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Life-cycle costs of a resource-oriented sanitation system and implications for advancing a circular economy approach to sanitation

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Abstract

Implementing a circular economy approach to sanitation requires knowledge of the costs to construct, operate and maintain resource-oriented systems. Yet the dearth of data on costs of urban sanitation in general, and resource-oriented systems in particular, limit opportunities to progress sustainable sanitation in low- and middle-income countries. This paper contributes empirical data on the life-cycle costs of a resource-oriented sanitation system in urban Sri Lanka, addressing a gap in evidence about how much it costs, and who pays, for a system that integrates fecal sludge management with nutrient capture and reuse. Costs across the system life-cycle were analyzed according to: (i) cost type; (ii) phases of the sanitation chain; and (iii) distribution between actors. Over a 25-year lifespan, the system had an annualized cost of USD 2.8/person or USD 11/m^3 of septage treated. Revenue from co-compost sales covered reuse-related costs plus 8% of present value costs for other phases of the sanitation chain. Findings affirm both the potential for resource-oriented sanitation to generate revenue, and the need for substantial complementary investment in the overall system. The system was found to be reliant on household investment, yet financially viable from the service provider perspective with revenue from desludging services (89%) and co-compost sales (11%) that exceeded costs over the system lifespan and in most years. The analysis of total costs, financial perspectives, and reuse specifics contributes critical evidence to inform policy and planning that supports a purposeful and equitable transition towards circular economy approaches to sanitation.

Keywords: sanitation; resource-oriented sanitation; circular economy; life-cycle costing; fecal sludge management; resource recovery

1 Introduction

There is a growing body of research and practical experience exploring opportunities for beneficial reuse of human excreta. Sanitation approaches that incorporate reuse are variously framed as resource-oriented sanitation (Hashemi et al., 2018) (the term adopted in this study), regenerative sanitation (Koottatep et al., 2019), sustainable sanitation (Andersson et al., 2016), resource recovery and reuse (Rao et al., 2017) and ecological sanitation (Simha and Ganesapillai, 2017). The benefits of sanitation-related reuse are cross-sectoral and far reaching, including partially offsetting treatment costs, providing alternatives to expensive or non-local inputs (such as synthetic fertilizers) and improving access to resources for constrained populations (Trimmer et al., 2020). End products can be used as soil conditioner or fertilizer in agriculture, fuel for combustion, generation of energy through biogas, animal feed, or in building materials (Diener et al., 2014). With a focus on low- and middle-income countries where sanitation systems are rapidly developing, 'reuse over disposal' has been identified as a theme of recent environmental science literature (Hyun et al., 2019).

Increasingly, sanitation systems incorporating reuse are being positioned within the circular economy discourse (Danso et al., 2017; Mallory et al., 2020a; Moya et al., 2019; Schroeder et al., 2019; Sgroi et al., 2018). However, reflecting divergence in circular economy conceptions generally (Kirchherr et al., 2017; Merli et al., 2018), the relevance of circular economy concepts to sanitation has yet to be comprehensively defined and interrogated beyond a central reference to resource-oriented systems that facilitate beneficial reuse of human waste. Within literature focused on sanitation in low- and middle-income countries, circular economy debates are dominantly concerned with business models (Otoo et al., 2018), with a particular focus on the potential (or not) for revenue generation, cost recovery and incentivizing investment (Danso et al., 2017; Diener et al., 2014; Mallory et al., 2020b; Rao et al., 2017). This business model orientation is consistent with wider circular economy literature, which tends to emphasize economic aims and be less concerned with the reality that realizing a circular economy requires holistic systemic change to achieve its central aim of sustainable development (Kirchherr et al., 2017).

Nevertheless, the potential for circular economy approaches to sanitation to address both human and environmental concerns and achieve sustainable development has been recognized by the international community. Sustainable Development Goal (SDG) target 6.3 is to improve water quality by 2030, including through "halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally" (United Nations, 2015). In tandem with SDG target 6.2 – achieving sanitation and hygiene for all – these widely accepted normative directions demand that the global sanitation sector focuses on solutions that facilitate safe reuse. The relevance of circular economy concepts to this aim has been affirmed in a review identifying a strong relationship between circular economy practices and SDG 6 targets (Schroeder et al., 2019).

Prioritizing safe reuse in sanitation requires redressing a tendency for resource-oriented systems to be pilot or niche in nature, lauded through rhetoric but lacking integration within larger systems and markets (Carrard and Willetts, 2017; Schrecongost et al., 2020). There is a need for further research about, and implementation of, resource-oriented systems at city or whole-of-community scales. Implementing such systems at scale demands a shift of perspective away from 'whether' resource-oriented systems can achieve cost recovery or incentivize investment – as is reflected in literature linking circular economy ideas with sanitation to date (Mallory et al., 2020a) – towards 'how' we can properly finance and manage systems where reuse is the requisite end-point of the sanitation chain.

To normalize a resource-orientation in the planning and delivery of sanitation services, it is critical to build evidence about the full costs of such systems. Economic and financial analysis of the costs of urban sanitation generally is a growing field of research (Daudey, 2018; Mills et al., 2020). Yet substantial challenges persist related to data availability and to the quality and comprehensiveness of cost studies. Daudey (Daudey, 2018) suggests a particular need for contextualized studies that identify the full range of costs associated with service delivery, across a system life-cycle, taking into account all phases of the sanitation chain.

Studies that identify the distribution of costs between actors is also a gap (McConville et al., 2019). Consideration of the financial perspectives of different actors is essential for the design of cost-sharing arrangements that ensure sanitation is affordable for all and support service providers with the requisite level of public investment, given sanitation's status as a public good (Schrecongost et al., 2020). More generally, there is opportunity to move beyond a project assessment approach to costing, towards closer analysis and monitoring of the financial characteristics of sanitation systems. Analysis of the financial dynamics of different configurations is critical for addressing a history of public underinvestment in sanitation service delivery and a lack of focus on financial viability (Schrecongost et al., 2020).

The need for contextualized, comprehensive, actor-oriented cost analyses is similarly apparent for resource-oriented sanitation systems specifically. A body of studies discuss the potential for resource-oriented sanitation to improve the financial viability of sanitation chains (Andersson et al., 2017; Diener et al., 2014; Otoo et al., 2018; Rao et al., 2017), while others include reuse options in comparative analyses of sanitation system costs (Dodane et al., 2012; McConville et al., 2019; Willetts et al., 2010). However most studies to date report projected rather than observed data, with a tendency to overestimate the value of reuse-related revenue (Mallory et al., 2020b). Building empirical evidence about the total costs of resource-oriented systems over their life-cycle, and across the full sanitation chain, can reveal opportunities for system optimization, underpin system sustainability by identifying the types and timing of investments required, and provide a foundation for the design of optimal cost sharing and financing arrangements.

