

Community-wide Waste Management System for Cape Maclear

Report

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Community-wide Waste Management System for Cape Maclear

Development and Implementation Proposal

Policy brief based on the master's theses of:

Raphael Meier, Philippe Colbach, Mose Peduzzi, Josch Stricker, and Elena Abgottspon

Abstract

Five students from ETH Zürich completed their Master's theses at the chair of Global Health Engineering. They spent two months in the town of Cape Maclear, Malawi (Figure 1) and four months in Zürich, Switzerland trying to establish a **community-wide waste management system**. This policy brief presents the results: a comprehensive proposal for developing and implementing a solid waste collection system for Cape Maclear. The study provides detailed insights into waste quantification, characterization, and management strategies for various waste fractions based on the research. This brief also presents a village-wide map, a population estimation, and a financial feasibility assessment. It concludes with recommendations for a conservative business model, emphasizing the importance of realistic stakeholder participation and payment compliance in implementing a successful solid waste management program.

Key findings

1. Organic waste constitutes a significant portion of the total waste generated, with the potential for composting to improve local soil quality.
2. A two-stage glass crusher was developed to address the issue of non-returnable glass bottles, reducing volume and preventing water accumulation.
3. Two new incinerators were designed and constructed to manage mixed and hazardous waste, including medical waste.
4. A village-wide mapping and population estimation were conducted to optimize waste collection routes and bin placements.
5. Financial feasibility was assessed by evaluating the willingness to pay of various stakeholders, including households, lodges, businesses, and tourists.



Figure 1. Research team in Cape Maclear.

Quantification and Characterization

To accurately determine the quantity and composition of waste, we conducted a large-scale measurement campaign. Empty bags of 17 L were distributed to 29 households; the residents were instructed to put all their waste into an empty bag. The bags were collected daily, and a fresh bag was given to the house for collection the following day. Every day, the waste was weighed and sorted. Similarly, waste was collected daily from 11 lodges in 110 L bags. The results of the quantification and characterization study are shown in **Table 1**.

Some of the interesting findings are:

- Stones are considered as waste and comprise about 46 % of the mass of waste collected from homes.
- The average waste generation rate per household per day is only about 2.85 kg.
- Organic waste production, especially from lodges, is a large part of the waste generated (nearly 50 %).
- The mass of recyclables like paper, metal, and glass is relatively small, while plastics dominate in household-generated waste. Glass and plastic are dominant among lodges.

Fraction: Organic Waste

Excluding stones, organic waste — either from gardens or food preparation — is the largest quantity of waste generated by both households and lodges. To determine how the inhabitants and lodge administration manage organic waste, a questionnaire was presented to 259 households and 13 lodges. The results are shown in **Figure 2**.

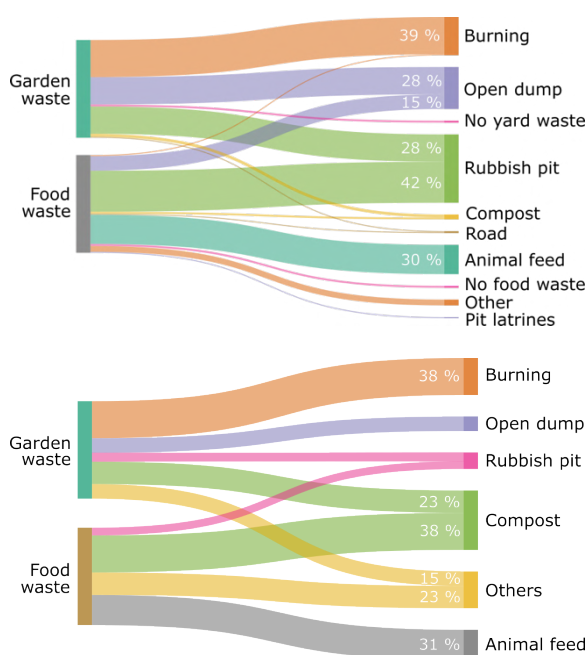


Figure 2. Waste management for garden and food waste fractions by households (top) and lodges (bottom).

