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Review

Sanitation financial tools (SFTs) for citywide inclusive sanitation (CWIS): A critical review

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ABSTRACT

Citywide Inclusive Sanitation (CWIS) is an approach for safely managed sanitation service provision aimed at achieving three core outcomes: equity, safety, and sustainability, which is crucial to achieve Sustainable Development Goal 6 (SDG 6). Financial planning is vital in promoting safe and sustainable sanitation services; hence, this study critically examines current Sanitation Financial Tools (SFTs) and the extent to which they incorporate the core CWIS outcomes. The analysis revealed that most tools consider these CWIS outcomes in isolation, if at all, and commonly neglect specific financial needs of low-income populations, protection of sanitation workers, gender equity, and disregard the financial sustainability of sanitation service provision. The findings underscore an urgent need for improved financial planning aligned with CWIS outcomes that support equitable, safe, and sustainable sanitation at scale, which contributes to informed decision-making for sustainable sanitation services.

1. Introduction

The global impact of inadequate sanitation services on health, education, and human capital (UNICEF/WHO JMP, 2017; Black et al., 2017) is aggravated by fast urbanization. Citywide Inclusive Sanitation (CWIS) is a new worldwide approach to tackle urban sanitation challenges, proposing to reach low-income communities (LIC), long-term service provision, financial sustainability, and a functional public system through three core outcomes: equity, safety, and sustainability for everyone in an urban area (Schrecngost et al., 2020). Attention must be given to all types of sanitation services delivery commonly observed in cities: (i) sewer-based conveyance to treatment, (ii) at-source containment followed by road-based conveyance to treatment, and (iii) at-source containment followed by land-based treatment (Strande et al., 2023) with an emphasis on low- and middle-income countries, to achieve Sustainable Development Goal 6 (SDG 6) (UN, 2025; World Bank, 2018; Wang et al., 2024).

Financial planning, among many other aspects, plays a pivotal role in sustainability of safe and equitable sanitation services provision. To that end, financial flow models (FFMs) are instrumental in illustrating various transfers of money within a Sanitation Value Chain (SVC), especially when aligned with Shit Flow Diagram (SFD) outputs, thereby aiding city administrations in understanding financial sustainability of diverse sanitation services and its safe or unsafe management (Furlong et al., 2020). Since the 1990s, several Sanitation Financial Tools (SFTs) have been developed to support selecting safe and appropriate sanitation technologies and services. These tools' common and crucial objective is to identify the least-cost scenario considering different technologies and ensure financial sustainability alongside users' affordability while protecting environmental and health safety.

Since CWIS is a relatively new approach and includes non-hardware elements, existing SFTs do not capture all the CWIS outcomes. Ensuring equity and safety among users and workers, considering financial and environmental sustainability, could be challenging. Therefore, the objectives of this study are (i) to identify all existing SFTs and investigate their main objectives, architecture, and components; ii) to analyse different costs and financial projections/models adopted by SFTs; (iii) to evaluate technological options within SVC components and (iv) to highlight how each SFT tackles the CWIS outcomes, identify main gaps and propose how to integrate into a comprehensive SFT. The paper posits that no single SFT addresses all CWIS outcomes and provides a systematic review of all available SFTs.

