Journal of
Water, Sanitation & Hygiene for Development

© 2022 The Authors Journal of Water, Sanitation and Hygiene for Development Vol 12 No 3, 318 doi: 10.2166/washdev.2022.218

Research Paper

# A qualitative study on resource barriers facing scaled container-based sanitation service chains

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## ABSTRACT

Container-based sanitation (CBS) is an increasingly recognised form of off-grid sanitation provision appropriate for impoverished urban environments. To ensure a safely managed and sustainable service, a managing organisation must implement a service chain that performs robustly and cost-effectively, even with an expanding customer base. These 'CBS operators' adopt varying approaches to achieve this objective. Following research including interviews with representatives from six current CBS operators, this paper presents a generalised diagrammatic model of a CBS service chain and discusses the three broad thematic challenges currently faced by these organisations. Supplying cover material is a universal problem with hidden challenges when taking advantage of freely available resources. There is no universally applicable approach for the efficient collection of faecal waste despite the high labour costs of waste collection. The best strategy depends on the CBS operator's overall expansion strategy and the location of fixed features within the served community. Although CBS is technically well-suited to being turned into new products within the circular economy, in practice, this requires a diverse range of skills from CBS operators and is hampered by slow growth in other organic waste recovery services and unhelpful regulation.

**Key words:** circular sanitation, off-grid technologies, sanitation, WASH

## HIGHLIGHTS

- CBS is a form of off-grid sanitation provision.
- Interviews are conducted with representatives from six current CBS operators.
- Supplying cover material is a universal problem.
- There is no universally applicable approach for the efficient collection of faecal waste.
- Although CBS has the potential to contribute to the circular economy, this is organisationally challenging.

## 1. INTRODUCTION

Achieving Sustainable Development Goal 6 will require innovation in the management and provision of water, sanitation and hygiene (WASH) services for the world's most deprived citizens (Sadoff *et al.* 2020). Evolution is required in the technologies being used (Guest 2019), in the legislative backing available from policy and governance (Horne 2020) and in the financial structures used when implementing projects (McDonald *et al.* 2021).

One recent technological development has been the expansion of container-based sanitation (CBS) since its inception in the late 2000s (Russel *et al.* 2019). This technology typically involves using sealable containers to temporarily store faeces (often within individual houses), with CBS operator responsible for the collection, transfer and treatment of the waste (Mackinnon *et al.* 2018). Recognised as an improved sanitation facility (JMP 2018), CBS is typically suited to low-income, densely populated urban areas that often have high levels of tenancy and/or ground conditions that prevent the safe use of latrines (Paterson *et al.* 2007). The technology avoids the need for significant upfront financial and spatial investment in fixed off-grid sanitation infrastructure (such as latrines) (Russel *et al.* 2015).

However, to ensure a safely managed system, CBS operators need to establish a viable 'CBS service chain', which typically operates beyond the boundaries of the community being served (Dewhurst *et al.* 2019). There are three distinct operational areas within this service chain. The first area deals with customer relations with CBS users (marketing, toilet installation, explaining servicing, etc.), which are crucial to establishing connections and trust within served communities. The second area covers operations that directly contribute to the provision of the safely managed sanitation service, including the containment and collection of household waste and subsequent transfer for safe disposal. The final area involves the commercialisation of any reuse product. In practice, different CBS providers will adopt different elements within their service chain.

It follows that as a CBS operation scales up, the constituent elements of this service chain must evolve accordingly (Rao *et al.* 2017). The characteristics of any given CBS service chain remain dependent on the context in which they are being conducted. Gaining an understanding of the collective challenges faced by CBS operators, therefore, requires a comparison of the experience of multiple organisations. This paper presents an informed evaluation of current pressures faced by multiple CBS organisations in managing their operational and reuse service chains, with the aim of offering a wider assessment of the barriers to further expanding these approaches.

## 2. METHODS

The nascent state of the technology means that the target population for this research remains small – the primary global coalition of CBS practitioners is the Container-based Sanitation Alliance (CBSA), which currently has seven practising members (CBSA 2021). This research includes an evaluation of five of these organisations. An additional sixth organisation is considered to be the largest CBS operator in the world (though it is not a member of the CBSA). Table 1 gives a full list of the organisations considered as part of this research.

This paper principally draws on qualitative information gleaned from semi-structured interviews conducted with representatives of each CBS operator. The interviewees were identified through discussion with each organisation to find appropriate staff members with knowledge across operational and any resource recovery procedures.