Table 1. Total and mean waste production by type in kg over 7 days. *Organic waste from households was measured together with garden waste.

Category	Households		Lodges	
	Total	Mean/day	Total	Mean/day
Paper & Cardboard	7.3	0.04	14.4	0.20
Plastic	33.2	0.17	31.4	0.44
Glass	2.4	0.01	71.6	0.99
Metal	3.1	0.02	12.2	0.17
Textiles	6.3	0.03	2.3	0.03
Hygiene products	0.1	0.004	0.8	0.01
Stones	259.3	1.31	254.2	3.53
Organic (garden)	176.9	0.89	456.4	6.34
Organic (food)	na*	na*	153.4	2.13
Other	59.6	0.3	20.9	0.29
Total	564.7	2.85	1003.2	14.40

From the analysis of the current organic waste management practices, we observe that:

- About 30 % of all organic waste is fed to animals (households and lodges).
- Lodges seem to be composting about 60 % of their organic waste, though this figure may be overstated or represent confusion about what composting means.
- There is a vast potential to divert significant volumes of waste from improper disposal to compost.

With an estimated population size of 15,000, the total amount of organic waste generated by all households in the village is estimated to be 985 t/year. Sixteen lodges produce around 45 t/year of organic waste (11 t/year of organic food waste and 34 t/year of organic garden waste).

The soil around Cape Maclear is highly degraded and could benefit from compost. Ten local farmers agreed to have their soil tested. The results showed that the soil is classified as a sandy loam with a total organic carbon (TOC) of less than 1 %. Healthy topsoil has around 5 % TOC, and rich organic soil contains more than 15 %. Despite frequent fertiliser use, the soils are deficient in nitrogen and phosphorus (see **Figure 3**); organic carbon is essential for microbial activity and to retain moisture, so soils with little organic carbon leach water and nutrients quickly.

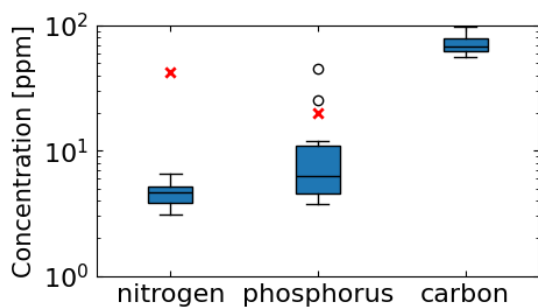


Figure 3. Nutrient concentration in soil from Cape Maclear (recommended concentration marked with red x, not available for carbon).

A survey of ten farmers helped to understand the role of organic waste in their agricultural practices. Nine farmers used chemical fertilizer, primarily NPK, though the choice depends on availability and affordability. Only three farmers received subsidized fertilizer from the government. Seven farmers applied cow manure; three

sourced it from their cows; the others bought it for 40 MWK/kg. The survey revealed that none of the farmers used compost in their agricultural practices, and only two had used it in the past. Furthermore, only three out of ten claimed to have a clear understanding of compost. However, they all expressed willingness to use it.

Following the first round of data collection, the farmers were invited to visit the central composting facility in Lilongwe (nine attended). The hosts explained the steps required to make compost, the benefits of compost, and how the farmers could do it themselves. A post-visit survey revealed that all farmers gained a clear understanding of compost, and all farmers emphasized their willingness to use it. A significant shift occurred in farmers' beliefs that crops grow well enough with only compost applied. After the visit, all farmers believed that compost was a sufficient substrate. However motivated, the farmers saw the need for water as a barrier to replicate the process themselves. Despite the challenges, most farmers (eight out of nine) expressed interest in participating in a community compost project, though only two were willing to take a leading role. Despite these reservations, farmers recognized the potential of community composting to benefit their farming activities significantly. Moreover, all farmers saw a business opportunity in composting, and as of January 2024, several farmers had started to create their thermophilic piles (see **Figure 4**).



