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Evaluating and modelling a decentralised community-based waste collection system in developing São Tomé city

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ABSTRACT

A small-scale waste collection service by means of a motor tricycle was put in place by the community of Boa Morte (in São Tomé e Príncipe), as a solution to face the lack of an adequate waste management in their neighbourhood. A qualitative and quantitative evaluation of the service was performed by the authors, including a characterisation of the generated waste, interviews with the population involved, a technical assessment and the development of a cost model. With respect to technical aspects, the vehicle chosen has been found to be a satisfactory choice, whereas the productivity of collection is still too low due to the dispersion of collection points. Concerning financial aspects, the cost model reveals that the scale of the scheme is still too small to be completely sustained by its own revenues, but this objective of self-sustainability is achievable within the limits defined for the system, by adding a determined number of new customers without exceeding the fixed maximum working time and introducing some improvements and time optimisation.

1. Introduction and objectives

1.1. Overview of municipal waste management in cities of developing countries

Most cities located in developing countries are dealing with an unprecedented waste management crisis. Along with a young growing population and unplanned urban development, local officials and institutions face an economical system that pushes citizens to use more packaging and plastics, contributing to increase the waste problem. Concerning municipal solid waste (MSW) collection, in the typical situation seen in these cities, an organised collection service remains in place solely for a part of the population, namely the most affluent people living in the central, most urbanised area of the city, while the economically less favoured and less urbanised neighbourhoods located in the periphery are mostly left behind – see specific cases in Rai et al. (2019) and Salazar-Adams (2021). In some of these neighbourhoods an informal network of MSW collectors exists, but in other waste collection does not exist at all, and household waste is simply accumulated in improvised dumpsites or burned. Regarding MSW effectively collected, its final destination is usually a landfill – which in many cases is not controlled and safely managed –, where sometimes an improvised recovery of materials for informal recycling takes place. The problem is worsened in small insular developing countries – focus of this study – by their particular geographic constraints (Mohee et al., 2015).

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MSW collection solutions applied in many developing countries have been hampered by a mix of inadequate technical choices and inefficient financial management, an unfortunately not unusual situation in developing countries. Fig. 1 summarises a typical cyclical process where the recourse to external support motivated by the insufficient own funding sources brings technological solutions not adapted to the local context, which ultimately fail, bringing the situation again to the same dead-spot.

In practice, complex equipment (vehicles, compactors, bins), often imported from foreign countries and based on technological solutions applied in industrialised countries, typically show a poor performance in the context of developing countries, due to a combination of several factors, among which: a difficult terrain which punishes equipment (most secondary roads are not paved), harsh climate conditions – tropical conditions such as high humidity favour metal corrosion – and deficient technical support, due to the difficulties to acquire spare parts for this foreign equipment and the lack of local experienced personnel for maintenance and reparations. Traffic congestion in the main streets and poor roadway condition in secondary roads render a mechanised collection less efficient. Moreover, in some cases the use of the equipment seems inadequate for the context where it is employed: for example, compaction equipment is mostly unnecessary in many developing countries, since biowaste is usually the clearly dominant component in household waste with more than 50% of MSW mass (ACCP, 2019), and that with the highest apparent density. Fig. 2a and b also show two examples of wrong equipment use in the republic of São Tomé e Príncipe.

In the end, all these circumstances result in the equipment being out of service most of the time, and finally, prematurely reaching the end of useful life before the expected time, sometimes even before the end of the amortisation period for the initial investment.

To overcome all these constraints and difficulties, the whole technological thinking of MSW management framework must be adapted to the conditions found in each place. Fig. 3 shows a comparison of the technological approaches recommended for both industrialised and developing countries: in industrialised countries the high personnel costs (salaries, insurance, etc.) imply a trend to implement more mechanised systems – since the initial investment in equipment results more profitable in the long term. However, in developed countries the problem is the opposite: prices of imported equipment are high for local developing economies – and even if external financial support is available for the acquisition, probably it will be not for the costly maintenance and reparations –,

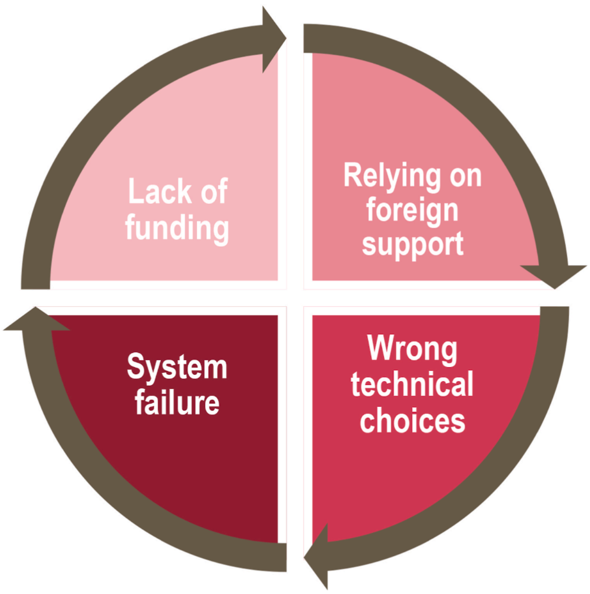

Fig. 1. Schematic representation of the failure process of MSW management frequently found in developing countries.

Fig. 2. Examples of inadequate collection equipment use in São Tomé island: (a) damaged fixed MSW storing compartment due to lack of maintenance; (b) an open container for street use, becomes an attracting hotspot for animals.

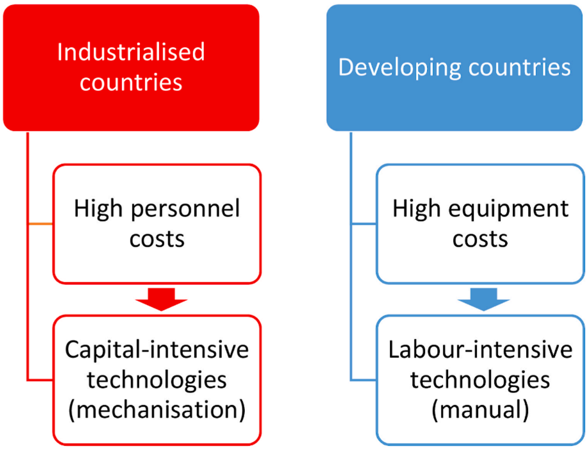

Fig. 3. Schematic comparison of technological approaches for MSW management in both industrialised and developing countries.

whereas on the other hand, personnel is available in large numbers as a consequence of high unemployment rates, thus favouring more manual, low-tech solutions (Tin et al., 1995; UN–HABITAT 2010).

Solutions based on simple technological approaches – namely, small size vehicles, either motor-powered or human-powered – should be less prone to malfunctions and breakdowns, thus increasing the technical reliability of the system. Also, highly skilled personnel is not required to operate such kind of equipment, while maintenance and reparations are easier. These advantages should allow a more regular performance of the service. Additionally, these solutions for waste collection may be more easily provided and supported by the local industry, hence avoiding or reducing the dependence on foreign assistance and supplies, whereas at the same time contributing to local economic development and employment creation.