**Table 1** | Key characteristics of the CBS operators considered in this study (as of July 2021)

| Organisation | Primary location (*inception*) | Organisation type | Approximate customer base[a] | Service type | Primary cover material | Reuse product | Monthly user cost |
|---|---|---|---|---|---|---|---|
| Fresh Life/ Sanergy | Nairobi, Kenya (*2010*) | Non-profit/ social enterprise | 3,500 toilets | Household/ community | Sawdust | Compost, briquettes, BSF larvae | $8.50 |
| Sanima (formerly x-Runner) | Lima, Peru (*2012*) | Social enterprise | 900 households | Household | Sawdust | NA *(formerly compost)* | 39 soles ~$9.50 |
| SOIL | Cap Haïtien, Haiti (*2011*) | Non-profit | 1,500 households | Household | Bagasse | Compost | 250 gourdes ~$2.50 |
| COCT | Cape Town, South Africa (*2010*) | Municipality | 20,000 toilets | Household/ community | Water-based | NA | Free |
| Clean Team | Kumasi, Ghana (*2012*) | Social enterprise | 3,600 households | Household | Sawdust | NA *(composted waste landfilled)* | 43 cedis (+6 cedis for extra cartridge) ~$7.14 |
| Sanitation First | Pondicherry, India (*2014*) | Charity | 50 toilets | Community | Ash | Compost | Free |

[a]Metrics are dependent on the structure of the CBS service provided.

Five of the interviews were conducted between May and July 2021, with interviews conducted over Zoom calls, each lasting approximately an hour. The questions are included as Supplementary Material. All interviewees were advised of the voluntary nature of the study and informed consent was obtained from each. This research was approved by the Cranfield University Research Ethics Board (reference no. CURES/13560/2021). An interview with a City of Cape Town (COCT) representative occurred separately in November 2020, with four additional interviews conducted between June and August 2021. For this, approval was obtained from the University of the Western Cape Ethics Committee (reference no. HS/20/8/1).

A semi-structured interview approach was preferred as it gave sufficient structure to cover the various elements of the operational CBS service chain, while still allowing greater detail and exploration of other elements beyond any preconceived ideas of the interviewer. The interviews covered topics such as the provision of cover material, waste collection techniques, land rental and the treatment or reuse of faecal waste.

Having been recorded and transcribed, the content of the interviews was then read carefully and an inductive approach taken to draw out cross-cutting themes (Graneheim *et al.* 2017). It is recognised that this research relies on a relatively small number of interviews. However, there is a precedent for such approaches in WASH research (Takala 2017) and the participating organisations make up a significant proportion of current CBS operators globally.

## 3. RESULTS

From the interviews, three themes emerged across different contexts. These were as follows: (i) the challenges surrounding cover material; (ii) the differing strategies employed in navigating neighbourhoods and cities and (iii) the feasibility of building a sustainable 'circular economy' model.

These themes will be considered in detail. However, they must all be understood within the context of some important differences in the underlying goals and organisational models of the different CBS providers listed in Table 1. SOIL, Sanima, Clean Team and Sanergy are all forms of social enterprise, looking to demonstrate the economic viability of their services at scale and thereby potentially attracting public funding or private investment. Social enterprises, an increasingly prevalent model for off-grid sanitation provision, use entrepreneurial behaviour to produce goods and services with the purpose of tackling social challenges and serving the communities within which they operates (Gero *et al.* 2014). Sanitation First is a charity providing CBS service to the most marginalised communities around Pondicherry, a union territory in India, and, in fact, is now scaling back its operations. Finally, the COCT is a municipality providing a CBS service to residents only when there is no other viable form of sanitation available. These different objectives influence each organisation's attitude to supplying and expanding its service chain.

Each of the identified themes will now be discussed in turn.

### 3.1. Sustainable sourcing of cover material

In urine-diverting CBS, the primary role of cover material is to mitigate odour, prevent vector transmission, create a visual barrier and enhance the drying of the faeces. Individual CBS users typically add cover material to the container after each toilet use (Moya *et al.* 2019a). The continued availability of suitable cover material is a key component for a CBS service to grow sustainably (Dewhurst *et al.* 2019).

Half of the organisations listed in Table 1 provide cover material as part of their service. Sanima and Clean Team supply their customers with sawdust, while SOIL provides sugarcane bagasse. All three organisations provide 3 kg of cover material/toilet/week. The choice of cover material is dictated by both (i) material characteristics and (ii) local context for each CBS organisation. For instance, SOIL's bagasse has a pleasant smell (which is helpful for combatting odours), is generally popular with its customers and decomposes alongside faeces in the later composting stage (*SOIL interview*). In addition to these material properties, the bagasse is sourced as a freely available by-product from a rum distillery neighbouring its headquarters (minimising collection costs) (*SOIL interview*). This advantageous local context is comparable to that of Clean Team, that obtains over 7 tonnes of free sawdust each week from Kumasi's 'wood village' (though it does pay for collection costs) (*Clean Team interview*). As well as being inert and finely granular, sawdust, which is a lightweight material, is key to maintaining efficiency in transport operations (see later Discussion) and makes it more attractive than alternatives such as neem leaves (*Clean Team interview*).