Figure 4. New compost pile in Cape Maclear.

In summary, the organic waste generated by lodges is relatively insignificant compared to the volume generated by households. If all organics were collected, approximately 295 tons/year of compost could be generated, which would, given the quantities of nitrogen (1.3 t), phosphorous (1.6 t), and potassium (7.5 t) would be able to substitute 1.3 t of NPK fertilizer. The estimated value of the substituted fertilizer is around \$1,000 USD,

although the extended benefits to the soil and community cannot be quantified.

Fraction: Glass

Globally, glass is one of the most recycled products. In Malawi, most glass bottles, e.g., Coke and Castel, can be returned for a deposit. However, Cape Maclear is unique because tourists consume a variety of beverages that cannot be returned for recycling, e.g., Savanna and Hunter's Cider, Amarula, gin, and all types of wine. Currently, non-returnable glass bottles are stockpiled or landfilled, which are neither sustainable nor safe. Until a long-term solution is found, we developed a two-stage glass crusher to reduce the glass volume, prevent the accumulation of standing water, and produce a product that eventually, can be used in a beneficial way.

Two-stage glass crusher

Glass bottles are designed to resist breaking; smooth, round edges help prevent the edges from being caught and distribute forces more evenly. This design feature also makes crushing them difficult. A pre-crusher was designed to break the bottle into pieces that could be crushed more finely in a second stage.

The pre-crusher consists of three main parts: a standing platform at the base, the main body embedded into the platform, and a stomping tool. The system relies purely on muscle strength and gravity. After the stomping tool is lifted past the chute welded to the body's side panel, the glass bottles fall into the chute. The bottles are then smashed by lifting and dropping the stomping tool, featuring two steel bands to punch the glass through two slots at the base (see **Figure 5**).



Figure 5. Stomping tool (left) and pre-crusher with inserted stomping tool (right).

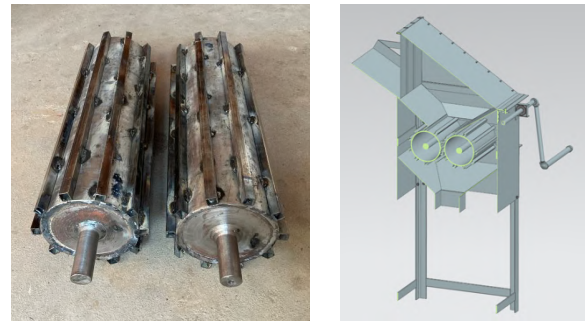


Figure 6. Rollers of the glass crusher.



Figure 7. Drive train.

Large, roughly broken fragments of glass from the pre-crusher are then crushed into more uniform pieces in the main crusher, shown in **Figure 6**. The main crusher consists of a single set of rollers. Below the rollers, a rectangular funnel guides the crushed glass into a container. Above the rollers sits a cover structure combining several elements: a ramp to facilitate glass insertion; a funnel to guide the glass to the rollers; a cover and front-facing plastic flaps to prevent dust and glass projectiles from escaping the crusher's interior. For the same purpose, a plastic flap covers the panel gap from which the roller shafts protrude. If needed, the top cover can be removed in one piece to give the operator unrestricted access to the rollers. The rollers are rotated with a hand-powered crank. The forces exerted on the crank are transferred to the rollers through a size 520 motorcycle drivetrain comprised of two chains, presented in **Figure 7**.

Operation and Efficiency

The glass crusher produces glass shards of different sizes, as shown in **Figure 8**; the medium size (1 cm to 3 cm) is the most



Figure 8. Crushed glass sorted by size from small (a) to large (c) with 15 cm ruler for scale.

predominant (61 % to 77 % of the mass). With a single setting, the crusher can produce a variety of particle sizes, ranging from powder to shards of several centimeters in length. If one is only interested in a specific size, the shards must be sieved.