This study contributes an analysis of the life-cycle costs of a resource-oriented sanitation system serving an urban area of Balangoda in Sri Lanka. In Sri Lanka, reflecting the urban sanitation situation globally, there is a critical need for improved excreta management, and considerable potential for reuse. The dominant form of sanitation in Sri Lanka is onsite systems, with 86% of households using septic tanks or pits (Ministry of City Planning and Water Supply, 2018). In urban areas, disposal of septage (solids and liquids removed from on-site sanitation) is a major problem faced by local authorities (Ministry of City Planning and Water Supply, 2018). Only 2% of households in Sri Lanka are connected to sewerage systems (Government of the Democratic Socialist Republic of Sri Lanka, 2018), with the majority of septage discharged into the environment without adequate treatment (ADB et al., 2017). Government policy articulates a need for sanitation initiatives to focus on improved septage management, including through treatment for safe reuse (Government of the Democratic Socialist Republic of Sri Lanka, 2017). There is both a need and opportunity to inform operationalization of the policy, including contributing evidence on the costs of sanitation reuse systems.

The resource-oriented sanitation system presented in this paper has been operating for a decade, and therefore provides locally-grounded, broadly relevant data on the costs of sanitation systems based on onsite containment, transport, treatment and reuse. With onsite systems used by 60% of households in Central and Southern Asian cities (UNICEF and WHO, 2019) and an estimated 66% of households in low- and middle-income cities worldwide (Berendes et al., 2017), the study has substantial potential to inform the implementation of resource-orientated sanitation globally.

We preface the analysis by noting the position of the authors that we must, wherever feasible, make reuse a part of sanitation planning and financing (Carrard and Willetts, 2017), in alignment with the SDGs and principles for citywide inclusive sanitation (Lüthi et al., 2020). We view this as a normative goal rather than one requiring justification through a promising business case, in line with the circular economy imperative to pursue systemic change (Kirchherr et al., 2017) and be regenerative and distributive by design (Raworth, 2017a). As such, the aim of this study was to explore in detail the cost-profile of a sanitation system with a view to informing future planning, investments, and cost-sharing arrangements for resource-oriented sanitation in Sri Lanka and more widely.

We first describe the details of the system under consideration and approach to costing. We then present and discuss findings from the analysis across three themes: total costs of the system over its lifespan; the distribution of costs between system actors, with a particular focus on the perspective of local government as service provider; and specifics of the reuse phase of the sanitation chain, including a discussion of critical considerations regarding cost optimization and system expansion.

2 Methods

2.1 Study objectives and context

The study explored sanitation system costs, and associated financial perspectives, in the context of a broader agenda to facilitate the application of resource-oriented sanitation systems at scale. The objective of the study was to identify the life-cycle costs of the resource-oriented sanitation system in Sri Lanka, taking into account actual incurred costs since system establishment and anticipated future required investments. Costs were analyzed by cost category, phase of the sanitation chain and from the perspectives of the main system actors. Analysis included an in-depth focus on costs associated with the reuse phase of the sanitation chain, and consideration of the role of local government as a resource-oriented service provider. The study was approved by the University of Technology Sydney Human Research Ethics Committee (Reference: ETH18-2522) and aligned with the International Water Management Institute Research Ethics Policy.

The analysis case is a fecal sludge management system in Balangoda, an urban centre in Sabaragamuwa Province of Sri Lanka with a population of approximately 30,000. Balangoda was selected for analysis due to the presence of an operational – and reportedly successful (Otoo et al., 2018; Rao et al., 2017) – example of a city-scale fecal sludge management system that incorporates reuse of treated sludge for productive agricultural use. Insights from the Balangoda case are relevant across Sri Lanka, where the 2018 National Sanitation Policy and national SDG targets to achieve safe sanitation (Ministry of City Planning and Water Supply, 2018) are driving investment in fecal sludge (as well as wastewater) treatment systems across urban centers. Results are also relevant more widely, given the prevalence of fecal sludge-based sanitation systems around the world in low- and middle-income countries.

The characteristics of the sanitation system are typical of urban contexts in Sri Lanka and other low- and middle-income countries. It comprises: household containment tanks (of various sizes and specifications); on-demand desludging by vacuum truck; transportation; and passive (gravity-based) treatment of septage at a fecal-sludge treatment plant (FSTP) comprising a receiving tank, two sedimentation tanks, an effluent treatment facility and drying beds (see supplementary material for a system diagram). The FSTP has capacity of 15m^3/day and average actual throughput of 10-12m^3/day. In Balangoda, dried fecal sludge is mixed with compost derived from the organic fraction of municipal solid waste to produce co-compost, which is pelletized for sale. The co-compost contains municipal solid waste compost (100 parts), dried fecal sludge (30 parts), mineral rock phosphate (10 parts) and rice husks (5 parts). The entire system is owned and operated by the local authority, Balangoda Urban Council. The fecal sludge treatment plant was constructed in 2008 at Council's already-operational municipal solid waste facility. A pilot-scale pelletizer was added to the system in 2016 by way of donation from the International Water Management Institute.

2.2 Approach to costing

The costing method was informed by a life-cycle costs approach adapted for water, sanitation and hygiene (WASH) analyses through the WASHCost initiative (Fonseca et al., 2011), and principles of integrated resource planning adapted for urban water and sanitation systems (Mitchell et al., 2007; Willetts et al., 2010). Life-cycle costing involves aggregating the full range of costs of ensuring an adequate, equitable and sustainable service to a population in a specified area (Fonseca et al., 2011). Three characteristics of the life-cycle costs approach justified its application in this analysis. First, the approach is oriented towards delivery of sanitation services rather than project evaluation. It seeks to articulate the full costs of providing a specified service (in this case sanitation incorporating reuse) such that they can be planned for, rather than informing project evaluation (Ratna Reddy et al., 2012). Second, the life-cycle cost approach uses defined and comprehensive cost categories that facilitate a systematic process of identifying all costs involved in service delivery. The use of defined cost categories – and in particular the inclusion of non-annual capital maintenance costs – makes transparent the types and timing of investments required. Third, application of life-cycle costing in the WASH sector intends to be directly useful for decision makers by improving understanding of the full costs of different sanitation systems and implications for what finance is needed, when, to ensure continued service delivery (Fonseca et al., 2011). In this study, articulating the full costs of a resource-oriented sanitation system (and zooming in on the reuse component) can inform future similar investments, including laying a foundation for system optimization and identification of potential cost efficiencies.