1.2. Strategies for financing municipal waste collection in developing countries

With regard to the financing of MSW management, this has proved to be a thorny issue in developing countries. A common situation found is that neither governments nor citizens put waste management as a high priority concern, preferring to shift their focus to other issues considered more urgent or important. As a consequence, the payment of fees for waste management by the population is in many cases not generalised, since municipal authorities do not possess resources to put in place and manage an adequate network of fees collection, and anyway for the least economically favoured population groups the payment of any fee is just unaffordable – the same happens in the case of payment for other services with a higher priority for basic life quality, such as electricity and water supply (Ribas Alzamora and de Vasconcelos Ramos 2020). Given that the payment of fees is the only reasonable way to finance waste management without external dependence, the most feasible practical solution is to charge the pricing effort on those population groups which have more ability to effectively pay a fee, namely: commercial establishments (at least, the formal establishments), which are easier to be scrutinised by the authorities, and also high-income citizens, for whom the fee value required will not be significant. By doing so, a kind of internal subsidising takes place, where those with greater economic capacity contribute to provide the service to the less favoured, so that the scheme cannot be regarded as unfair (UN–HABITAT 2010).

Regarding the actual collection of fees, given the barriers for establishing automatised billing systems due to limited banking access and the lack of effective tax collection bodies, the easiest approach is the direct cash payment of the fee to the waste collection operational staff – *door-to-door* (DtD) collection schemes are appropriate for this practice. Hence, the provision of service remains directly attached to the payment: if the fee is not paid by the users, then their waste is not collected – although, as mentioned before, this measure would not be applicable for the lower income population. Payment for waste collection would be better accepted if the community of citizens feels that the service is satisfactory and useful for improving their living conditions. Related to this aspect, the involvement of the community itself within the service management – to some extent, at least – appears to be a promising way to overcome the sometimes existent mistrust between citizens and governing authorities. In this work, the feasibility of establishing a waste collection service at the level of a neighbourhood, totally self-sufficient and managed by the same neighbourhood community will be assessed and evaluated.

1.3. Objectives: assessing community-based waste collection

Decentralised, small scale MSW collection, run by the community itself and self-sufficient waste collection systems such as the one here addressed, are uncommon, but regarded as a feasible way of implementing essential urban services, beneficial for public health, in locations where the local authorities do not have the ability to do it with the same efficiency and especially, in a sustained manner along time until reaching a long-term stability (Wynne et al., 2018). There is a gap in scientific literature regarding the evaluation of the technical performance and economic sustainability of such systems, whereas among the reported cases – particularly from South-Eastern Asia – a varying degree of success has been observed (Budihardjo et al., 2022; Colon and Fawcett 2006; Medina 2010; Mongkolnchaiarunya 2005; Satibi et al., 2021; Sekito et al., 2013). Among the factors contributing to failure of such collection models, lack of population interest for participation – as users, but also, and more critically, as volunteers for managing the system – and a too small scale, were commonly mentioned. On the other hand, a perceptible improvement of the environment appearance, due to the decrease of waste littering, was a typical positive outcome achieved.

The purpose of this work is to contribute in filling that gap of information by describing and assessing the efficiency and sustainability of the community-based waste management model in Boa Morte, especially in those aspects concerning performance of MSW collection. Moreover, this study aims at modelling the waste collection system with the purpose of verifying its sustainability in financial terms in the context of a particular African city, by means of a scientific and systematic approach not seen in the studies previously mentioned, more focused in surveying the population opinion. With respect to this aspect, and assessment framework consisting of a cost model was developed and later applied for building several alternative scenarios, in which some feasible improvements to the collection system are put to the test. Additionally to these improvements, the viability of a more complex scenario envisioned for the near future, in which separate collection of waste is firstly introduced, was also tested.

2. Case study and methodologies

2.1. Case study: a small-scale decentralised MSW management model

In this paper the authors are reporting a field experience developed by the local community of Boa Morte, located in the west periphery of São Tomé city (Fig. 4a and b) – the capital and main city in the island republic of São Tomé e Príncipe (in the African Gulf of Guinea). The total population in the district of Água Grande (roughly equivalent to São Tomé city) was estimated in 81,000 inhabitants for 2020, with an expected +2.3% annual growth rate until 2035 (INE–STP 2015a). Boa Morte community itself and surrounding neighbourhoods had a population of 7600 in 2012 (INE–STP 2015b), probably reaching 9000 as of 2021.

The Boa Morte community shares most of the problems previously described regarding the lack of a proper MSW management. A majority of the residents (at least 75% of the population) do not have access to the regular municipal collection service, which only covers a small fraction of the territory – the closest to the city. This lack of collection results in residents dumping their waste in the surrounding environment, or sometimes burning it. The situation is further aggravated by the existence within the community area of the largest waste disposal site of São Tomé city, a significant source of pollution for air, water and soil.

In view of this situation, a group of citizens of Boa Morte who identified the deficient management of MSW as a relevant problem, organised themselves within the scope of *Bairro Limpo* project – funded by the Portuguese cooperation through *Camões – Instituto da Cooperação e da Língua*, in order to put in place a regular and efficient MSW collection service, innovative in the way that is totally managed by the community and self-sufficient in financial terms, even though its scale reaches only the level of the neighbourhood. In addition to household waste collection, street bins for rubbish were placed in strategic gathering places, in the vicinity of the various drinking/grocery stores existent in the community, with the goal of avoiding littering from these establishments, since no means of street cleaning are present. Furthermore, sustainable MSW management practices such as home-composting and separated collection – namely, glass collection for recycling –, were introduced in the neighbourhood.

The type of small-scale MSW collection established in Boa Morte corresponds to a *door-to-door* (DtD) model: the collection vehicle goes to every participating household three times a week to pick their mixed household waste and take it to the municipal dumpsite. For this service every customer – either a household or a commercial establishment – pays directly to the driver a fee of 100 STN per month (roughly 4€).

The vehicle chosen for the collection task is a motor tricycle. The use of small-scale collection vehicles – either motorised or not – is in in fact a widespread practice in developing countries, since it is in line with the approach previously shown in Fig. 3. Handcarts, many variants of freight bicycles and motorised tricycles like the one used in Boa Morte neighbourhood are examples of simple technological solutions, inexpensive if compared to large lorries and in many cases locally built, easy to operate, to maintain and to repair. Their ability to move through unpaved roads and narrow pathways allow the MSW collection service to reach places where larger collection vehicles will never arrive, or at least not in an efficient manner – as reported by Saja et al. (2021). Examples of these systems have been analysed in scientific literature, see for instance Hazra and Goel (2009) for the use of handcarts in the city of Kolkata (India) or Imam et al. (2008), when comparing the formal and informal collection means in Abuja (Nigeria).

The results shown here are based on the field work developed by the authors during a visit to Boa Morte in January/February 2021 (corresponding to the dry season in São Tomé Island). Several tasks were performed, aimed at data collection, following the strategies presented in Sections 2.1 and 2.2.

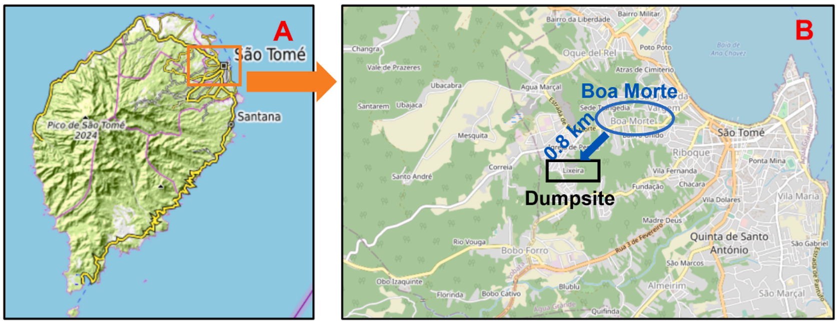

Fig. 4. (a) Location of São Tomé city within São Tomé island; (b) Boa Morte within São Tomé City; adapted from ©OpenTopoMap (CC–BY–SA).