The system is, however, not without problems. On two occasions during testing, the crusher jammed when it encountered a particularly rigid piece of glass. The first time, it was caused by the circa 9 mm thick base of a Jägermeister bottle during one of the crusher's preliminary tests, and the second time by the neck of a cider bottle. After removing the pieces, the crushing process was resumed without issues.

Our analysis suggests that, after some practice, a throughput of 1.98 kg/min for the pre-crusher and 0.91 kg/min for the main crusher should be achievable for a single operator without too much effort. It amounts to 0.62 kg/min (equivalent to 3.15 cider bottles per minute), not including the time spent transferring the glass from one crusher to another. With an estimated daily glass production in Cape Maclear of 48.8 kg/day, both crushers should process it in around 1 h 19 min; using the pre-crusher only, this time decreases to 25 min. Additional time must be factored in to handle the glass outside the crushers. Even if this production is underestimated by a factor of two, and the glass production is 76.5 kg per day, it would still only require around 2 h to process with both crushers.

The cost of the main crusher is around \$730 USD (equivalent to 1,280,000 MWK in December 2023).

Fraction: Mixed and hazardous waste

No matter how good a waste management system is and how much waste is separated for other uses, there will always be products that cannot be recycled: nappies, medical waste, single-use plastics, etc. And, until there is a sanitary landfill, incineration is the best option for these pesky products. This section discussed the old management practices for such waste and proposed solution for a new one.

Incinerator 1: Billy Riordan Memorial Clinic

Medical waste is the most hazardous type of waste produced in Cape Maclear and must be managed carefully to prevent the spread of disease and injury. The waste within the hospital is divided into two categories: medical waste of low/medium risk, which is collected in black plastic bags, and sharp waste, which is mainly composed of syringes and glass vials and is collected in cardboard safety boxes.

Every morning, the collected waste is incinerated in an incinerator that is not fully functional and unsafe. It consists of a single chamber, where all the bags are deposited before igniting. Once the combustion starts, the operator leaves the area because the material frequently explodes in an open incinerator (no door or cover). The ashes are removed once per month and dumped in an open ash pit nearby, generating a significant amount of toxic, airborne dust and likely contaminating the soil and water.

The design of the incinerator we built at the Billy Riordan Memorial Clinic is based on the well-known De Montfort Incinerator. All incinerator designs, including the existing one and two new ones, are shown in **Figure 9**.