Integrated resource planning is an holistic approach that accounts for both material flows and financial exchanges required to achieve a defined service outcome (Beecher, 1996; Mitchell et al., 2007; Willetts et al., 2010). As such, integrated resource planning aligns well with the principles of citywide inclusive sanitation and the WASHCost life-cycle costing approach. Two principles from integrated resource planning as described by Mitchell et al. (2007) usefully informed the study. First is the explicit definition of an appropriately holistic system boundary. In this study, the system encompassed all phases of the sanitation chain (containment through to disposal/reuse) and a clear costing boundary was articulated that incorporated financial costs and benefits but excluded externalities (as discussed in section 2.4). Second, an integrated resource planning approach emphasizes the importance of applying appropriate cost perspectives. In this analysis, all financial costs and benefits were included to determine whole-of-society costs (as advocated for in both life-cycle costing and integrated resource planning approaches), with a secondary analysis exploring the distribution of costs between primary system actors.

Costs were identified for four phases of the sanitation service chain: (1) containment; (2) transportation and emptying; (3) treatment; and (4) reuse. Containment was deliberately included, in contrast to many sanitation costs analyses (Daudey, 2018), to ensure potentially substantial costs incurred by households – which are often overlooked (Danert and Hutton, 2020) – were considered and made transparent. The costing boundary was defined to incorporate all costs borne by the primary system stakeholders, namely the local authority (as the service provider) and households (as the main service users). Finance provided by the national government and the costs of a pelletizer donated by the International Water Management Institute were also included. In this system, service users include smaller commercial and some institutional premises, as well as households. For simplicity, 'households' were used as a proxy for all users, as they are the dominant group in this mix. The costing analytical boundary is shown in Figure 1.

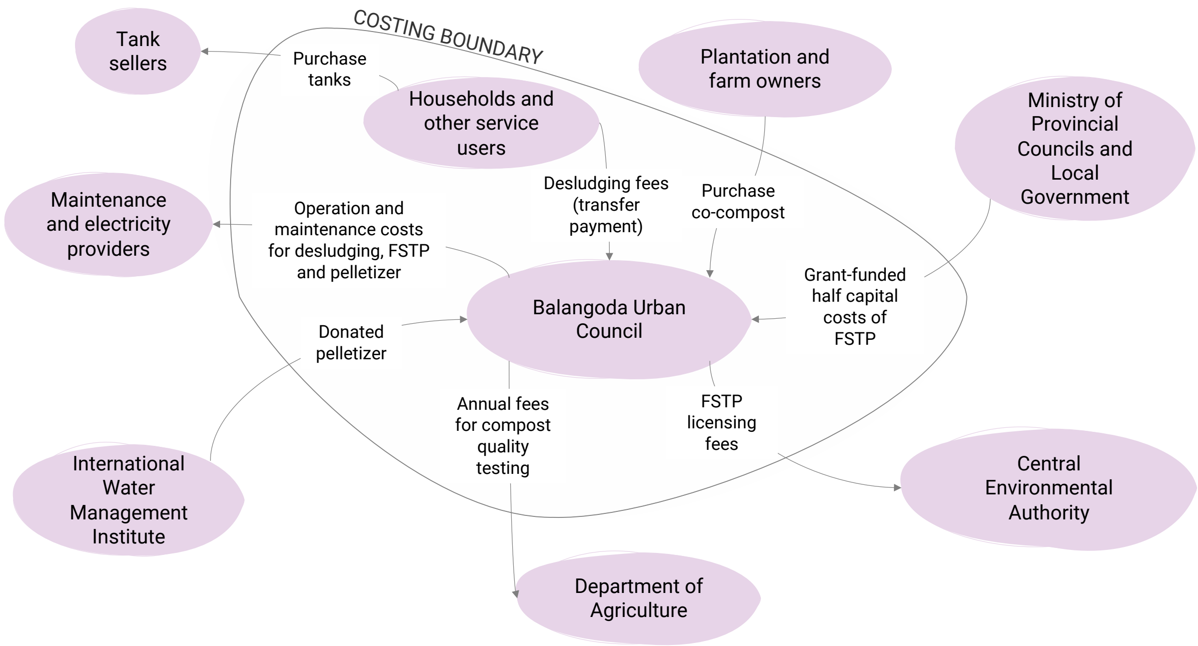

Figure 1 Costing boundary showing financial flows included in the analysis. The direction of arrows indicates the direction of financial flows.

In defining the costing boundary, it is important to acknowledge that the resource-oriented sanitation system sits within, and is dependent on, a larger system that includes municipal solid waste management and agriculture. The wider system costs and implications for interpretation of this study are discussed further in Section 3.1.

Cost data was sourced from written records and semi-structured interviews with government officials involved in establishing and/or operating the sanitation service system. Cost categories described in the WASHCost life-cycle costing approach (Fonseca et al., 2011) were used to identify the range of relevant costs to include. For the system in question, this comprised: capital expenditure; operational expenditure; capital maintenance expenditure; and support costs. Data resolution was not sufficient to separate direct and indirect support costs as described in the WASHCost methodology, so they are included as a single category. The cost of capital was also considered but was not relevant in this case as all finance was provided through grants or capital works budgets. Revenue associated with the sale of co-compost was included based on the median of available data (10 years) with sensitivity analysis conducted for a 95% confidence interval of the mean. Household payments for desludging services (when taking the local government perspective) were also included. Costs were apportioned to the sanitation system (from wider system costs) based on the ratio of fecal sludge included in co-compost, and the marginal difference in sale price achieved when selling the more nutrient-rich product. Cost estimates relied on a mix of actual (historic) costs reported in current values, and hypothetical costs predicting likely future investments required for the system to function as intended over time. Costs included in the analysis are described in supplementary material.

2.3 Data analysis

A spreadsheet-based model was used to calculate the net present value of life-cycle costs over a 25-year system lifespan. The analysis timeframe was defined to reflect the expected asset replacement period for household tanks and treatment components (as reported in interviews) and ensure that long-term operation and maintenance costs were included in the analysis. The net present value calculation applied a discount rate of 10%, which is the rate used by the Sri Lankan Department of National Planning. Relevant costs identified during semi-structured interviews were aggregated according to WASHCost cost categories described above. The frequency of capital maintenance costs was predicted by key informants and included in the model when incurred (rather than annualized) to show the timing of required investments. All costs were converted to 2018 US dollars by applying deflator factors (World Bank, 2019a) and a period average exchange rate of USD 1 equal to LKR 162.465 (World Bank, 2019b).