Some organisations are not so fortunate in terms of local context. Sanima also provides its customers with sawdust for cover material (and has done so since its inception). However, the high cost of sawdust in Lima, along with the subsequent storage costs, means sourcing cover material accounts for over 35% of Sanima's operational expenditure and makes it a key operational challenge (*Sanima interview*). To mitigate this vulnerability to costs, in 2018, the organisation moved towards using a single sawdust supplier. The economy surrounding sawdust in Lima can be highly informal and having multiple suppliers created difficulties in tracking costs, uncertainty in delivery timings and challenges in establishing traceability (i.e. avoiding sourcing from illegal deforestation) (*Sanima interview*).

It should be noted that SOIL and Clean Team (who have been able to take advantage of local context) have also faced challenges with providing cover material. Clean Team tries to ensure that the sawdust is as dry as possible, by not collecting it immediately after rain events. There are two reasons for this: (i) to minimise microbial growth during storage and usage and (ii) to mitigate the significant weight gain and its consequent effect on the efficiency of collection vehicles (*Clean Team interview*). Meanwhile, there are several reasons why SOIL considers the sustainable provision of cover material as one of its most critical future challenges. First, its bagasse comes from the only nearby distillery with the technical capacity to squeeze sufficient juice out of the cane such that it only requires sieving before being transferred to customers as cover material (*SOIL interview*). Imminent growth beyond the current provision would necessitate sourcing bagasse from smaller distilleries that are not able to grind the cane sufficiently and, therefore, would require a more expensive secondary grinding process (*SOIL interview*). Additionally, investigations to find alternatives (which have included evaluating sorghum, corn, banana leaf, coffee grinds and peanut shells) have been frustrated by (i) unsuitable material properties (e.g. weight, poor composting characteristics, etc.), (ii) insufficient supply and/or (iii) customer resistance. Interestingly, customers tend to dislike darker materials such as ash or compost, partly from having fears about the cover material containing faeces (*SOIL interview*). However, with the unstable situation in Haiti in late 2021, SOIL has been able to use its own compost as a cover material when fuel shortages forced its primary bagasse supplier to cease operations.

While Clean Team's demand for sawdust is met by the wood village, there are concerns that demand might outstrip supply within the next 5 years. Clean Team has evaluated alternatives (historically, it has also trialled non-organic additives (Parker *et al.* 2015)), but similar issues with material properties have arisen. Ash, derived from sawdust, is seen as a potential alternative (but is yet to undergo widescale trials) (*Clean Team interview*).

In a broader sense, the experiences of Clean Team and SOIL provide an interesting demonstration that taking advantage of local context can create issues for CBS operators. Firstly, it makes it more difficult to demonstrate to potential investors the viability of the model at scale. Secondly, there can be a risk of gravitating towards an 'optimum' size of customer base (i.e. one that fits within the resource restraints in the local context) rather than having continued growth. However, Sanima used a similar situation to its advantage when undergoing significant organisational restructuring in 2018. The organisation spent 2 years without actively growing its customer base (of approximately 700 CBS units), instead focusing on how to improve efficiencies in its sanitation service (*Sanima interview*).

A part of this streamlining at Samina involved evaluating the possibility of eliminating cover material through a pilot programme investigating fitting CBS units with electric fans (*Sanima interview*). These fans would be powered by users' domestic electricity (this has only been deemed possible with the increased electrification of Pamplona Alta in recent years), and the pilot aims to finish in Autumn 2021 (*Sanima interview*). This demonstrates the potential for technology advancement to be used to circumnavigate issues of local market conditions. Additionally, Sanima has also highlighted the user's desire to have the CBS experience mirror that of a full-flushing toilet and believes that removing sawdust will help with this.

Interestingly, there are other operators who have tackled the issue of providing cover material by putting the responsibility on the CBS user. For instance, Sanitation First's model typically relies on cover material being supplied from the ash of users' cooking fires (although this model is not uniform – some users are supplied with ash or rice husks) (*Sanitation First interview*). Interestingly, Sanitation First believes that its community toilet model (see Table 1) results in a higher usage of cover material per capita as customers will use it both before and after using the toilet (for hygiene concerns) (*Sanitation First interview*).

Similarly, while Sanergy also predominantly uses sawdust as the cover material, it requires customers to supply their own material (*Sanergy interview*). This sawdust is typically bought from local vendors, who source it from sawmills outside Nairobi (*Sanergy interview*). Sanergy feels that this has benefits for its customers, allowing lower prices and making it easier to obtain during times of shortage (*Sanergy interview*). These periods have occurred, for instance when in 2018, the government implemented a ban on logging and timber harvesting (Sola & Cerutti 2021). To enforce the appropriate use of sawdust, Sanergy provides each toilet with a standard measure scoop and also threatens closure of CBS toilets for non-compliance (*Sanergy interview*).