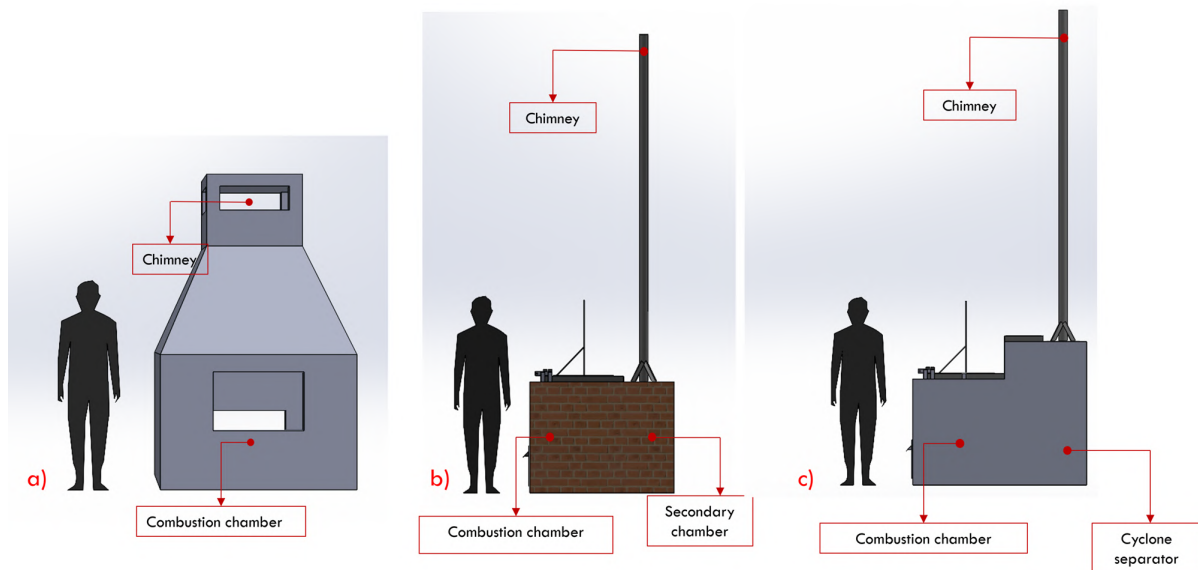


Figure 9. Schematic view of three incinerators and positions of the temperature sensors: a) Old incinerator at the clinic; b) New incinerator at the clinic; c) New incinerator at the waste depot (with cyclone).



Figure 10. Four steps of the cyclone separator production: a) Empty oil drums at the market in Blantyre; b) Drum cutting and piece assembly; c) Pieces produced from the drum; d) Welding of all parts and painting.

Constructed in multiple countries around the globe, the incinerator built at the clinic is a low-cost and efficient technology that can be constructed without specialized materials.

With a base of 1 m x 0.5 m and a height of 1 m, the incinerator was constructed with bricks and cement, and a metal frame on the top. The interior space is divided into two combustion chambers: the operator can access the first through a door at its top to add waste. The second combustion chamber remains inaccessible and is solely intended to

treat fumes. The purpose of the second combustion chamber is to reduce carbon monoxide to carbon dioxide through secondary combustion. The fumes pass from one chamber to another through a tunnel, then they exit the second combustion chamber through a 4 m chimney made of a 120 mm diameter metal tube located at the top. The setup consists of two walls, one internal, in contact with the fumes, and one external, completely enveloping the inner one. A removable metal drawer replaced the front door of the incinerator with a grate for removing the ash. Including labor and materials, this

incinerator cost about \$250 USD (MWK 435,000).

Incinerator 2: Sustainable Cape Maclear

The second incinerator was constructed at the Sustainable Cape Maclear (SCM) site to be used for waste separated from other collection activities. Its design is the same as the first, but a cyclone separator was added to further process fumes. A cyclone separator is a device that separates solid particles from gas. Gases are forced to circulate inside a cylindrical and conical structure; thanks to the centrifugal force, particles are pushed towards the walls, decelerate, and fall downwards, while the lighter gas exits the separator through the opening on the top of the cyclone. The cyclone separator in SCM was built from a 200 L empty oil drum (see **Figure 10**). The cost of this incinerator, including the cyclone separator, was around \$330 USD (MWK 565,000).

Operation and efficiency

The temperature of three incinerators (including the old one) was measured in the combustion chamber. To ensure safe combustion, the de Montfort incinerator should achieve temperatures around 800 °C; recorded temperatures reached a maximum of 772 °C. However, the average values in the primary chamber over the burning period ranged from 120 °C to 435 °C. These lower-than-optimal temperatures result from burning wet and non-flammable waste and overloading the incinerator, limiting oxygen flow. The location of the temperature sensors in each incinerator is schematically shown in **Figure 9**.

Long-term monitoring of the incinerator use showed that 3.41 kg/h of waste can be burned, and the optimum use time for each ignition is between 1.5 h and 6 h. The mass of the ashes produced by the incinerators represents around 20-30 % of the total mass of waste burnt and based on the data collected from over one month of usage, 5 m³ of ashes are estimated to be produced per year per incinerator. Lined pits are recommended to prevent the ashes from leaching into the soil.

Logistics

To identify the best collection routes and bin placements, we first needed to map the village, estimate its population, determine

the location and number of collection points, and identify the best collection vehicles and routes.