Analyzed costs were disaggregated according to cost category, phase of the sanitation chain, and cost perspectives. Costs are reported as net present value and annualized per person costs, the latter to situate costs relative to those reported in other studies. A cost per m^3 of septage treated was also calculated as a metric that reflects the cost of actual service provided: the amount of septage that is treated. Reflecting inherent uncertainties in the input data (particularly for future projections), cost findings are reported to two significant figures. Sensitivity analysis examined the impact of a lower discount rate (6%) and changes in assumptions about the population served. The cost per m^3 of septage treated provides an alternative metric given uncertainty about the population served.

3 Results and Discussion

This section presents and discusses findings from the analysis including: (i) system costs across different cost categories and phases of the sanitation chain; (ii) the distribution of system costs between actors; (iii) detailed analysis of the reuse phase, including cost drivers and implications for extending the reach of resource-oriented sanitation; and (iv) areas for further research.

3.1 System costs

The sanitation system – from containment to reuse – has a total net present value of approximately USD 370,000, with an annualized per person cost of USD 2.8 (equivalent to USD 12 per household) and cost of USD 11 per m^3 of septage treated. Sensitivity analysis using a lower discount rate found a comparable annualized per person cost. System costs are shown in

Table 1 and Figure 2 by cost category and phase of the sanitation chain. Treatment costs represented the largest portion of total system costs (35%) followed closely by containment costs (33%), which were included as part of capital maintenance expenditure to reflect the staggered nature of household tank replacements over time in established urban areas. The cost of emptying and transfer constitute just over a quarter of the costs (28%), with investments required for reuse a far smaller portion (4%). Costs associated with reuse portion of the chain are net positive, with revenue from co-compost sales covering costs associated with preparing compost for sale plus 8% of the present value costs for other phases of the sanitation chain. Reuse costs are discussed further below in section 3.3. The summary of costs by category shows that capital maintenance costs exceed other categories due to the inclusion of household tanks, which account for 78% of all capital maintenance expenses.

Table 1 Present value costs of the sanitation system by cost category and sanitation chain phase

	Containment	Emptying & transport	Treatment	Reuse	Total costs by category
Capital costs	0	-49,000	-77,000	-4,700	-130,000
Operational costs	0	-52,000	-39,000	-7,400	-99,000
Capital maintenance costs	-140,000	-14,000	-25,000	-1,900	-180,000
Support costs	0	0	-8,400	-1,300	-9,700
Revenue	0	0	0	46,000	46,000
Total costs by phase of sanitation chain	-140,000	-120,000	-150,000	31,000	-370,000

All costs are shown in USD 2018 values to two significant figures

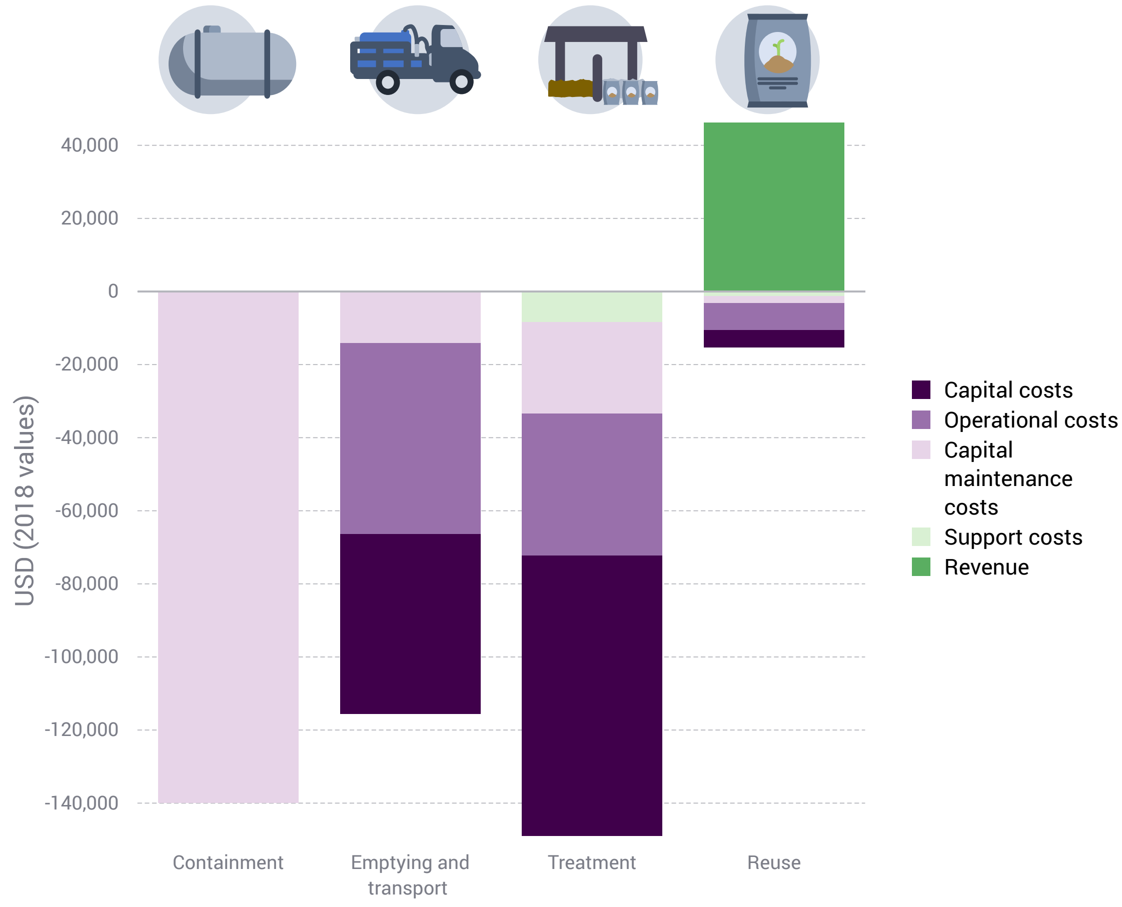

Figure 2 System costs (NPV) across the sanitation chain shown by cost category

The timing of costs over the system lifespan – and therefore required investments – is illustrated in Figure 3. The system requires an annual investment of around USD 22,000, a figure which includes operational costs borne by the service provider and rolling household tank replacements. A more detailed breakdown of how costs are borne by different stakeholders is provided below in section 3.2. The higher costs incurred approximately every five years represent required capital maintenance investments in desludging trucks, the treatment facility and the compost pelletizer.