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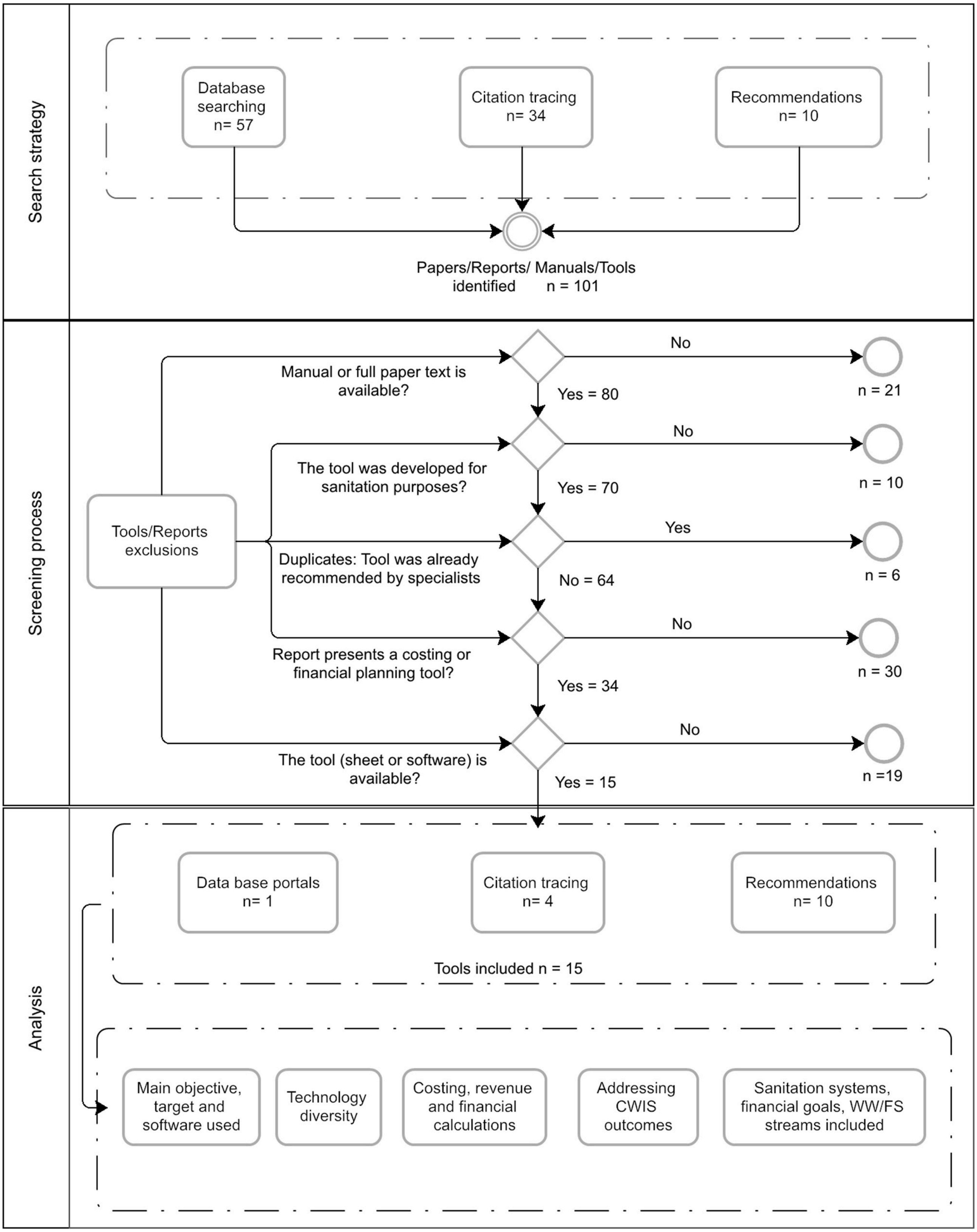

Fig. 1. Process of search strategy, screening and analysis of SFTs.

2. Data and methods

2.1. Definition of sanitation financial Tool (SFT)

Sanitation Financial Tool (SFT) is a tool that captures at least one of the following financial aspects of sanitation technologies or systems: capital expenditures for investments (CAPEX) or reinvestments, operational and maintenance expenditures (OPEX), sales/revenue, or financial projections over the years. SFT can be applicable where users want to compare financial sustainability of different technologies or sanitation systems, establish different system scenarios in SVC concerning financial flow choices, or even compare costs for sanitation services between different regions, cities, utilities, or countries.

2.2. Search strategy, screening and analysis of SFTs

Existing SFTs were identified through searches in academic search engines, such as Google Scholar, citation tracing of previously identified literature, and specific recommendations developed in English with open access to the tool software or sheet. As CWIS is agnostic about technology choice, all SFTs found were considered in this study, independently of technology used or component of SVC addressed in tools. The Google Scholar search used keywords to represent sanitation, as in: “sanitation” OR “wastewater” OR “faecal sludge”, AND to describe financial aspect: “financing” OR “planning” OR “business” OR “cost”; AND to represent a tool, as in: “tool” OR “software” OR “dashboard,” with a focus on the first five pages of search results (out of 34), because the most useful results appear earlier in the search results and at the same time ensures quality while managing scope of the review (Google Scholar ranking of search results is based on relevance, quality and usability of content and appears as per the ranking). Citation tracing was primarily focused on reviews related to sanitation and decision support tools, as well as papers resulting from Google Scholar search and online library sections of websites focused on sanitation sector, such as the International Water and Sanitation Centre (IRC - ircwash.org).