Street and population mapping

We collaborated with Nkhwazi Aeros, a Malawian drone company, to take aerial photographs and create a map of the town. The drones (2016 DJI phantom 4 pro) flew orthogonally from the coastline in lines 3 metres apart at a speed of 15 m/s. They took a new image as a every 5 s. The created map is available [online](#). On the created map, all visible roofs were marked and counted. Afterwards, the number of inhabitants was estimated using the map and a survey. In addition, household data were collected using a questionnaire (N = 259). The following two questions helped gain information about the population:

- How many people slept in this house last night? (including fisherman)
- How many buildings do you live in? (Defined as the number of roofs you have, including living house, kitchen, stable, shed, garden house).

Combining these data allowed us to estimate that there are 16 lodges, 13 cottages, and 351 businesses. Based on the average household population of 5.3 and 6154 roofs, we estimated a population of 10,488 people living in about 2000 households.

Collection points and routes

With a complete map and a population estimate at hand, we investigated the potential locations for skips. The roads were classified for car (A=good, B=restricted, C=not possible) or bicycle passability (D=good, E=restricted, F=not possible). The map of all roads is shown in **Figure 11**.

Similarly, 168 of the existing waste collection hot spots were mapped. These points were locations within the community where waste was already being piled, which could serve as collection points, although they varied significantly in accessibility and area. With the most promising, centrally-located points, a model showing the distribution of walking distances was created (**Figure 12**). Even with only 4 points, the maximum walking time was estimated to be 10 minutes, and 80 % of residents could reach a



Figure 11. Road accessibility in Cape Maclear.



Figure 12. Estimated walking time to one of four collection points.

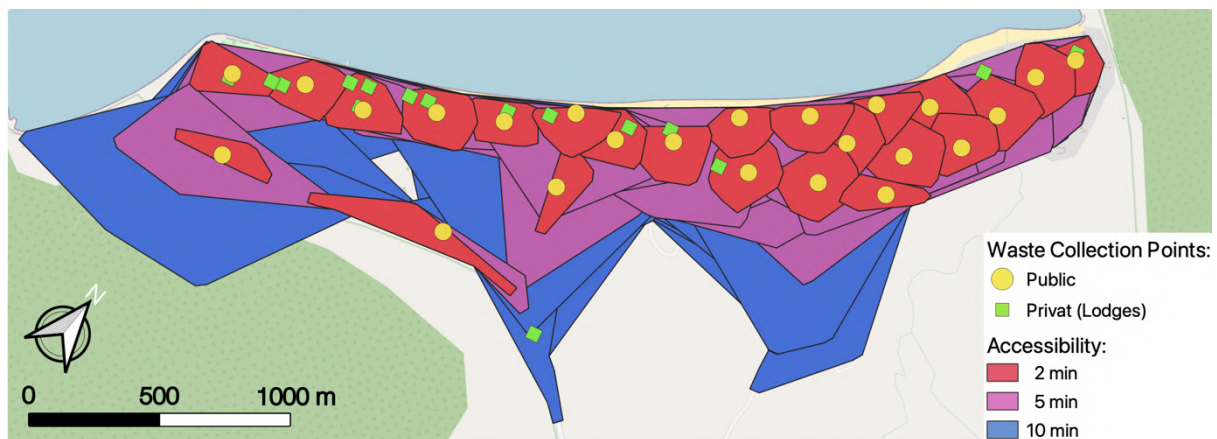


Figure 13. Estimated walking time to one of 24 collection points.

skip within 5 minutes. Installing 24 collection points would reduce the walking time for most people to only 2 minutes (Figure 13). We propose that the number of serviced waste

collection points should fall between 4 and 24. The number installed should balance convenience for the population and collection price.

Table 2. Collection costs [USD/month], associated with each vehicle type.