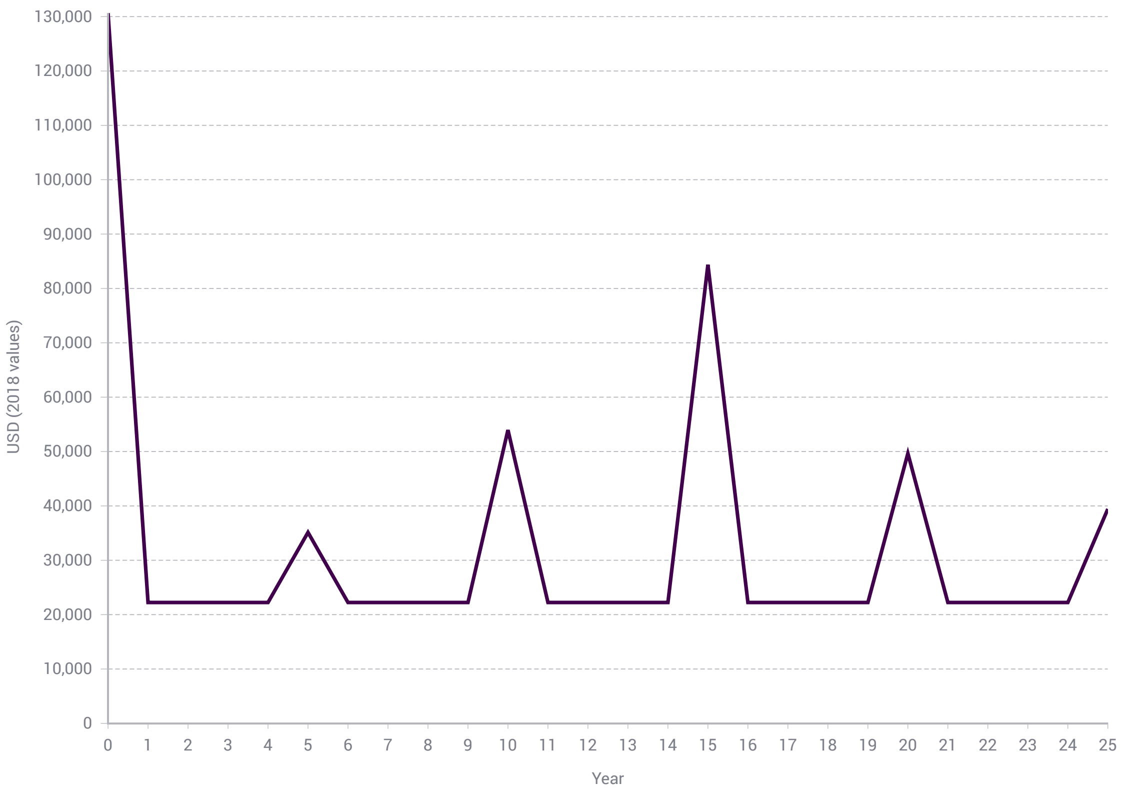

Figure 3 System costs over time. The required annual investment in most years is USD 22,000, with higher capital maintenance investments required approximately every five years.

The annualized per person cost found in this study (USD 2.8/person/year) is lower than other sanitation cost analyses. Studies in Kampala, Uganda (McConville et al., 2019) and Dakar, Senegal (Dodane et al., 2012) found annualized per person operating costs for full-chain fecal sludge management systems of USD 14 and USD 11.6 respectively. A study of the costs of full-chain fecal sludge management systems globally found annualized per person costs in the range of USD 6.3-24 (Cairns-Smith et al., 2014). Costing studies of onsite systems in Dhaka, Bangladesh (Ross et al., 2016) and Johannesburg, South Africa (Manga et al., 2020) found per household annualized costs of approximately USD 100 and USD 150 respectively, pointing to higher per person costs than was found in the Balangoda analysis. It is important to note that different methodologies and included costs make direct comparison of costs across studies inappropriate, however it is clear that the Balangoda system has a relatively low per person cost.

The lower costs found in this study are explained by the sanitation system's integration within a wider municipal solid waste facility and passive treatment design. Because the FSTP was constructed on the existing municipal waste management site, capital costs did not include land or road construction. Road and facility construction costs amounting to USD 300,000 were incurred as part of compost plant establishment in 2003 (equating to approximately USD 1 million in 2018 values), financed by the Central Environmental Authority through its Pilisaru program and Provincial Council (Otoo et al., 2018). Land was provided at no cost from the Land Reform Committee (Otoo et al., 2018). The passive treatment design keeps operational costs low, requiring no electricity and few manual laborers (who also work within the wider municipal solid waste plant). Integration of the sanitation system within an existing waste facility means Balangoda cost findings are applicable in other Sri Lankan cities, where more than 100 similar composting facilities exist. However, in interpreting their relevance to other contexts where these facilities are not common, costs of the wider system would need to be factored into analysis and planning.

It is also important to note that the per person annualized cost found for the Balangoda system is calculated from assumptions about the actual population served, size of household tanks and desludging frequency, all of which have a degree of uncertainty given the absence of validated data and anecdotally wide variation in household practices. To validate findings, calculations were repeated for a range of scenarios based on different assumptions about tank sizes and desludging frequencies, all of which resulted in a per person annualized cost of USD 2.3-2.8. The reported figure of USD 2.8 is considered the most reliable of these, being based on Council records of revenue received from desludging services and a schedule of fees charged to households and other service users. The assumptions and scenarios underpinning these calculations are further detailed in supplementary material. For future sanitation cost analyses, acknowledging a widespread lack of data on household tank sizes and desludging frequencies, we propose that reporting a metric based on the cost of actual septage treated (USD 11/m^3 treated each year in Balangoda) could be a helpful addition to reporting of per person annualized costs.

3.2 Who pays? The distribution of system costs

Exploring the financial perspectives of system actors is an essential foundation for sustainable and equitable sanitation services. Articulating who pays (and when costs are incurred) for different system components can inform equitable distribution of costs and ensure ongoing costs are planned for and adequately financed. The distribution of costs in the Balangoda case (Table 2; Table 3; Figure 4) is typical of similar onsite sanitation systems. Insights from the analysis (discussed in turn below) relate to: the system reliance on household investment; the substantial revenue received by the local government (as service provider) from desludging fees and fertilizer sales; and a simplicity in the distribution of costs that would shift with involvement of private sector service providers.