Another example of users having responsibility is in Cape Town, where the domestic CBS system does not use cover material. Instead, it relies on two connected water containers to maintain the hygiene of each unit (or portable flush toilet, PFT). A top container (volume approximately 10–12 l) is filled by the user. When the PFT is used, a small proportion of this water fills the toilet bowl, before being 'flushed' with the waste into the lower collection container. However, within served neighbourhoods, residents typically obtain their water from community standpipes. The water required for this system creates an additional collection burden for users, raising concerns about (i) promoting illegal in-house connections from municipal supply lines and (ii) insufficient water being used to maintain cleanliness levels of the toilets.

### 3.2. Efficient collection of waste

A key area that CBS providers look for efficiency is in the different strategies used to navigate neighbourhoods and cities efficiently. This is partly because of concerns around the labour requirement needed for collection and transfer of waste (Tilmans *et al.* 2015). There are interesting comparisons to be drawn when comparing the approaches of the six organisations listed in Table 1.

Three of the organisations visit individual households to collect waste from CBS units. SOIL does this primarily by collectors driving converted three-wheeled motorcycles, of which they have three operations at any one time (each with a capacity of just over 80 containers) (*SOIL interview*). On a collection trip, these vehicles can serve 40–50 households (with a maximum load of 81 containers). Each vehicle can make two collection trips each day and each customer is visited once a week. Depending on the collection location, the waste is transferred to either (i) SOIL's headquarters in Tilmari district or (ii) their waste treatment site in the satellite town of Limonade. The waste at the Tilmari office is routinely transferred on a flatbed truck (with a capacity of 500 units) to the treatment centre. SOIL highlights traffic and road quality as key inhibitors to the efficiency of its collection process (*SOIL interview*).

This is similar to Clean Team's approach, which has a fleet of vehicles consisting of approximately 16 vehicles, a 10-tonne truck and over 35 converted tricycles (each of which can take 60 containers) (*Clean Team interview*). The organisation visits each household twice a week to collect waste. Where Clean Team differs is its geographic scale over which it operates, serving customers up to an approximate 28- km radius around Kumasi (*Clean Team interview*). This involves serving many disparate 'clusters' of communities, with the organisation consolidating waste by transferring it between increasingly larger vehicles as they transport it to its composting site in the Doampase area (*Clean Team interview*).

Sanergy runs a collection strategy that has largely been based on employee-operated handcarts transferring waste from individual households to 'neighbourhood collection centres' (*Sanergy interview*). These collection centres are served by a manhole, connected to the government sewer system, where urine is disposed of, whereas faecal waste is collated into barrels before its transfer by a 7-tonne truck to Sanergy's treatment site (*Sanergy interview*). Each collection centre serves approximately 300 households (although this does vary significantly), though trucks can carry waste from up to 700 households (but often such trucks are also filled by other forms of waste – see later Discussion on circular sanitation models) (*Sanergy interview*).

All three organisations providing a household service (Sanergy, SOIL and Clean Team) are looking to increase their customer base, each with varying philosophies.

Although waste collection is currently Sanergy's largest cost (approximately 70% of which are labour costs), the organisation feels that this is a robust collection model for scaling up (*Sanergy interview*). The organisation has a clear philosophy of scaling by 'building density' within its customer base (i.e. gathering additional customers in areas already being served), to ensure labour costs become more efficient with time. Its collection centres offer a robust customer-facing operation (i.e. not easily disrupted by traffic or mechanical breakdown) and also allow city-wide operations (i.e. movement of trucks) to happen during the night when traffic is at its lowest, thereby increasing efficiencies (*Sanergy interview*). There have been certain issues surrounding the leasing of land for collection centres within served neighbourhoods (with community concerns over smell and hygiene); therefore, this requires careful liaison with the local community (*Sanergy interview*). Finally, there have also been recent efforts to completely mechanise the process by replacing the carts with agricultural vehicles, with the ambition to have completed this by early 2022 (*Sanergy interview*).

Despite looking to grow in similarly sized cities (3–5 million inhabitants) and having comparable customer bases (see Table 1), Clean Team's 'clustering' approach differs significantly from that of Sanergy. While Sanergy relies more on land rental (i.e. neighbourhood collection centres), Clean Team continues to utilise its larger fleet of collection vehicles (and have increasingly complex routing operations) (*Clean Team interview*). Interestingly though, Clean Team is beginning to consider alternative models for its most distant customers (as household service is deemed unfeasible with significant further geographic scaling). One consideration is adopting a 'drop and swap' system (referred to as a 'cartridge vending system') (*Clean Team interview*).