Scenario	Pickup truck	Hand trolley	Motorcycle	Small truck
Lodges	84	76	75	94
Lodges + 4 CP	236	349	282	216
Lodges + 24 CP	271	384	312	263

Vehicle options

Given the varying road types and the costs associated with operation, we investigated the costs associated with four types of vehicles:

- A hand-pulled trolley can be made for about 150,000 MWK, requiring two people to pull the 700 L trash capacity.
- A motorcycle-pulled trolley would cost the same, but a motorcycle would cost additional 1-2 million MWK. However, it would only consume about 5 L/100km of petrol.
- A pick-up truck: the current model is a 1996 Isuzu that consumes about 15 L of petrol per 100 km.
- A flatbed truck like the Mazda Titan, which has nearly 4 m³ of capacity, would cost about 30 million to buy and consume about 14 L/100 km.

While the estimated costs per vehicle are based on average labour costs (100,000 MWK/month) and current fuel prices (2,000 MWK/L), as shown in **Table 2**, it's important to note that the actual costs will vary, considering the volumes of waste generated.

In summary:

- A small truck is the most cost-effective option if a waste collection system is to be introduced for the whole village.
- The Sustainable Cape Maclear site is not suitable for handling large quantities of waste; if a significant volume of waste should be separated, the projected costs and collection frequencies could be lowered.
- An optimised distribution of skips and bins would reduce the walking time for every resident to no more than 5 minutes.

Financial Feasibility

To understand the financial feasibility of a comprehensive Cape Maclear-wide waste collection system, we assessed the potential for financial contributions from four stakeholder groups (households, lodges, businesses, and tourists) and explored opportunities for value creation to support the waste management system.

Households

Residents from six parts of Cape Maclear: Muonda, Nkhono, Katukumala, Kafukuta, Chembe, and Madothi, completed 259 valid questionnaires. Participant statistics are as follows:

- Families have 5.3 members on average.
- 60 % of participants are unemployed.
- Over 40 % of the surveyed households reported a monthly income below 50,000 MWK.

Eighty-one percent of respondents were satisfied with the current waste management in Cape Maclear.

To measure a household's willingness to pay for different models of waste collection, we used a bidding system: the respondents were asked whether they would agree to pay x MWK for waste collection and depending on their answer, a higher or lower offer was proposed, which they had to accept or refuse again. The aggregated results indicated that households are willing to pay:

- 1500 MWK/month for waste collection or
- 900 MWK/month, if they have to separate the waste into fractions (e.g. organics, plastic, glass).

Businesses and Recyclers

Most of the businesses surveyed claimed they were satisfied with the current waste situation. Around 50 % of the 240 interviewed businesses were small shops and

Table 3. Tourists' willingness to pay for solid waste management in Cape Maclear.

	Low season	Season	High season	Holidays
Occupancy	5 %	50 %	75 %	100 %
WTP* [USD/month]	1347	13,472	20,208	26,945
Duration [months/year]	3	4	4	1

*based on an average estimated willingness to pay of \$1.75 USD per tourist per night.

Table 4. Summary of potential financial contributions.

Stakeholder	n	WTP/stakeholder [MWK/month]	WTP/stakeholder [USD/month]*	Total revenue [USD/month]
Households	2,830			
- no separation		1,507	0.90	2,539
- separation		899	0.54	1,514
Lodges	16			
- no separation		21,840	13.00	208
- separation		7,090	4.22	68
Businesses	~500	0	0	0
Tourists	513	25,226	26.92	13,809
Recyclers	5	0	0	0

Note: 1 USD = 1680 MWK

markets, and 46 % were based in Muonda. Unlike residents, respondents from the business sector were not willing to pay for improved waste collection. However, 80 % stated they would be willing to contribute time (their own or an employee's). Five recyclers are making products or crafts using waste, but as they are currently sourcing their materials for free, they had no willingness to pay more.