Table 2 Distribution of costs between actors for each phase of the sanitation chain

	Local govt	National government	Households	Donation
Containment	0	0	-140,000	0
Emptying and transfer	250,000	0	-360,000	0
Treatment	-110,000	-37,000	0	0
Disposal/reuse	35,000	0	0	-3,600
Total	170,000	-37,000	-500,000	-3,600

Table 3 Distribution of costs between actors for each cost category

	Local govt	National government	Households	Donation
Capital costs	-90,000	-37,000	0	-3,600
Operational costs	-41,000	0	-360,000	0
Capital maintenance costs	-99,000	0	-140,000	0
Support costs	-9,700	0	0	0
Revenue	410,000	0	0	0
Total	170,000	-37,000	-500,000	-3,600

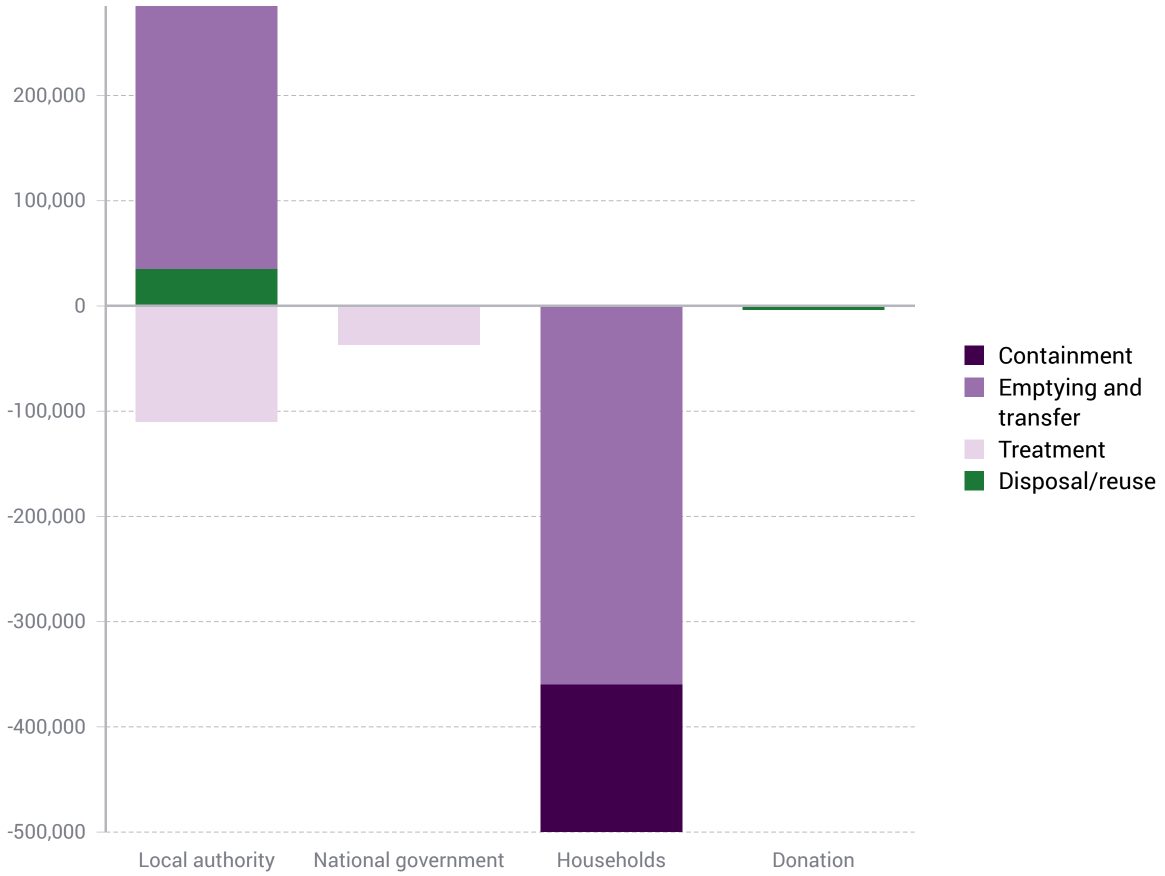

Figure 4 Costs by actor. Households bear the greatest costs, revenue outweighs costs for the local authority as the service provider

Households bear the largest share of costs. More than three-quarters of the whole-of-life costs are borne by households, and just 23% is borne by the local authority. Household costs comprise investment in onsite containment (constituting a third of costs borne by households) and fees paid for desludging (two thirds of household costs). Fees paid for desludging were excluded from the total system costs as they represent transfer payments between households and Council from a whole-of-society perspective, but are included in the analysis of who pays given their importance for exploring the financial perspectives of system actors.

Substantial household investment is a characteristic feature of onsite sanitation systems (Daudey, 2018; Dodane et al., 2012; McConville et al., 2019; Satterthwaite et al., 2019). This has important implications for equity, with unaffordability driving unsafe practices for lower-income households (for example improper containment and insufficient frequency of desludging). In Balangoda, population calculations indicate that the Council-operated desludging service is used by approximately half the town population, raising questions as to how septage is dealt with by remaining households. Consideration of how to ensure services are affordable for all is demanded from government agencies responsible for service oversight, which may include subsidization of onsite systems as is common for sewer systems (Gambrill et al., 2020). More generally, further research on household investment in sanitation services is warranted, given household investments are a significant, poorly understood and largely ignored part of the water and sanitation financing picture (Danert and Hutton, 2020).

The perspective of the local government service provider contrasts markedly with that of households, with revenue that exceed costs over the system lifespan and in most years of service. At the time of system establishment, local government investment was matched by a grant from the national government, which supported construction of the FSTP. On an annual basis, revenue from household payment of desludging fees plus sale of fertilizer is sufficient to cover the ongoing costs associated with desludging, treatment and reuse aside from one point in time (year 15) where forecast capital maintenance costs are more substantial and additional finance (in the order of USD 30,000) would be required. From the service provider (Council) perspective, the sanitation system therefore achieves financial viability on a user pays basis; an often-idealized though disputed approach to financing service delivery in the water and sanitation sector (Franceys et al., 2016).

However, the reality of government budgeting processes means that sanitation-related revenue is not necessarily used to cover ongoing sanitation system costs. In Balangoda, revenue from sale of co-compost is earmarked in budgeting processes for reinvestment in the waste management system (along with revenue from sale of recyclable waste) and therefore contributes to covering ongoing costs. In contrast, desludging fees received from households are directed to a common revenue pool, which is subject to annual negotiations about priority investments across a range of Council services. With revenue from desludging services constituting 89% of the modelled financial benefits, the extent to which Council can rely on sanitation-related revenue to cover ongoing system costs is uncertain. As such, earmarking of sanitation-related revenue – for the reuse phase and more widely – is an important factor in determining how the modelled cost-profile of an urban sanitation system plays out in practice. Furthermore, in contexts with an active private desludging market (as is the case in many low- and middle-income cities including elsewhere in Sri Lanka), additional thought would be required to arrange transfer payments such that Council is able to cover whole-of-system costs, and businesses are incentivized to discharge at the FSTP.