2.2. Exploratory research

a) Direct observation: visits to the neighbourhood to check the current situation and practices for MSW management. The team followed the DtD waste collection on three occasions.
b) Unstructured interviews were made to the driver of the collection vehicle, the managing team of the collection service and the residents – both beneficiaries from DtD MSW collection and others not participating – in order to gather through qualitative perception a first insight about the collection service and its importance and relevance to the population, as well as to identify problems that must be addressed and corrected.
c) Field visits to the waste final disposal site and to existing valorisation facilities in the vicinity of the community: a composting centre (1000 t/year), run by the local authorities, and a valorisation facility for glass, metals and plastics, run by a local NGO.
d) Interviews with local authorities (district governments of Água Grande and Mé-Zóchi) and local NGOs related to waste management (*Santa Casa da Misericórdia, TESE*).

2.3. Descriptive research

2.3.1. Quantitative assessment

The necessary information for the technical evaluation of the MSW collection service was obtained from the driver and the management team: households served, fuel consumption, operating costs and revenues. Moreover, the collection circuit made by the vehicle was recorded on 3 different occasions using a commercial geo-referencing application installed on a mobile phone which was carried by the driver. Recorded data was then transferred to a computer for analysis. This allowed to obtain a clear profile of the distance travelled, time consumed in each stage of collection, number of trips made to the landfill to dispose of waste, etc.

2.3.2. Monitoring and characterisation campaign

A monitoring and characterisation campaign was carried out with the goal of getting information about the amounts of generated MSW *per capita* and the percentage of its different material components. Monitoring consisted on daily weighing, during one week, of the quantity of waste generated by a sample of 33 households of neighbourhood residents, encompassing different socio-economic levels. Two 25 L bags were given to each household, to put inside their daily waste, using one of the bags for the *wet fraction* – suitable for composting – and the other bag for the *dry fraction* – not suitable for composting. Each bag containing the corresponding fraction was weighted every day of the week, divided in two periods for better optimisation and comfort: first, from Tuesday until Friday (4 days) and second, from Saturday until Monday (3 days). After the first period, the household waste accumulated in the bags was taken to perform a characterisation of its composition, by manually sorting and weighing MSW, classified on its main material components (see Fig. 5 on Section 3.1). For the sake of coherence in the results, only bags from households where the weighing values were correctly validated were used for the analysis.

In parallel to the MSW characterisation, structured interviews were made to a sample of residents (23 households) in the neighbourhood focusing on their waste disposal practices and their opinion of the DtD collection service, irrespectively of being or not beneficiaries of the service. The interview comprised 7 questions: three of them were directed to the household characterisation – number and age of members, whether they practice agriculture or not and whether they participate or not on the DtD MSW collection –, three multiple choice questions asking for their consideration of waste as a problem and for their common practices with wet and dry fractions of household waste, respectively, and finally an open question for their opinion and comments about the DtD MSW collection service implemented by the community.

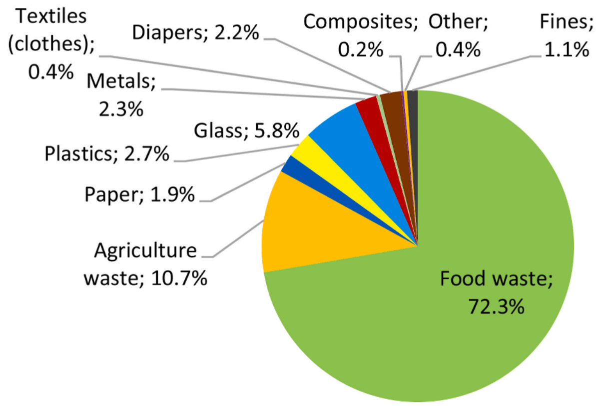

Fig. 5. Composition of domestic waste determined in the first part of the characterisation campaign at Boa Morte.

3. Descriptive assessment of waste collection in the target area

3.1. Waste generation and overview of current waste management practices

3.1.1. Monitoring and characterisation results

The results of the MSW weighing and characterisation campaign pointed to an average production of wet wastes (food and garden waste) of 400 g (± 260 g) a day per inhabitant and of dry wastes of 100 g (± 80 g) a day per inhabitant. This accrues to a daily MSW production per inhabitant of 500 g, of which 80% is wet (organic) waste and 20% is dry waste. These results are in line with those put forward in the National Plan for Municipal Solid Waste for the larger district of Água Grande, which is 450 g•inhab.$^{-1}$•day^{-1} (MIRNA, 2018), although higher than the national average reported in different sources: 0.39 kg•inhab.$^{-1}$•day^{-1} by MIRNA (2018) and 0.37 kg•inhab.$^{-1}$•day^{-1} by Kaza et al. (2018), probably because Boa Morte belongs to the most urbanised district of the country. Daily waste generation was 430 g•inhab.$^{-1}$•day^{-1} during weekdays (Tuesday to Friday) and 600 g•inhab.$^{-1}$•day^{-1} on the weekend (between Saturday and Monday), likely due to a more active family and social life at home during weekend.

Wet waste represents 83% of total waste (Fig. 5), of which the larger fraction is food waste, composed mainly by fruit peels (bananas and jackfruit, among other). Cooked food waste is mostly absent, likely because these leftovers are given to domestic animals. The percentage of wet waste found in the target neighbourhood is higher than those reported for the district of Água Grande (53%) and for the country (58%), (MIRNA, 2018). The difference may lay in the fact that the campaign focused on domestic waste, thus excluding commerce where dry packaging waste is more relevant. The analysis took place only during the dry season, but even though higher moisture content might be expected in the rainy season, the extremely high biowaste ratio in the waste composition is thought to be unlikely to become much higher in other conditions. To this respect, the waste generation pattern seems to be influenced much by the agricultural cycles – i.e. higher waste generation corresponds to harvesting periods – rather than by the climate itself, as pointed by other studies in similar conditions (Afon 2007).

Glass is the dominant material in dry waste. The high specific weight of glass contributes to a high representativity of this fraction among the dry waste, when compared to plastic or paper. A distortion induced by the waste campaign itself is also possible, because this event might have been used by the residents to tidy up and discard old glass bottles. Looking at the metal waste, there is a constant presence of soda drink cans. Clothing and traditional slippers are dominant in category "Other".

3.1.2. Assessment of waste management practices

Waste disposal and valorisation practices by the residents in the target area are depicted in Fig. 6. For wet (organic) waste, most respondents refer using it as fodder for domestic animals (Fig. 6a). Some families do home composting, either as a result of previous training sessions or by their own initiative. However, due to lack of information composting is not yet recognised by the general population as a viable option to treat organic waste.

For dry waste, reusing is well-rooted in community practices (Fig. 6b), especially for plastic bottles, cans, and other containers. Only materials that are so thorn-up that re-use is no longer possible are discarded. Abandoning waste in outdoor spaces behind houses (Fig. 7a), in the woods (Fig. 7b) and in vacant slots along the main road and walking paths are common practices. In some situations, there is a certain spontaneous organisation of disposal sites, and a cluster of houses dump their waste at the same spot, that can even be delimited (Fig. 7c). In some cases, waste dumping sites reach relatively larger dimensions. Waste burning is also adopted by the residents as a waste management strategy (according to the interviews and direct observation) and burning waste piles can occasionally be seen in the area (Fig. 7d).