SOIL is also considering evolving its collection philosophy, moving closer towards the approach being used by Clean Team. It has started running tests with a large truck (with a capacity of 500 containers) acting as a 'mobile collection centre' with satellite collection vehicles (i.e. their converted three-wheelers) visiting individual households (thereby requiring fewer return trips along the main traffic artery) (*SOIL interview*). Indeed, with the recent instability in Haiti, SOIL has also found fuel accessibility emerge as a key operational challenge. To mitigate this problem, the organisation has been restricted to covering only essential collection and treatment operations and has been increasingly reliant on the use of these mobile collection centres.

The other three CBS organisations do not operate a household collection strategy. Instead, Sanima currently serves Pamplona Alta with converted tuk-tuks employing a 'transfer station approach'. This requires its customers to carry their waste to preagreed 'transfer stations', which in Sanima's case are typically just parking areas alongside the road network. On an agreed timetable, the collection vehicles (which can each serve approximately 50 customers) meet CBS users at a series of these locations along their route, collecting waste and handing out cover material (*Sanima interview*). Each user is typically served twice a week. Each vehicle makes up to three rounds, usually between 6 am and 9 am. The routes are based out of a depot within Pamplona Alta, where waste is accumulated before a subcontractor removes it to be treated by the municipality (*Sanima interview*). Interestingly, Sanima does not consider traffic a significant hindrance to its operations, as its vehicles operate completely within the served neighbourhood and avoid any major highways. However, the area is spread over a steep-sided valley and access up steep dirt roads can be difficult, particularly with full loads. Furthermore, narrow roads mean that getting past oncoming vehicles can create delays (*Sanima interview*). In scaling up, Sanima has identified two issues with its current model. First, there has been a broader concern about the health and service implications of users carrying their own waste (Bischel *et al.* 2019) – users carry approximately 6 kg of waste to meet the collection vehicle. Secondly, the model does not lend itself to incremental growth – adding customers to collection routes requires constant timetable alterations (which is disruptive for both collectors and users). The model worked very well with a constant customer base, but now the organisation is looking to scale and the model may need to evolve (*Sanima interview*).

By contrast, in Cape Town, the service is provided by two contractors (serving roughly equal geographic areas) and the customer base is so large that the service model depends on the neighbourhood being served. However, in the main, users carry filled waste containers to the nearest access road where large trucks provide a kerbside pick-up service. A local community worker is paid by the CBS contractors to inform a particular neighbourhood of collection (and assist in carrying filled containers) (*Cape Town interview*). The containers are then taken to Bocherds Quarry wastewater treatment works where they are emptied and cleaned before being returned to the users (users have two containers; so theoretically are never without a container). While appropriate for the much larger operation in Cape Town, the contractor model has also created difficulties for the COCT (the provider) in implementing quality control over the experience of CBS users around the city. For instance, served neighbourhoods are supposed to have 13 collection days each month, but in interviews with users in an informal settlement, this has been contested, with statements describing the service as unreliable and unpredictable.

Sanitation First's service is much smaller, but the use of households sharing CBS units means that only a single van is needed to collect boxes of waste. There are a team of five people who cover customer relations, waste collection and toilet maintenance. The collection of waste boxes can be logistically challenging, as the organisation's customers are in the most ostracised communities with poor road access.

In comparing all six organisations, several common factors emerge. The first is that the relative scale of a service can influence which collection model is most effective. The second is that the available efficiencies in any given collection model are heavily regulated by the geographic spread of the customer base and a fixed infrastructure needed to support the service chain. The organisations here have widely differing experiences in this regard. For instance, in Cape Town, the municipal treatment site sits beside the city's main airport and is centrally located. Similarly, Clean Team's composting site is within Kumasi's southern district of Agogo. By comparison, Sanergy's facility is within an area zoned by the city's municipality for waste treatment and disposal, which is a journey of over 35 km from Nairobi city centre, thereby increasing fuel and transportation costs. Alongside this, the six case studies suggest that labour efficiencies are difficult to find in a CBS collection operation as it scales up. It is also noted, however, that this is not an inherently bad phenomenon – particularly given the often-low rates of employment in the served communities (as has been seen in other sanitation contexts (Hubbard *et al.*

2014; Uddin *et al.* 2019)). A community-based labour force can engender positive sentiments towards the service and increase adoption. Given the low cost of CBS capital expenditure, high operation expenditures on labour can be an effective method of keeping money circulating in these communities.