Lodges

Questionnaire respondents from the lodges were the least satisfied with the current waste collection system: only 1 of the 13 respondents claimed to be content with the current system (most respondents were Lodge owners, and a quarter were managers). Currently, 46 % of the respondents are paying for private waste management and as such, lodges were, on average,

- willing to pay 22,000 MWK/month for their waste management,
- but would additionally be willing to contribute 7,000 MWK/month to manage public waste.

Tourists

Eighty-five tourists were questioned about their perceptions of the waste in Cape Maclear and their willingness to contribute towards its betterment. Only 7 % of

respondents were satisfied with the waste situation, and this perception is reflected in their willingness to contribute to waste collection with about \$1.75 USD/night of their visit. Given that all lodges in Cape Maclear have a combined capacity of 513 tourists, the revenue for the solid waste management system per month, considering different seasons, is shown in **Table 3**.

Summary

A summary of the potential financial contributions is presented in **Table 4**. However, the calculations in the total revenue column assume that all members within a stakeholder group would pay the estimated average WTP, e.g., 2,830 households in Cape Maclear would pay 1,507 MWK/month without waste separation, which is unrealistic. Furthermore, the stated WTP will likely overestimate the actual WTP as people can rarely estimate their future situation, especially regarding money. Collecting and accounting for various contributions across multiple villages is another obvious challenge requiring careful negotiation, especially among chiefs.

Given the uncertainties around payment compliance, tourism rates, and lodge participation, the actual budget for a Cape Maclear-wide solid waste management system will likely be much lower.

Business model

Our comprehensive studies have yielded crucial empirical values. These findings are instrumental in estimating the total operating costs of the waste collection and treatment service for Cape Maclear. The waste treatment system, which encompasses an incinerator and a glass crusher, was constructed during the fieldwork phase in Cape Maclear. The following operational assumptions were made:

- Worker salary: 100,000 MWK/month.
- Glass crusher operation: 2 hours/day.
- Cost of operating the incinerator: MWK 60,000/month
- Cost of maintaining the incinerator: MWK 50,000/year.

In terms of revenue, we assume:

- Businesses and recyclers have no willingness to pay (WTP = 0).
- Lodges are willing to pay \$15 USD/month (total = \$240 USD/month).
- Tourists are willing to pay \$1.75 USD per day (in total, up to \$13,800 USD per year).
- Households are willing to pay about \$0.50 USD/month (in total, up to \$1,500 USD per year).

The operational costs for different scenarios are summarized in **Table 2**.

However, all of these estimates are based on three critical assumptions, none of which will be confirmed in practice:

- Households and lodges pay what they said in the questionnaire (i.e. the willingness to pay values are accurate).
- There is 100% participation (i.e. every household and every lodge is willing to contribute).
- All contributions are regularly collected and accounted for.

Therefore, we recommend basing a business model on much more conservative, and realistic, values. Specifically, if we assume that only 12 % of households pay 750 MWK per month, the total generated from households (\$150 USD/month) along with the contributions from lodges (\$240 USD/month), the total (\$392 USD/month) will be sufficient to service all lodges and 24 collection points. We recommend that the contributions from tourists

be saved and used for annual repairs, maintenance, landfill development, and cost-of-living increases.

Recommendations

Organic Waste

- Promote composting to improve soil quality, as organic waste constituents a significant portion of total waste.
- Involve local farmers in composting practices to enhance agricultural productivity.

Glass waste

- Use glass crusher to decrease the volume of non-returnable glass bottles.
- Explore beneficial use for crushed glass.

Mixed and hazardous waste

- Incinerate mixed and hazardous waste, including medical waste.
- Ensure proper handling and disposal of ashes to prevent environmental contamination.

Financial feasibility

- Base the waste management system on a conservative business model with realistic stakeholder participation and payment compliance.
- Encourage contributions from tourists and lodges in first place to sustain the waste management system.
- Engage chiefs to find a realistic, functional business model for payment collection from households.

Community engagement

- Engage the community in waste management practices and ensure their participation for long-term sustainability.

Global Health Engineering

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