In addition to households, commercial and public establishments also dump waste. Piles of abandoned paint cans were seen in the vicinity of a vehicle repair workshop and mixed waste similar to household waste was found behind the school yard. Shopping kiosks regularly sweep to some distance away the waste dumped nearby. Near Boa Morte stands the largest dumpsite (uncontrolled) of São Tomé Island. This is the destination of all household waste collected in the district, mostly from the capital city, which is served by a waste collection service. The dumpsite is open, and everyone can go there to dump their waste. But for most people in the neighbourhood of Boa Morte, in the absence of a regular collection service it is more convenient to simply abandon waste outside their homes.

3.2. Financial structure of the model

The full detailed structure of costs and revenues of the collection service is shown in Table 1, in a monthly basis.

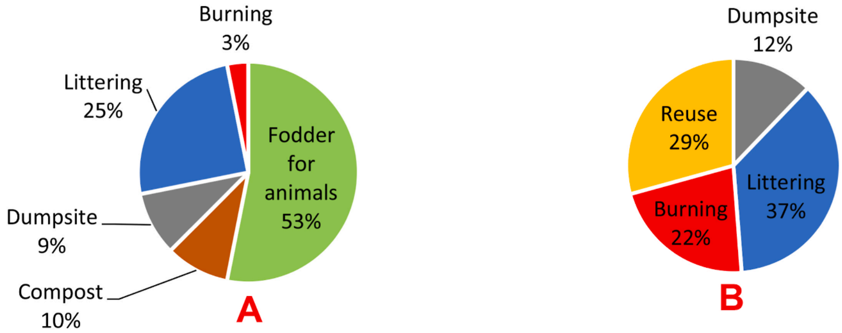

Fig. 6. Waste management practices of the community of Boa Morte for: (a) wet waste; (b) dry waste; in % of total answers.

Fig. 7. Waste disposal/littering practices at the target community: (a) waste abandoned at the backyard; (b) "fenced" waste disposal site serving a cluster of a few houses; (c) waste abandoned in the woods; (d) waste burning at the backyard.

Table 1
Structure of monthly costs and revenues (1 EUR = 24.5 STN).

Revenues		Costs	
Collection fees (paid by clients)	1200 STN	Maintenance	1250 STN
Vehicle renting on days without collection (paid by the driver)	2520 STN	Insurance + taxes	399 STN
		Spare parts (tyres, cover)	350 STN
		Communication using a mobile phone	115 STN
		Protective equipment and others	107 STN
Subtotal	**3720 STN**	**Subtotal**	**2221 STN**
Fuel costs (paid by the driver)		← Fuel for the collection vehicle	1170 STN
TOTAL	**4890 STN**	**TOTAL**	**3391 STN**

Remarkably, there are no personnel costs (salaries) in this model: the driver works for free (voluntarily) and pays also for the fuel, provided that he can profit from using the vehicle in other private activities the rest of time – when there is no collection – for a rent value below the market price, reflected also in Table 1; the rest of tasks (accounting, relations with clients, coordination, etc.) are assumed voluntarily by a small management team (3–5 members of the community). Without the revenue obtained from this renting, the model would not be financially sustainable, since the revenue obtained from clients is too low because there are still too few households participating; actually, the price of 100 STN paid by each household per month is somewhat high considering the common prices and salaries in São Tomé e Príncipe, so this value might be a barrier for low-income households.

The benefit for the driver relies on the price paid for renting the vehicle (140 STN per day); it is still low if compared to the usual market prices for renting this kind of vehicles in the city of São Tomé (not less than 200 STN per day), and this compensates for the time freely dedicated to the collection (3 half-days per week). However, this price initially established has revealed to be too difficult to afford for the driver, so it has been proposed to reduce it to 100 STN per day – still enough to cover the part of the expenses attributable to the external use of the vehicle – i.e., other than for collection.

Since collection fees alone do not cover all expenses, the sustainability of the system depends on the renting of the collection vehicle for other activities than collection. This represents an uncertainty and a risk and makes the system highly susceptible to outside conditions that it cannot control; for instance, in case there is a lower demand for using the vehicle, it remains unrented for some days. However, on the positive side the vehicle renting by the driver plays a positive role of engagement, which goes beyond the mere payment of a money value: since the driver is dependent on the good condition of the vehicle for obtaining an income in other professional activities, the responsibility for taking good care and maintenance of the tricycle is effectively shared by both the driver and the community service managers: every failure in the vehicle availability would be critical for both parts of the agreement. This responsibility sharing would not exist – or not so explicitly – in case of the driver being just an employee. This is considered a key distinctive aspect of the collection model implemented at Boa Morte, which could be useful to replicate in other similar situations. Given that poor motivation of the system operators constitutes a risk for its performance (Colon and Fawcett 2006), this solution might well contribute to successfully overcome that threat.

In other cases, motivation of the system operators is achieved by allowing them to make profit from selling recyclables (Budihardjo et al., 2022; Colon and Fawcett 2006), but this alternative is not feasible in developing countries similar to São Tomé e Príncipe, since unfortunately there is not established a well-developed recycling market, due to a lack of economic conditions for it. In fact, source separation of valuable materials has not yet been introduced in the current collection system, but it is expected for it being implemented in the near future, provided that stakeholders interested in recovering materials for recycling are found, along with composting facilities for the organic fraction.

Lastly, a remark should be done regarding the cost structure: capital expenses are almost non-existent, since the most important asset – i.e. the tricycle – was acquired by means of external financial support. Similar support should be granted for acquiring the necessary equipment – through development assistance programmes, soft financing mechanism, etc., in case the own resources or equipment of the community organisation are not enough. Renting of equipment – maybe with similar arrangements to the one put in place in Boa Morte might also be an alternative option.

4. Cost modelling of waste collection in Boa Morte

In view of the financial structure presented in 3.2 and the technical indicators (3.2), it is of the interest for the viability of the service to gain more financial autonomy and cover all costs by itself, including fuel consumption, instead of relying on vehicle renting. The renting of the vehicle may be kept as long as a salary is not paid to the driver, but it should no longer be essential, so that the sustainability will not be compromised if the renting is not paid by any reason.

Financial autonomy can be achieved by expanding the number of clients. Besides the increase of revenues, this expansion will also result in a more optimised use of resources, as well as fulfilling a primary objective of every MSW collection system: to reach a substantial part – if not all – of the population, an objective which is still far from being reached in this case.

To better understand the system and estimate how many clients would be necessary to achieve financial autonomy, as well as to be able to assess the impact of changing other system parameters (amount paid per client, renting fee, etc.), a cost model of the collection system was built, according to the model structure seen in Fig. 8. The model comprises 4 main modules: (i) Waste Generation, (ii) Time, (iii) Distance and (iv) Costs & Revenues. The first three modules are related to technical aspects of the collection service and the last is related to the financial assessment.

To build the technical modules the following assumptions were made:

- Three groups of waste producers are considered: residential clients, non-residential clients, and street bins. For each group, the model distinguishes: *per capita* amount of dry and wet MSW discarded, average specific weight of MSW discarded and monthly fee for the service (this is only for residential and non-residential, while not applicable for street bins).
- New clients are located within the previously established trajectory, so distance between collection points does not increase with increasing number of clients (households served). But the overall distance travelled increases with the number of clients because more journeys to the dumpsite are required during the collection circuit (one working day).
- The number of itineraries required in each working day is calculated based on the weight and volume collected in that day and the maximum capacity of the collection vehicle: a journey to the waste dump (and back) was added whenever the collection vehicle reaches its maximum capacity (either weight or volume).
- The time required for the collection circuit increases with the number of clients: time halted during DtD collection at clients increases and the time required for travelling to the dumpsite increases with the number of journeys to the dumpsite.