### 3.3. On the application of 'circular' sanitation models for CBS

Since its inception, the CBS service chain has been seen as amenable to the development of 'circular economy' models (Saul & Gebauer 2018; McNicol *et al.* 2020). There has been discussion around the benefits and potential barriers to such models in faecal sludge management (FSM) generally (referred to here as 'circular sanitation') (Odey *et al.* 2017; Mallory *et al.* 2020) as well as CBS organisations more specifically (Moya *et al.* 2019b). With appropriate treatment, the collected faecal waste can have value to the CBS operator. In practice, different organisations have had varied successes in harnessing such value.

From the list given in Table 1, only one organisation directly manages across the entirety of a circular sanitation model at scale. This organisation is SOIL, which typically produces agricultural compost from the waste it collects. It is interesting to note that, by retaining these operations 'in-house', it has been more resilient to external shortages of its traditional cover material (by replacing it with its own compost). Traditionally, the composting process takes approximately 6 months, with no co-composting materials or additives used (i.e. only faecal waste and bagasse) (*SOIL interview*). After composting, each batch is tested for *Escherichia coli*, pH and conductivity (with an annual sample test in the USA to establish nutrient content) before being sold to local customers (farmers, nurseries, reforestation projects, etc.) in ∼10–20 kg bags (*SOIL interview*).

Sanitation First also operates a circular sanitation model (at a much smaller scale), selling composted waste to local agricultural industries. However, it is clearly challenging for a small- or medium-sized CBS operator to have sufficient breadth of management and technical expertise both to manage a sustainable CBS service and to commercialise the disposal of the compost to maximum financial effect. Indeed, at one point, SOIL considered producing compost mostly to be used as a supplementary cover material. However, recently it has placed increased emphasis on compost sales and hired a dedicated salesperson.

Sanergy has adopted a novel approach to tackling this issue by adopting a 'split' operational structure. On the one side, there is a non-profit organisation called 'FreshLife' that operates the customer-facing CBS collection within the served neighbourhoods (*Sanergy interview*). On the other is 'Sanergy', whose purview technically now covers only extracting value from organic waste with the aim of creating profit. As such, Sanergy collects organic waste from market and hotels alongside the CBS faecal waste at neighbourhood collection centres (which has earlier been collected by operatives of 'FreshLife') (*Sanergy interview*). The 'split' operational structure has also enabled Sanergy to diversify its reuse products – alongside putting waste through a black soldier fly (BSF) process, it has been producing briquettes that have been used to run internal company furnaces (though these need much higher sawdust content to achieve the necessary calorific value) (*Sanergy interview*). Finally, the model has allowed Sanergy to build a much larger commercial operation, selling its compost in over 12 of Kenya's 47 counties, mostly through intermediaries (agricultural stores, farm shops, etc.) and supported by its own sales associates (*Sanergy interview*). The high nutrient content allows significant mark-up, with sales in higher-value agricultural markets (e.g. flowers and horticulture) continuing to increase.

Clean Team also composts its waste after collection but puts the output straight into landfill (in Oti landfill). However, this is in the context of 45% of all faecal waste going untreated in Kumasi (Mikhael *et al.* 2017). In Cape Town, waste is deposited into traditional waste streams for treatment, and there is no real appetite for recouping revenue through composting or other techniques.

Another observation is that while composting is a simple process, the process creates both technical and market challenges for CBS operators. From a technical viewpoint, composting takes time and, therefore, becomes a space-intensive process. For instance, even before putting its waste to landfill, Clean Team composts its waste for up to 8 months (*Clean Team interview*). Sanergy initially puts its waste through a BSF process, which takes roughly a week to complete but reduces the required composting time from 8–9 to 3–4 months (*Sanergy interview*). For SOIL, composting traditionally has taken 6 months, although it is currently testing increased aeration of compost (i.e. encouraging aerobic digestion), and the results suggest that this period can be reduced to approximately 10 weeks (*SOIL interview*). Interestingly, it is also looking at developing a BSF process – the flies are endemic in Haiti, but establishing a captive colony has proved challenging. However, early trials are ongoing and the organisation hopes to have a stable colony by early 2022, with the aim of selling dried larvae to poultry farmers (*SOIL* interview). Interestingly, SOIL has managed to steadily reduce the proportion of total expenditure spent on treatment and waste transformation processes as it has grown – from nearly half in 2016 (Remington *et al.* 2017) to under a third in 2021 (*SOIL interview*).

Market issues relating to compost result from both (i) the resultant quality of the compost and (ii) regulatory restrictions. This is exemplified by Sanima's experience, which stopped composting its waste (which it had sold to small agriculture around Lima) in 2018. The compost was difficult to sell because of both low nutrient content and regulation governing its use (*Sanima interview*). Furthermore, Sanima underwent restructuring in 2018 with the purpose of cutting costs, realigning to core goals and in-house technical expertise (i.e. running their service in Pamplona Alta) and pivoting away from composting. As of mid-2021, Sanima employs a contractor who regularly removes the consolidated waste using a tanker and takes it for treatment by the municipality in conventional waste streams (*Sanima interview*).