Five criteria were used to screen the papers, reports, and tools: (i) availability of a manual, report, or full text; (ii) purpose or objective being explicitly sanitation; (iii) eliminating duplicates from different sources; (iv) used for costing or financial planning; and (v) availability of software, dashboard or spreadsheet (Fig. 1).

A total of 101 papers, reports, manuals, and tools were identified. After the screening process (Fig. 1), 15 tools were included in the next step for detailed analysis considering the following criteria: 1) tool’s main objectives, target audience (such as national, regional, city, utility or treatment plant level) and software used in each tool; 2) inclusion of type of sanitation systems – sewered sanitation (SS) and non-sewered sanitation (NSS) systems and their financial goals (including costing and/or long-term financial planning) and encompassing wastewater (WW)/faecal sludge (FS) quality and quantity stream and flow estimates; 3) prevalence of SVC components and technologies within SFTs, consistent with the list and definitions outlined in the Compendium of Sanitation Systems and Technologies (Tilley et al., 2014); 4) details of costing, revenue and financial analysis; and 5) assessment of SFTs against CWIS outcomes consistent with the complete list of CWIS Indicators outlined by Athena Infonomics (2021). The findings led to a guideline/checklist for updating SFTs to address the main gaps in CWIS outcomes, which should enable costing and financing of safety and equity for both sanitation workers and users, as well as promoting financial and environmental sustainability in citywide sanitation services.

To analyse prevalence of type of sanitation systems (2nd criteria); SVC components and technologies (3rd criteria), and CWIS outcomes and indicators (5th criteria) in the SFTs, presence/absence of each item/indicator was marked, and percentage of tools that include each item/indicator was calculated using equation (1) (an example to calculate prevalence of gender pay gap in SFTs)

$$\text{Prevalence of gender pay gap analysis in SFTs } (\%) = \frac{\text{Total number of tools analysed}}{\text{Number of tools including gender pay gap analysis}}\,100 \qquad \text{(equation 1)}$$

A binary matrix with different tools and prevalence of different criteria can be found in supplementary materials (Tables S3, S4, and S6), which allowed comparison of SFTs in several criteria, as mentioned earlier.

3. Results and discussions

3.1. Existing SFTs: historical development, objectives, and descriptions

The 15 SFTs selected from the screening process have been developed since 1994 (Fig. 2), conducting financial analysis at national level (20 %), 60 % at city level (60 %) for decentralized analysis, and 20 % for more detailed analysis at Treatment Plant (TP) level (Table 1). Most of the SFTs are Excel-based tools (73 %), which are simpler to use compared to four online platforms that utilize proprietary software and require hosting and maintenance (Table 1).

SFT objectives are diverse, covering: (i) to build CAPEX, OPEX and revenue from disaggregated cost data as inputs (FAT, CACTUS, eSOSview™, QSDSan, LCCA, Equiserve); (ii) to propose FFMs for SVC (eSOSview™); (iii) to calculate cash flow for financing sanitation services (FAT and eSOSview™); (iv) to evaluate cost of implementing resource recovery systems and potential revenue or cost savings (WAWTTAR, BioWatt, QSDSan, Poseidon); (v) to share data and allow comparisons between cities, regions, utilities and countries (IBNet, CACTUS, CWIS CP); (vi) to compare different scenarios using Life Cycle Costs (LCC), especially between SS and NSS (LCCA, eSOSview™, CWIS CP, CACTUS, SaniPlan, Equiserve, CLARA), (vii) to calculate national financial needs for achieving global WASH targets (WASHCost, WSNAT), (viii) to help users find costs on different technologies and systems at an early stage of planning by cost functions built in the tool, for limited input availability (flow, loading or people served) (CLARA, Poseidon, WAWTTAR, FAT), (ix) to find gaps between financing and costing needs (WASHCost, SaniPlan, Equiserve), (x) to plan for financing improvements actions in a city considering Key Performance Indicators (KPI) (SaniPlan), and (xi) to evaluate safety, service regulation and equity between Low Income Communities (LIC) and non-LIC (Equiserve), among others (Table 1).