To build the Cost & Revenues module the following considerations were made:

- Two revenues are included: residential and non-residential clients pay a monthly fee for the collection service; and the collection vehicle is rented some of the days when collection does not take place.
- The model distinguishes between two types of costs: those that do not depend on the number of clients (fixed costs) and variable costs which depend (directly or indirectly) on the number of clients.
- Fixed costs comprise insurance, taxes, individual protection equipment and subscription of mobile communications.

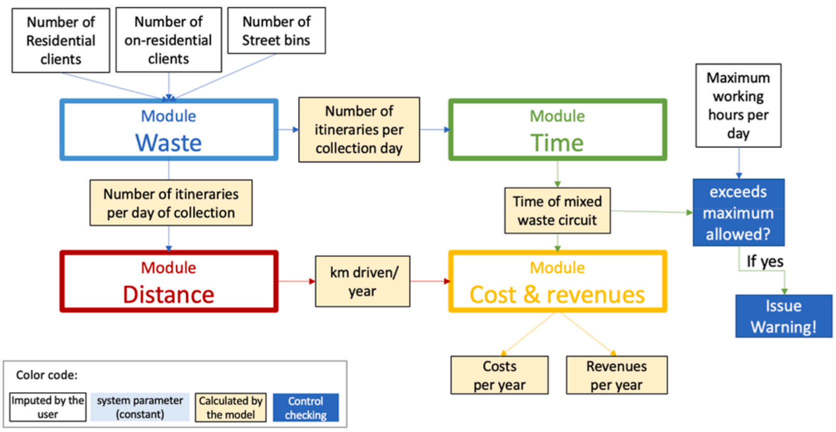

Fig. 8. Simplified conceptual view of the MSW collection cost model: the 4 main modules “Waste”, “Time”, “Distance” and “Cost & Revenues” interact to calculate the cost and revenues per year in different scenarios.

- Maintenance, tyre replacement and petrol costs are variable and depend directly on the distance travelled during the collection service.
- Driver's wage depends on the time required to complete one working day and on the number of collection days per week.

5. Results and discussion

5.1. *Technical evaluation of the waste collection: collection circuit and collection vehicle*

The collection implemented in the framework of this community-based model takes place three times per week – on Monday, Wednesday, and Friday – using a motor tricycle with a 150 cm^3 petrol engine (Fig. 9a). Collection is carried out by the driver with the occasional help of a waste collection worker and is technically a mixture of primarily DtD collection, for households and small shopping kiosks (locally named "*quitandas*"), and secondarily, kerbside collection (small kerbside street waste bins, depicted in Fig. 9b).e.

5.1.1. *Overall route characterisation*

In January 2021 the route (journey of the collection vehicle during one working day) comprised 18 collection points: 7 households, 6 small kerbside waste bins, 4 shopping kiosks and 1 nursing home for elder people. The first collection itinerary starts at the location where the collection vehicle is parked overnight. From there the vehicle goes consecutively to each collection point until the vehicle reaches its maximum working load or, more typically, working volume. The collection vehicle then goes to the dumpsite to discharge the waste collected and starts the second itinerary by returning to the next collection point. This is repeated a third time, if necessary, until all collection points are covered. At the end of the third itinerary the vehicle returns to the parking spot. The registered collection route comprised 10.81 km, distributed in three itineraries (Fig. 10) and required 131 min. According to the driver there is some variation of the registered values depending on the day (Table 2).

Fig. 9. Collection equipment: (a) motor tricycle in circulation; (b) kerbside small street waste bin.

Fig. 10. Representation on a map of a geo-referenced recording of the collection route in Boa Morte. Each colour represents an itinerary: red is itinerary 1 (7 collection points), blue is itinerary 2 (8 collection points) and green is itinerary 3 (3 collection points), plus the final return (purple); adapted from ©OpenTopoMap (CC–BY–SA). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Collection route parameters (from instrumental recording) and indicative variability (as communicated by the driver).

	Measured	Indicative variability
Number of itineraries	3	2–3
Distance	10.81 km	(not available)
Total collection time	131 min	90–180 min
Average speed (excludes stops)	14 km/h	(not available)
Maximum speed	44 km/h	(not available)

5.1.2. Analysis of waste collection time

The distribution of time among the different activities carried out during the route is represented in Fig. 11.

The time spent strictly in collection was 91 min: 19 min travelling between collection points and 72 min for loading at each point. The average stopping time at each collection point is 4 min, which is noticeably very high. The reason for this extended time at the collection point lays in the DtD procedure selected: knocking at the door of the household, waiting for someone inside to answer, getting the waste from inside the house in a bucket, transferring the waste to the vehicle and returning the bucket. More than often the driver needs to wait long before someone answers the door.

Each trip to/from the dumpsite takes on average 4.7 min each side and 4 min to unload the waste, totalling 13.3 min. When considering the 3 journeys, the total time used for trips to the dumpsite and unloading the waste is 40 min in the daily route. A comparison of the circulation time (47 min) with the time the vehicle is halted (84 min) highlights that only a minor part of the time during collection is spent circulating.

5.1.3. Critical analysis of waste collection vehicle

The waste collection vehicle is technologically simple, the maintenance is not complex and is quite common in the country, making it easy to find repair shops and replacement pieces. Its small size allows circulating through narrow road where larger collection vehicles could not circulate. The loading volume of the vehicle (measured up to the height of the rear door and sidewalls fitted to the trailer), is 0.64 m^3. There are no mechanisms to restrain the movement of the load, so it is not possible to add load above that height due to the risk of it falling out. If a specific weight of 100 kg/m^3 is assumed for MSW, this means a maximum waste load of 64 kg, to which the weight of two adult workers is added, totalling approximately 200 kg (workers + loaded MSW). Since the maximum weight allowed for the vehicle is 600 kg, the low loading volume is the limiting parameter and constitutes the main limitation of the motor tricycle, making necessary to go often to the disposal site. However, the dumpsite is close to the collection circuit (1.5 km from the first collection point) and this compensates for the low loading volume of the tricycle. It is possible to make several trips to the dumpsite without taking too much time or spending too much petrol. Published data by the United Nations Human Settlement Programme recommends this type of collection vehicle when the distance to the final disposal site is less than 5 km (UN–HABITAT 2010).

The fuel consumed by the motorised tricycle was estimated as 3 L of gasoline for each working day. Taking this value as a reference and assuming that this consumption corresponds to the collection and transport of two persons (70 kg each) and a load of another 70 kg of MSW, going to the waste dumpsite for three times – equivalent to the travelled distance of almost 11 km measured for the circuit in Section 3.2., the usual efficiency parameters for establishing the performance of the collection circuit were calculated: MSW collected vs. Fuel consumed vs. Distance travelled. The results are presented in Table 3.

The vehicle requires, in theory, more than 50 km to collect 1 tonne of MSW; this is a rather poor collection rate, especially if considering that the population living in the area covered by the current collection (less than 3 km) is generating a daily amount of MSW which is greater than 1 tonne. This can be explained by the great dispersion of collection points, with most households located along the collection route not having subscribed the service.