There has been wide discussion in the literature on the economics and perceptions of selling compost derived from human compost and the difficulties posed by regulation (Diener *et al.* 2014; Moya *et al.* 2019a; Simha *et al.* 2021). Sanergy is a good example of this, with the compost it produces limited to application for less-lucrative domestic crops (as permits for international crops remain bureaucratically opaque and expensive) (*Sanergy interview*). Another example of policy impacting CBS reuse operations is given by Sanitation First, which, despite producing a compost with high nutrient content, has been unable to charge a premium (charging only 10 rupees/kg), because the market is saturated by the local government offering subsidies on compost obtained from municipal organic waste (*Sanitation First interview*). This makes income from compost negligible, covering only minor expenses such as the purchasing of ash or neem cakes (*Sanitation First interview*).

## 4. DISCUSSION

There has been limited academic discussion to date on the feasibility of scaling CBS. Russel *et al.* (2019) is the exception, providing a review of the broader opportunities and challenges to scaling the technology. This paper's holistic scope goes beyond the CBS operational service chain, but it similarly highlights the need for clarity over regulation, the possibilities of mechanised and digitised logistical operations (e.g. collection strategies) and the difficulties that social enterprises face in building sustainable economic models around CBS. Figure 1 contains a diagram depicting the generalised CBS service chain based on the discussions with the six providers. The three broad areas of operation (that agree with reporting elsewhere (Mackinnon *et al.* 2018)) cover the following: (i) relationships with the community, (ii) operations directly contributing to the

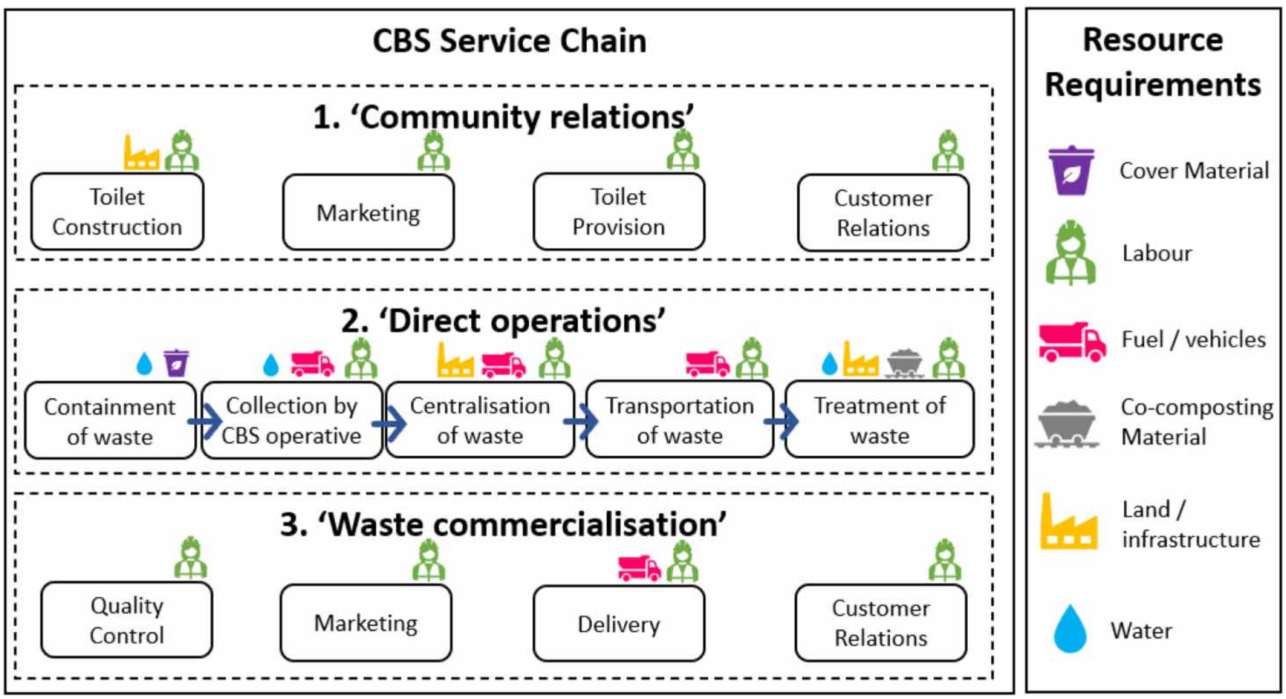


**Figure 1** | Generalised CBS service chain with potential resource inputs (identified from semi-structured interviews).

safely managed service and (iii) generation of revenue from treated faecal waste. The figure demonstrates how a widely skilled labour force is needed to operate across these domains, while requirements for other resources (e.g. water, land and fuel) are dependent on the structure of operations. Different CBS operators will use different components of Figure 1, depending on the structure of their service. Nonetheless, in comparing the experiences of the organisations considered here, several broader discussion points emerge.