3.3 The reuse sub-system: detailed costs and implications

In this section we present detailed findings for the reuse phase of the Balangoda system and discuss implications for investment in resource-oriented sanitation systems in Sri Lanka and more widely. Implications suggest that: (i) reuse-related revenue makes a moderate contribution to whole-of-system financial viability and other sources of finance (from households or government) are needed for the whole system to function; (ii) detailed costing of the reuse sub-system can inform optimization of its financial contribution, making apparent key cost drivers and testing assumptions about the value of different system investments; and (iii) to extend the reach of resource-oriented sanitation systems, there is a need for further analysis of pathways for system expansion.

The reuse sub-system generates a net surplus over the system lifespan and on an annual basis. Over the lifespan, present value costs of USD 15,000 and financial benefits of USD 46,000 result in a total net benefit of USD 31,000. Sensitivity analysis based on the range of recorded revenue values found a minimum net benefit of USD 30,000 and a maximum of USD 78,000, indicating our findings are conservative regarding revenue potential. The proportional distribution of present value reuse costs are shown in Figure 5, including pelletizer purchase (23%) and replacement (13%), electrical connection (7%) and running costs (4%), phosphate valorization (15%), bags (30%) and licensing and inspection fees paid to the Central Environmental Authority (8%).

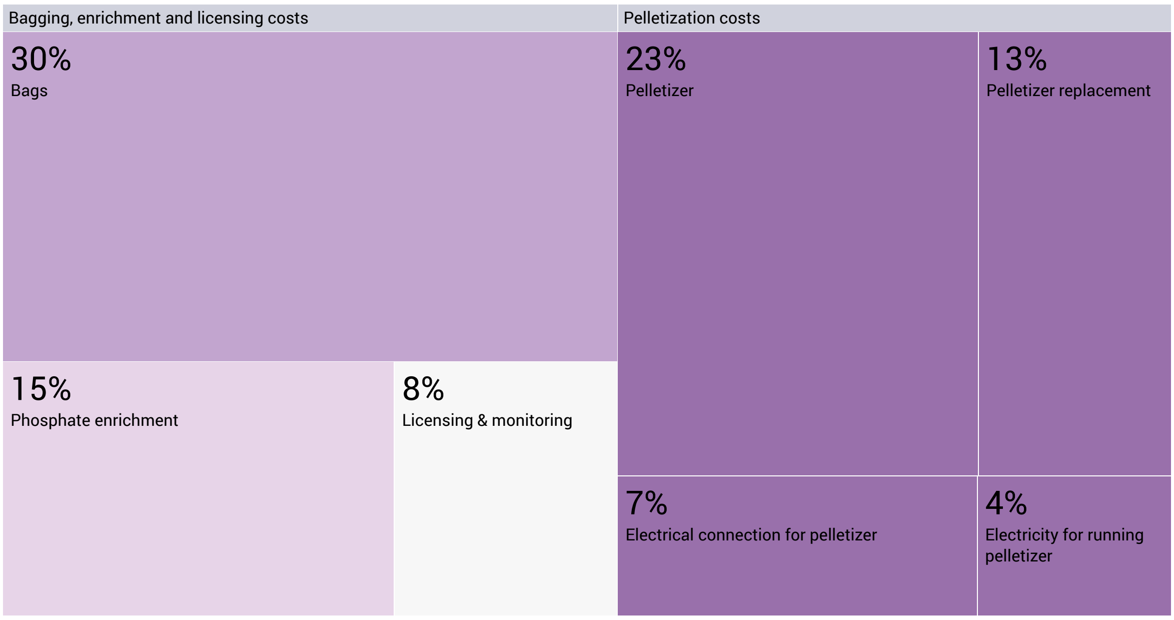

Figure 5 Pelletizer-related costs constitute almost half of all life-cycle costs associated with the reuse sub-system

The reuse sub-system has a net benefit over the system lifespan, however revenue from reuse makes a relatively small contribution to wider system costs. On an annual basis, revenue from the sale of co-compost is sufficient to cover just under half (43%) of the annual operating and support costs for other phases of the sanitation chain. Over the system lifespan, revenue (after covering reuse-specific costs) equates to approximately 10% of present value costs of the wider system. More specifically, it represents 8% of present value costs of containment, emptying/transport and treatment and 12% if containment (household) costs are excluded.

Findings affirm that resource-oriented sanitation can generate revenue in practice, but suggest caution in asserting the potential for a resource-orientation to drive investment in sanitation services at whole-of-system scale, as has been hypothesized (Diener et al., 2014; Murray and Ray, 2010). The inability of reuse to underpin overall system profitability has been similarly identified in analyses of reuse systems in India (Center for Water and Sanitation - CEPT University, 2019) and in Haiti and Kenya (Moya et al., 2019). A review of the financial value of fecal sludge reuse from 43 studies in low- and middle-income countries also found resource recovery to have a limited role in the overall financial viability of resource-oriented sanitation systems (Mallory et al., 2020b). Further, while resource-oriented sanitation options have been found to have lower costs than traditional systems in economic cost comparisons (Hashemi and Boudaghpour, 2020; Shi et al., 2018), this does not signify potential for full financial cost recovery and specific attention on financial viability for whole-of-chain systems is required (Schrecongost et al., 2020). As such, while a resource-orientation can improve the overall financial profile of a sanitation service and partially offset required public investment, additional finance will be required to ensure the viability of earlier phases of the sanitation service chain as preconditions for a successful reuse scheme.

The contribution of reuse-related revenue is nevertheless meaningful and warrants detailed analysis towards cost optimization. In Balangoda, costs associated with the reuse phase of the sanitation chain are driven by the decision to pelletize the co-compost, which raises questions about whether investment in pelletization is financially justified. Costs related to pelletization – including purchase of the pelletizer, an electrical connection fee, machine replacement and electricity running costs – constitute almost half of all reuse-related expenditure. In this case, pelletizer purchase (17% of reuse costs) was externally financed in the form of a donation from the International Water Management Institute, however ongoing annual costs and future maintenance costs are borne by Balangoda Urban Council as the service provider.

