of 2 ton/day of residue waste from the landfill site to the port in Gili Trawangan. Three trips a day by a horse-drawn box with 1 m^3 of capacity are used. The cost is 6.8 USD per trip (100,000 IDR per trip[a])
Sea transportation for residues		718	47.9 USD per trip (700,000 IDR per trip[a]), 15 times a month (4.125 t/trip)
Landfilling fee at the landfill site in Lombok including transportation cost		1112	18.5 USD per ton (271,000 IDR per ton) for 2.0 ton/day of residue waste. (Assuming the number of households is 3.52 and the waste generation rate was 0.70 kg/person/day, one household produces 73.9 (= $0.7 \times 3.52 \times 30$) kg/month of waste, and the collection fee of waste from one household is USD 1.37 per month (20,000 IDR per month[c]), including the fee for landfilling. The cost of collection is 18.5 USD (271,000 IDR = 20,000/0.0739) per ton of waste)
Total		14,188	

Income	USD/month	Remarks
Fee from waste collection service[a]	6360	
Potential income from the landfilled recyclables	197	
Compost selling	5416	2.64 t/day of compost is produced. The price of compost is 0.068 USD per kg (1000 IDR per kg[a])
Total	11,973	

[a]Obtained from FMPL

[b]Obtained from an interview with the project manager of a composting project at the East Lombok Landfill site in 2016

[c]Obtained from the Environmental and Hygiene Services of East Lombok Regency

month (175.1 million IDR per month). For the composting, 6811 USD per month (99.6 million IDR per month) was the cost of processing 5.4 tons of organic waste using 500,000 IDR per ton for the current operation cost. The amount of residual waste, which should be transported to the main island, was 2.0 tons/day (14.0% of the total waste generated on the island). The monthly cost for all SWM operations including the composting process was estimated as 14,188 USD (207 million IDR). This was larger than the income (11,974 USD per month) from the collection fees and the selling of the compost and recyclables. In order to equalize the income and cost, the fee for collection on the island would have to increase to 1.5 times the current fee. Considering the number of tourists that visit Gili Trawangan per year (around 316 thousand people), the additional cost would be only 0.08 USD per person to equalize the costs and benefits. In order to establish a proper waste management strategy of maintaining the environment of Gili Trawangan sustainably, a small additional amount of support by tourists would be required. Further studies of the promotion of compost production, segregation of organic waste from the waste stream, and achieving a balance of seasonal variation for the supply and demand of compost are necessary to apply these results in the field.

5 Conclusions

This study showed the waste flow and waste generation rate in Gili Trawangan. From the waste stream results, approximately 19% of the island's solid waste was recovered, and 71% of the waste was landfilled. The hospitality industry, including hotels and restaurants, contributed to over 70% of the total waste generated. In particular, about 50% was generated from large hotels. This result indicated that the recovery of resources from the waste generated from these sources is effective in reducing the landfilling waste.

For the reduction in the strain on the environment and sustainable solid waste management, a new solid waste management strategy, including organic waste composting and zero waste landfilling, was proposed. The demand for organic fertilizer was larger than the potential supply; therefore, the use of compost from organic waste on the island would be feasible. However, the estimated cost–benefit of the proposed waste management strategy was insufficient for its operation, and it would be necessary to charge tourists an additional fee for waste management in order to implement this strategy. In order to sustainably maintain the environment of Gili Trawangan, tourists should be involved in the operation of the appropriate waste management strategy. The presented results and conclusions not only provide support for the decisions of the Lombok Regency but may also be a guideline for the implementation of solid waste management on other small islands.

The variables used in this study such as the costs for composting, landfill operation and collection, and the demand for compost must to be revised corresponding with changes in the economic conditions and demographics. As a future study, wastes generated irregularly, such as e-wastes, hazardous wastes, and wastes from demolition, should be considered.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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