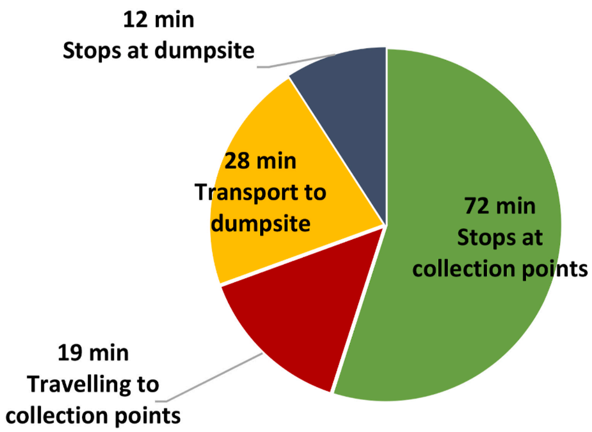

Fig. 11. Time distribution of a recorded collection route in Boa Morte (February 2021).

Table 3
Performance parameters of the collection circuit.

Performance indicators
14 L fuel/tonne collected
51 km/tonne collected
28 L fuel/100 km

Additionally, a disadvantage of this vehicle is the small wheel size, which makes it difficult to circulate in the narrow and uneven unpaved roads that connect the main road to the inner parts of the neighbourhood. The circulating speed in these inner roads is reduced to less than 10 km/h, which is comparable to walking speed. Moreover, the loading and unloading process is done by hand and takes time. Because the waste is transported without bags or other type of containers and in direct contact with the floor of the vehicle, cleaning is required at the end of the collection route. As a final point, the vehicle is not fit to transport both the driver and the waste collector worker, as often occurs in the current community-based collection.

5.2. *Evaluation of financial sustainability*

Basing on the assumptions presented in Section 4, a first scenario was created (Table 4) in which the expansion of the service to additional clients occurs based on the current conditions – that is: the *baseline scenario*. In the baseline scenario the renting of the vehicle may still happen (because a salary is not paid to the driver), but it should no longer be included as revenue, so that the sustainability will not be compromised if the renting is not paid by any reason.

According to the manufacturer specifications the maximum load of the collection vehicle is 600 kg, but the management team states that above 300 kg the maintenance expenses increase significantly, so this last value was considered as the maximum load allowed. Considering one or two people are also on board during collection and that these will amount to 150 kg, the maximum waste load (weight) was set at 150 kg.

Table 4
Specifications for the construction of the baseline scenario (Notes: [a] Based on the questionnaires; [b] Determined in the waste characterisation campaign; [c] Conditions in 2021; [d] Estimated considering the distance to the dumpsite from the furthest collection point is 1.5 km; [e] Measured (circuit recordings); [f] Estimation based on data reported by the management team; [g] Estimation based on data reported by the driver).

System Parameter	Value
WASTE MODULE	
Household size [a]	5 people
Per capita daily production of wet waste [b]	0.40 kg
Per capita daily production of dry waste [b]	0.10 kg
Waste discarded at a street bin per week [b]	15.54 kg
Specific weight of waste discarded by residential and non-residential clients [b]	75 kg/m^3
Specific weight of the waste discarded in street bins [b]	50 kg/m^3
Number of street bins [c]	6
Maximum waste load (in volume) of the motor tricycle [b]	0.64 m^3
Maximum waste load (mass) of the motor tricycle	150 kg
DISTANCE MODULE	
Average distance from collection point to dumpsite [d]	2 km
Length of the trip from the first to the last collection point during one collection day (excludes journeys to and from the dumpsite) [e]	4 km
TIME MODULE	
Time required to go from one collection point to the dumpsite, unload the waste and return to the next collection point [e]	13.3 min
Time of the trip from the first to the last collection point during one collection day (excludes journeys to and from the dumpsite) [e]	19 min
Time halted at one client during collection [e]	4 min
Time halted for collection of a street bin [e]	4 min
COST MODULE	
Driver's wage/hour [c]	0 STN
Motor tricycle renting fee per day [c]	140 STN
Motor tricycle renting days per month [c]	0
Monthly fee for residential clients [c]	100 STN
Monthly fee for non-residential clients [c]	100 STN
Maintenance cost [f]	9.62 STN/km
Number of new tyres/5000 km [f]	3
Unit cost of tyre [f]	1068 STN
Fuel consumption of collection vehicle [g]	27.75 L/100 km
Fuel cost/L	30 STN/L
Fixed expenses per year [f]	8653 STN

Fig. 12 shows that, the more households joining the collection service, the more profitable it is, since the revenues increase at a higher rate than costs. Assuming as starting point the initial situation with only 12 households, the point of balance between costs and revenues is reached when another 46 households are added, thus 58 households served in total with 290 inhabitants. But a problem appears when checking the working time required for MSW collection in these 58 points: it would be more than 6 h. Even though it is not completely unrealistic, this working time is regarded as excessive for an activity of this nature in this context. Based on judgement of the authors, a daily working time closer to 4 h is preferred.

Therefore, it is desirable to introduce some improvements in the collection service which would contribute to increase productivity and then making it more efficient. A suitable proposal is to increase the volume capacity of the motor tricycle from current 0.64 m^3 up to 1 m^3. This can be achieved by increasing the height of the sidewalls and rear door by 18 cm, using panels. With this modification the number of trips to the disposal site would be reduced, and, as consequences, not only the time necessary for collection is reduced, but the fuel, maintenance and tyre costs decrease also. The representation of this new scenario, called *Scenario 1*, is shown in Fig. 13.

The consequence of the improvement introduced is the lower effort required to reach the point of balance between costs and revenues: now it is necessary to add only 24 new households besides the initial 12. The daily working time needed corresponds now to 4 h and 12 min, a much reasonable duration since it leaves some room for breaks and other auxiliary and maintenance tasks.

Another possible improvement concerns the time needed for collection at each client. The average time dedicated to every collection point was established as 4 min – as shown in Section 3.2. This value seems quite high and is mainly due to a deficient coordination between the driver and the householders. If a time schedule for MSW collection is put in place, with both driver and householders respecting the appointed time, it is assumed the average time drops to 2 min, resulting in a significant time optimisation. This improvement gave place to *scenario 2*, presented in Fig. 14: costs and revenues are the same as in scenario 1, so financial balance is achieved with 36 clients in both scenarios. Now the x-axis corresponds to the working time, which thanks to the optimisation introduced has been reduced to 167 min (2 h 47 min), against 4 h 12 min required in scenario 1.

But if total working time is allowed to increase until 4 h per day in this scenario 2, it would then be possible to serve 60 clients, well beyond the minimum 36 clients from which costs are covered by revenues. This leads to a further question: at 4 h working time how much could the fee be reduced, just looking to keep costs and revenues balanced? The answer is seen again in Fig. 14, where a new point of balance is fixed at a working time of 4 h, corresponding to the revenues paid by 60 households in total, with a monthly fee of 77 STN, instead of the previous 100 STN, thus making the service more affordable.