Firstly, the upscaling of CBS operations is intrinsically linked to the nature of the provider, obfuscating any universal 'viable scale' (as this means different things to different entities and stakeholders). The issues around the efficiencies of scaling up on transport strategies are discussed in detail in Ferguson *et al.* (2021). The growing social enterprises detailed in this study use business models relying predominantly on either (i) subscription-based approaches and/or (ii) 'impact investors' (who can accept low financial return for high social impact).

Issues around payment for sanitation services (Whittington *et al.* 2012; Sinharoy *et al.* 2019) and the need for subsidisation (Dos Santos *et al.* 2017) have been discussed elsewhere. However, scaled CBS offers a mechanism with which to provide widespread, safely managed sanitation to our most impoverished communities, and consequently, the technological providers employing subscription-based models must balance the building of a sustainable financial model around users' 'willingness to pay' against a moral obligation of providing a fundamental human right. There is need for greater research and discussion on the practicality of these questions.

On the other hand, relying on impact investors can leave a sanitation provider vulnerable to funding shortfalls. Moreover, structuring a CBS provider to rely on such funding can make it harder to demonstrate sustainable economic models for attracting public funding (which is often seen as a necessary mechanism to achieve scale) (Russel *et al.* 2019). This is demonstrated by Sanima's recent restructuring exercise, which was partly done to demonstrate that its financial model was sustainable without donor funding. The CoCT has shown that large-scale CBS can be incorporated into a publicly funded, multi-sanitation provision strategy. However, the efficacy of incorporating CBS into a city-wide inclusive sanitation (CWIS) model of sanitation delivery (administered by municipal or local governments) remains an area for further study.

The second theme to emerge is the role of reusing and commercialising faecal waste within the CBS service chain. There would appear to be an inherent duality to the CBS concept. On the one side, there is providing safely managed sanitation to impoverished communities. On the other is the attraction of a viable circular sanitation model. Across multiple contexts, nascent CBS operations have found that the necessary breadth in technological expertise needed to realise both ambitions is difficult to achieve. Alongside this, it is recognised that the revenue recouped from any reuse of faecal waste is a fraction of the costs of running a CBS service chain (Mallory *et al.* 2020), and any environmental benefit, created through reducing reliance on inorganic fertilisers, remains under-recognised. This often results in CBS operators pivoting away from their reuse operations, instead focusing on prioritising efficiencies within the 'customer-facing' elements of their service. In many cases, viable 'circular sanitation' CBS models will require growth in aligned industrial sectors such as organic waste recovery (this follows earlier observations by McCusker (2020)), as well as greater clarity over regulation governing compost derived from human faeces. Further research is needed on operational interactions between actors in CBS service chains and the identification of potential strategies to combat resource scarcity.

It is worth stressing that, while challenges remain, CBS presents one of the most promising methods of economically delivering safely managed sanitation in low-income urban communities (Coates & Gray 2020). In fact, it could be argued that the challenges facing the technology stem from historic gravitation towards social enterprise models, which created unreasonable expectations for CBS to produce commercialised organic compost and then operate for profit when no other comparable sanitation technology service has achieved this.

## 5. CONCLUSIONS

CBS organisations face a variety of challenges in scaling their operations at different stages of growth, many of which are context-specific. Nevertheless, in contrasting different approaches, broader themes emerge to offer interesting conclusions on CBS organisations' ability to scale. Almost all parts of the CBS service chain are labour-intensive, with a wide variety of skills needed by that labour force. There are other resources needed as well, including waster, land and fuelled vehicles, although these vary depending on the exact structure of the operations. Supplying cover material is an almost universal resource challenge that requires overcoming economic, technical and social barriers. Taking advantage of freely available resources can lead to CBS operators facing vulnerabilities when expanding beyond their immediate capacity. Certain growing organisations have attempted to circumnavigate these issues by instead placing greater responsibility on their customers to source material and highlighting how this reduces the subscription fee for their service (although this can have unintended consequences such as an additional burden on vulnerable household members). Other organisations have built their service in such a way that they rely on users' familiarity with CBS enabling the adoption of other, more cost-efficient, options (although this can backfire if customers continue to be reluctant to change).

## ACKNOWLEDGEMENTS

The authors would like to particularly thank the representatives of the participating organisations (SOIL, Sanergy, Sanitation First, Clean Team and x-Runner/Sanima/City of Cape Town). The research was funded by the ESRC, grant ref: ES/T007877/1.

## DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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First received 1 December 2021; accepted in revised form 7 February 2022. Available online 22 February 2022