The decision to pelletize co-compost was justified by Balangoda Urban Council based on two assumptions: first that a pelletized product can retail for double the price of a non-pelletized product (USD 0.12/kg instead of USD 0.06/kg); and second that pelletization increases demand for the product in a market accustomed to applying pelletized commercial fertilizer. Pelletization has also been identified as a strategy to address perceived cultural barriers associated with handling and using a compost containing dried fecal sludge (Otoo et al., 2018). There is mixed evidence from literature about the validity of these assumptions. Pelletization is claimed to command higher prices, improve usability, achieve a steadier rate of nutrient release compared with traditional powdered fertilizers, and enable access to new markets (including through reducing transport costs and improved product desirability) (Moya et al., 2019; Nikiema et al., 2013; Otoo et al., 2018). Yet consumer willingness to pay is uncertain. A study in Kampala, Uganda found that while farmers prefer a pelletized product, the modelled cost of pelletization exceeded farmer willingness to pay for this attribute (Danso et al., 2017). A study in the Sri Lankan district of Nuwara Eliya found higher willingness to pay for fecal sludge-fortified compost in powdered, rather than pelletized, form (Waidyarathne et al., 2018), though willingness to pay relative to costs was not considered in this case. Further empirical evidence, in the form of future sale records and pelletizer-related costs (including validation of modelled future costs), is required to assess whether pelletization is a cost-effective investment in the Balangoda system and for resource-oriented sanitation systems more widely.

More generally, further research on the relative costs and marketability of different end-use products across contexts is needed to inform the technical, institutional and financial design of resource-oriented sanitation systems at scale. In a review of the market potential of multiple fecal sludge-derived end-use products in Ghana, Senegal and Uganda, Diener et al. (Diener et al., 2014) found the use of sludge as soil conditioner to be less profitable than other options, though they noted the challenges of calculating cost recovery given limited empirical evidence. Mallory et al. (Mallory et al., 2020b) also identified the dominance of theoretical studies and limited evidence on markets for a range of reuse products. Murray and Ray (Murray and Ray, 2010) argue for a "back-end user" focus to ensure the outputs of sanitation systems meet the specific needs of end-users (as customers). This "designing for reuse" approach (Murray and Ray, 2010) requires consideration of commercial fertilizer markets if the planned product is intended to reduce the extent of reliance on chemical fertilizers. In Balangoda, government subsidies for chemical fertilizers place co-compost in a competitive market (Otoo et al., 2018), a consideration which has driven valorization of the co-compost with the addition of 7% mineral rock phosphate. In other locations, calls have been made to 'level the playing field' between sanitation-based fertilizers and the wider market, for example by providing incentives for use of organic fertilizers (Moya et al., 2019). Ultimately, both market analysis and policy interventions are required to optimize the nutrient reuse and financial contributions of resource-oriented sanitation systems in different contexts.

Finally, analysis of the Balangoda system highlights priorities for research and practical action towards a stronger resource-orientation within efforts to advance citywide inclusive sanitation. A critical question for Balangoda, and onsite sanitation service systems more generally, is how to ensure services reach all. At present, analysis suggests that although the Balangoda sanitation service is theoretically available for all residents to make use of, in practice it serves approximately half the population. There may be options for increasing customer desludging demand towards achievement of citywide service delivery, for example through the institution of scheduled desludging as has been successfully piloted in other locations (ISF-UTS & SNV, 2019; Mehta et al., 2019). Prospective analysis of the potential costs required to increase rates of desludging, expand FSTP production and optimize reuse-related revenue is critical to inform future investment strategies. As part of this analysis, it will be important to explore the relative merits of maintaining Council monopoly or facilitating private sector provision of desludging services. In undertaking similar analyses more generally, it is important to acknowledge a tendency in fecal sludge reuse studies to overstate projected revenue (Mallory et al., 2020b). This study – building on a decade of empirical data – is well-placed to inform robust analysis of future scenarios and cost-sharing arrangements that ensure resource-oriented sanitation services are financially viable and affordable for all.

3.4 Limitations and future research

A limitation of this study is its focus on financial costs and exclusion of social and environmental externalities. Relevant externalities include greenhouse gas emissions incurred or avoided due to fecal sludge transport and treatment, the expected health benefits associated with safe sanitation service provision, and environmental benefits linked to safer management of fecal sludge. The decision to exclude externalities was made in the knowledge that the economic benefits of fecal sludge management are already well documented (Balasubramanya et al., 2017), and are challenging to comprehensively monetize for particular contexts. We therefore chose to focus on the actual financial flows within the Balangoda system for reasons of scope. Nevertheless, further analysis of the health and environmental benefits of safely managed fecal sludge in Balangoda would add value to the findings of this study.

The study would ideally also be complemented by assessment of opportunities to optimize the case study sanitation system beyond those identified in this study as relevant to the reuse phase. Optimization could include cost efficiencies in specific phases of the sanitation chain, or system re-configuration (for example exploring different technological options) to maximize financial and wider reuse benefits. Considering the system with reference to principles of regenerative sanitation (Koottatep et al., 2019) could identify future improvements. Analysis of system efficacy would also be of value given rapid scale-up of FSTPs and an associated need for evidence about their functioning (Klinger et al., 2019). Additionally, the necessity of drawing a manageable system boundary for analysis means that important aspects of demand (agricultural markets for the co-compost) and supply (producers of system components) were excluded, and future research could inform strategies to reduce input costs and increase demand for the end product.

A final area for future research relates to innovative financing and the equitable distribution of costs and benefits associated with resource-oriented sanitation systems. A focus on equity is critical to ensure resource-oriented systems align with the imperative to address deep inequalities within and between countries as we grapple with global sustainability challenges (Raworth, 2017b). There is scope to explore different models of cost sharing between government agencies, service providers (whether government or privately owned) and households. Cost sharing arrangements will ideally encourage widespread use of sanitation services and facilitate system viability over the long term. This includes ensuring affordability for households and incentivizing proper tank installation and emptying. It also includes incentivizing (and regulating) appropriate emptying in situations with an active private desludging market. Exploration of innovative financing opportunities for resource-oriented systems is a priority, including strategies to enable the public investment required to ensure system viability and affordability.

4 Conclusion

The merits of resource-oriented sanitation are well established and far reaching. This analysis contributes empirical data on the life-cycle costs of an established, successful resource-oriented system in Balangoda, Sri Lanka. Findings affirm both the potential for resource-oriented sanitation to generate revenue, and the need for substantial complementary investment to ensure whole-of-system financial viability. Analysis of financial perspectives revealed system reliance on household investment (as is common in places with dominantly onsite systems) and a promising business case for the local government service provider – though this derives primarily from a monopoly on desludging services rather than sale of co-compost and is subject to budget prioritization processes. Costs of the reuse phase indicate potential for optimization, informed by critical questioning of assumptions regarding system investments and exploring pathways for system expansion.

The findings of this analysis can inform efforts to advance the implementation of resource-oriented systems in cities where onsite sanitation is common, as is the case across low- and middle-income countries. The global sanitation community is striving to achieve the Sustainable Development Goals and citywide inclusive sanitation in a context of increasing environmental pressures. Building evidence about the costs of resource-oriented sanitation systems in practice can inform greater ambition and practical action towards more widespread implementation and optimization of circular economy approaches to sanitation.

CRediT author statement

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