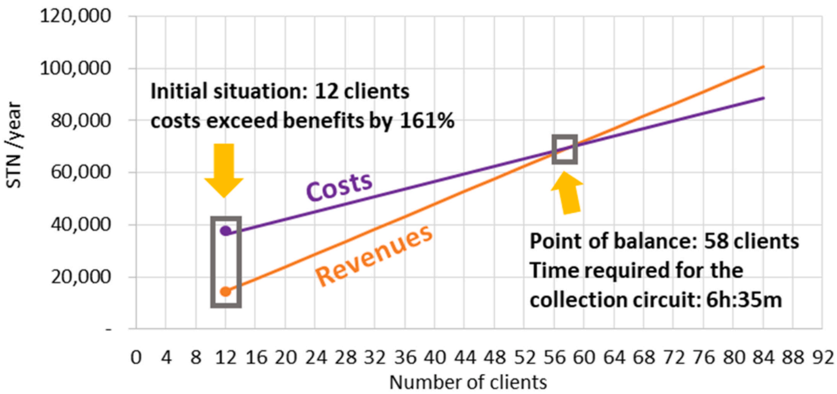

Fig. 12. Costs and revenues for the baseline scenario with varying number of clients for DtD collection.

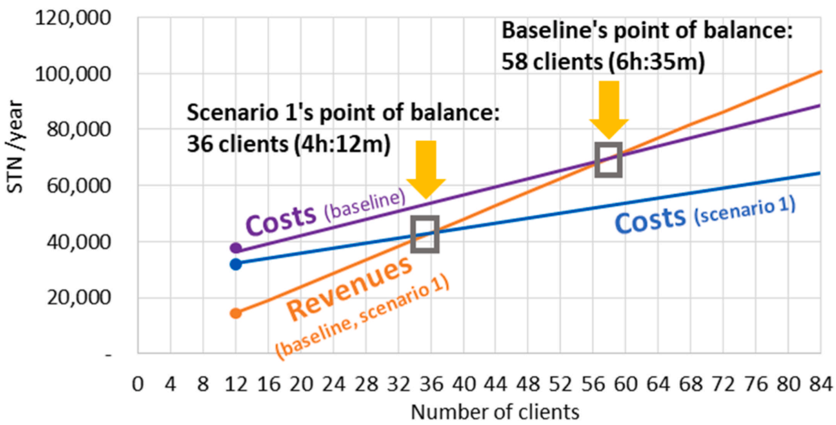

Fig. 13. Costs and revenues for scenario 1 with varying number of clients for DtD collection.

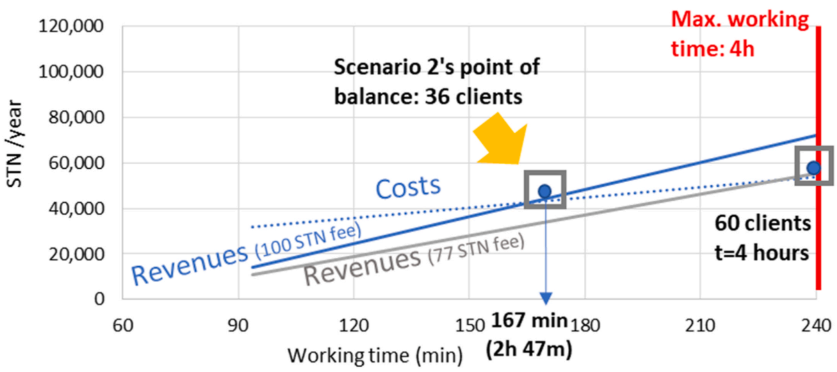

Fig. 14. Costs and revenues for scenario 2 with varying working time for DtD collection.

Finally, a last question is addressed. If a separated collection of the two fractions of MSW – wet and dry –, is adopted in the future, then the collection scheme has to be adapted to the new situation.

Separate collection was introduced into the model by distinguishing both MSW fractions – wet and dry – and distinguishing also waste producers collected on a specific day of the week. Furthermore, the model was adjusted to distinguish 3 types of clients: i) households with separate collection of wet and dry MSW fractions; (ii) households with only dry MSW collection (since they are presumed to manage their biowaste through domestic composting and (iii) commercial establishments with mostly dry MSW (chiefly packaging materials).

A "separate collection" scenario was built in which the improvements introduced in scenarios 1 and 2 are kept, thus maintaining a maximum number of 60 collection points from clients per day. Additionally, the work schedule was increased from 3 to 4 days per week to assign 2 days for the exclusive collection of each of the two fractions, wet and dry. A possible distribution of the new collection scheme is proposed in Table 5.

Collection of wet fraction is only directed to the first group of households, with 2 collection days per week for each household; whereas collection of dry fraction is directed to the three groups plus the street bins, with one collection per week. The numbers are hypothetical, but based on the theoretical maximum daily number of collections, fixed at 60 in Fig. 14. The model approach enables establishing different fees for each specific group of clients, and higher fees were set for commercial establishments than for households, as well as favouring practices such as home composting with lower fees. The fees parametrisation used is shown in Table 6. Once again, the values are hypothetical, but were chosen so that the overall balance between costs and revenues is preserved.

6. Conclusions

The implementation of DtD collection schemes such as the one here analysed has proved to be beneficial for the community: it not only provides an alternative for mitigating littering and open dumping of MSW within the neighbourhood – with the subsequent benefits for public health and for environment, but also contributes to the social progress thanks to the new, cleaner appearance of the neighbourhood which might attract visitors and new economic activities. It constitutes also an empowering achievement for the community, since it demonstrates their ability to collectively cope with a problem which directly affects their quality of life, in the absence of external solutions. This capacity for undertaking autonomous initiatives may well be applied to deal with other relevant issues for the community.

Table 5
Additional specifications for the construction of the "separate collection" scenario.

Customer type	Fraction	Specific weight (kg/m^3)	Weekly collection frequency	No. clients	No. clients (per week day)				
					Mon.	Tue.	Wed.	Thu.	Fri.
Household	Wet	150	2x	60	60			60	
	Dry	50	1x			60			
Composting household	Dry	50	1x	30					30
Commercial	Dry	50	1x	10					10
Street bins	Mostly dry	50	2x	6		6			6

Table 6
Proposal of new values for fees in the "separate collection" scenario.

Customer type	**Waste fraction**	Monthly fee (STN)	No. customers	Yearly costs (STN)	Yearly revenues (STN)
Household	Wet + Dry	50	60	58,896	59,400
Composting Household	Only dry	15	30		
Commercial	Dry	150	10		

The technical and financial assessment and modelling performed in this work has been useful to demonstrate the feasibility of the small-scale DtD collection system proposed by the Boa Morte community. The analysis showed that, even though in the moment of the assessment the scale of the system was still too small to achieve full financial sustainability by itself – understandable, since it was still on a beginning phase and had been running only for some months –, this objective is not an unrealistic goal. It can be achieved in a short term, provided that the simple improvement proposals suggested in the cost model scenarios are introduced in the service, but without changing the current working scheme. In the mid-term, it was demonstrated that the service would be able to implement a separate collection of the two MSW fractions, wet and dry, thus enabling valorisation options such as composting and recycling – and thence, diverting waste from the current dumpsite –, as well as further improving the sustainability by increasing the scale of the system, opening the possibility of professionalization – and subsequent employment creation – by the payment of salaries, instead of the current voluntary collaboration, and also reducing the current fees paid, attracting new clients.

More specifically, the cost model developed allows making similar projections of future costs and revenues for other cases where the model of small-scale collection is intended to be replicated. The costs and revenues structure presented for waste collection in Boa Morte heavily relies on external revenue, namely: the renting of the collection tricycle by the driver for other activities. This apparently unusual arrangement allows better exploiting the tricycle as an asset, during the initial period where the waste collection service still has a too small scale to cover all the expenses. Additionally, it enables the integration of the driver as an active member of the project by sharing the assumed responsibility of taking care of the vehicle, even if for the time being it is still not possible to provide salaries to the whole team. This kind of mutually beneficial agreements between the involved stakeholders might be advantageous for overcoming situations of lack of commitment and motivation which are a constant threat to these systems based on voluntary cooperation.

It is expected that this initiative could be replicated in other communities similar to Boa Morte in São Tomé city or in other cities in developing countries, provided that the local community is able to organise itself in a similar manner to that of Boa Morte. The distribution of population and road network of Boa Morte is comparable with that found in other peripheral neighbourhoods of cities in developing countries, more adequate to the transit of small size vehicles than for conventional waste collection lorries, thus justifying this kind of technological solutions. Nonetheless, a key aspect for the replication of the model proposed is the distance to the final destination of collected MSW, which, as shown in Subsection 3.2.1, in Boa Morte was short enough to compensate for the limited capacity of the vehicle. This advantage would not exist in other localities, making necessary in those cases an articulation between the in-depth proximity collection in neighbourhoods – first level – with a broader, more conventional collection network – second level – based on larger vehicles, capable of efficiently transporting MSW for longer distances. This second level would typically be under responsibility of municipal authorities – or its equivalent – and the articulation between both levels would consist on some kind of transfer stations, an aspect not addressed in this study.

Ultimately, this work demonstrates that it is possible to put in place with a reasonable effort, effective solutions for MSW collection in cities of developing countries, totally based on the locally available means and resources, avoiding (or at least reducing) the dependence on imported equipment and external financial support. The community has been able to identify the challenge to be tackled regarding waste, select and implement an adequate collection strategy to solve it, and in the end, in spite of the observed limitations and difficulties, to manage the collection service by themselves.

Authors statement of contributions

Álvaro Fernández Braña contributed to the conceptualisation of the research goals, was responsible for the field investigation, acquisition of data and subsequent formal analysis of the gathered data, and collaborated in the model developing, writing, editing and review of the manuscript.

Célia Dias Ferreira contributed to the conceptualisation of the research goals, model developing, writing, editing and review of the manuscript.

In Coimbra (Portugal), 12th January 2022.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

ACCP, 2019. Solid Waste Management Data Book 2019. Africa Clean Cities Platform (ACCP), Tokyo.

Afon, A., 2007. An analysis of solid waste generation in a traditional African city: the example of Ogbomoso, Nigeria. Environ. Urbanization 19 (2), 527–537. https://doi.org/10.1177/0956247807082834.

Budihardjo, M.A., Ardiansyah, S.Y., Ramadan, B.S., 2022. Community-driven material recovery facility (CdMRF) for sustainable economic incentives of waste management: evidence from Semarang City, Indonesia. Habitat Int. 119, 102488. https://doi.org/10.1016/j.habitatint.2021.102488.

Colon, M., Fawcett, B., 2006. Community-based household waste management: lessons learnt from EXNORA's 'zero waste management' scheme in two South Indian cities. Habitat Int. 30, 916–931. https://doi.org/10.1016/j.habitatint.2005.04.006.

Hazra, T., Goel, S., 2009. Solid waste management in Kolkata, India: practices and challenges. Waste Manag. 29, 470–478. https://doi.org/10.1016/j.wasman.2008.01.023.

Imam, A., Mohammed, B., Wilson, D.C., Cheeseman, C.R., 2008. Solid waste management in Abuja, Nigeria. Waste Manag. 28, 468–472. https://doi.org/10.1016/j.wasman.2007.01.006.

INE–STP, 2015a. Projeccões demográficas de São Tomé e Príncipe no horizonte 2035. Instituto Nacional de Estatística de São Tomé e Príncipe. São Tomé. (INE–STP) [in Portuguese].

INE–STP, 2015b. IV Recenseamento Geral da População e da Habitação 2012 – Resultados gerais sobre localidades. Instituto Nacional de Estatística de São Tomé e Príncipe. São Tomé. (INE–STP) [in Portuguese].

Kaza, S., Yao, L.C., Bhada-Tata, P., Van Woerden, F., 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series, World Bank, Washington. https://doi.org/10.1596/978-1-4648-1329-0.

Medina, M., 2010. Community-based organics diversion. Biocycle 5 (4), 57–59. https://www.biocycle.net/community-based-organics-diversion-indonesia/. (Accessed 26 October 2022).

MIRNA, 2018. Plano Nacional de Gestão Integrada de Resíduos Sólidos Urbanos (PNGIRSU) 2018-2023. Ministério das Infraestruturas, Recursos Naturais e Ambiente de São Tomé e Príncipe (MIRNA), São Tomé. [in Portuguese].

Mohee, R., Mauthoor, S., Bundhoo, Z.M.A., Somaroo, G., Soobhany, N., Gunasee, S., 2015. Current status of solid waste management in small island developing states: a review. Waste Manag. 43, 539–549. https://doi.org/10.1016/j.wasman.2015.06.012.

Mongkolnchaiarunya, J., 2005. Promoting a community-based solid-waste management initiative in local government: yala municipality, Thailand. Habitat Int. 29 (1), 27–40. https://doi.org/10.1016/S0197-3975(03)00060-2.

Rai, R.K., Bhattarai, D., Neupane, S., 2019. Designing solid waste collection strategy in small municipalities of developing countries using choice experiment. J. Urban Manag. 8, 386–395. https://doi.org/10.1016/j.jum.2018.12.008.

Ribas Alzamora, B., de Vasconcelos Ramos, R.T., 2020. Review of municipal waste management charging methods in different countries. Waste Manag. 115, 47–55. https://doi.org/10.1016/j.wasman.2020.07.020.

Saja, A.M.A., Zimar, A.M.Z., Junaideen, S.M., 2021. Municipal solid waste management practices and challenges in the southeastern coastal cities of Sri Lanka. Sustainability 13, 4556. https://doi.org/10.3390/su13084556.

Salazar-Adams, A., 2021. The efficiency of municipal solid waste collection in Mexico. Waste Manag. 133, 71–79. https://doi.org/10.1016/j.wasman.2021.07.008.

Satibi, I., Sugiono, Turmudzi, D., 2021. Model implementation of community-based waste bank management policy in Bekasi city through mentality, systems, and networking approach. Rev. Int. Geogr. Educ. 11 (6), 835–844. https://doi.org/10.48047/rigeo.11.06.101.

Sekito, T., Prayogo, T.B., Dote, Y., Yoshitake, T., Bagus, I., 2013. Influence of a community-based waste management system on people's behavior and waste reduction. Resour. Conserv. Recycl. 72, 84–90. https://doi.org/10.1016/j.resconrec.2013.01.001.

Tin, A.M., Wise, D.L., Su, W.H., Reutergardh, L., Lee, S.K., 1995. Cost-benefit analysis of the municipal solid waste collection system in Yangon, Myanmar. Resour. Conserv. Recycl. 14, 103–131. https://doi.org/10.1016/S0921-3449(95)80004-2.

UN–HABITAT, 2010. Collection of Municipal Solid Waste in Developing Countries. United Nations Human Settlements Programme (UN–HABITAT), Nairobi. ISBN: 978-92-1-132254-5.

Wynne, A.L., Nieves, P.M., Vulava, V.M., Qirko, H.N., Callahan, T.J., 2018. A community-based approach to solid waste management for riverine and coastal resource sustainability in the Philippines. Ocean Coast Manag. 151, 36–44. https://doi.org/10.1016/j.ocecoaman.2017.10.028.