3.2. SFTs’ sanitation systems and architecture

Many SFTs (10) focus on SS and NSS, and 9 simulate WW and FS streams, considering volumes, mass, and/or flows generated (Fig. 3 and Table S2 in supplementary materials). Using these estimates and population growth, 7 SFTs can project WW and FS generation over the years. This enables calculation of quantities, volumes, and technological as well as financial planning for storage units, Emptying and Transporting (E&T) equipment (such as number of trucks or sewer expansion), treatment plants, and reuse possibilities. However, most SFTs (12) only work with baseline scenario costs excluding future financial planning,

Fig. 2. Historical development of SFT.

which can compromise long-term financial sustainability of sanitation services. In terms of quality of FS/WW treatment, six SFTs can assess pollutant removal efficiencies or compliance with standards. Conventional models are used to calculate load balance at each SVC component or treatment, and the choice of technology can significantly influence efficiency, costs, as well as safety/safely managed sanitation.

Regarding SFTs' architecture (additional data in supplementary materials Fig. S4), some require technological quantities inputs separated for each SVC component (eSOSview™, Equiserve, CACTUS, CWIS CP) or sanitation system (LCCA), and others initiate with defining a case, or space or system, where, user chooses systems and technologies to input people served, coverage, flow or load (QSDSan, Poseidon, WAWTTAR, CLARA, WSNAT, BioWatt). In SaniPlan, inputs are required for performance assessment, where user identifies and activates actions for improvements, and the tool provides financial planning. FAT determines number of trucks based on FS estimates and FSTP requires criteria such as flood-proneness, groundwater table level, area, climatic conditions, energy availability, skill level, capital, and operational capacity to select appropriate technologies. Cost functions or inputs provide financial planning and determine financial viability. WASHCost utilizes the Joint Monitoring Program (JMP) (WHO & UNICEF, 2015) national service coverage information to determine costs for reaching the unserved, improving basic to safely managed sanitation, and sustaining current services for 2030; however, user verification of data is required. IBNet requires inputs to calculate quality and sustainability indicators, and, like CACTUS, users must upload the sheet online to assess results (supplementary materials Table S3).

FS and WW streams are estimated to be 40 % of SFTs as a starting point for calculating costs and financial planning for safely managed sanitation. Shit Flow Diagram (SFD) is a practical framework to illustrate safe and unsafe sanitation flows throughout the SVC, widely used to stimulate dialogue on safely managed sanitation, and sometimes one of few sources of information on city's sanitation (SuSanA, 2024). However, only 27 % of SFTs utilize some of SFD's outputs to estimate flows, plan for improvements, and estimate costs. Specifically, WASHCost, SaniPlan, and Equiserve require user input on safe and unsafe SS and NSS information. In contrast, the WSNAT tool lacks only unsafe NSS information from SFD outputs. Equiserve is the only SFT that evaluates LIC and Non-LIC separately, although SFD provides data for the entire city. Estimating safe and unsafe WW and FS management flows using SFDs' outputs is the first step in establishing sanitation systems in the city and this link is only available only in QSDSan and BioWATT tools, where minimizing emissions and recovering costs can be anlaysed, contributing to financial and environmental sustainability.

3.3. SFTs, and SVC components

Entire SVC (user interface, containment, conveyance, treatment, and use or disposal) must be included in planning and financial analysis of SFTs, aiming for the highest technological diversity to enable inclusion in the city for safely managed sanitation (Schrecongost et al., 2020). Following the Compendium of Sanitation Systems and Technologies (Tilley et al., 2014), most SFTs prioritize containment (70 %), conveyance (87 %), treatment (100 %) and reuse (70 %) over user interface, which is less than 30 % (Fig. 4, supplementary materials S1 and S3), which can be related to the historical neglection of toilets' CAPEX/OPEX (as this is the responsibility of households), and abandonments (or "toilet loss") registered worldwide Economist Impact supported by Unilever, 2024. All SFTs include (semi) centralised treatment technologies, but only IBNet and WSNAT classify them as primary, secondary, or advanced treatment levels.

SFTs' objectives (Table 1) define technological necessity and diversity. Most SFTs have a list of technologies for users to choose from. Some allow users to input technologies through online platforms (CWIS CP), open-source code (QSDSan), non-online software, and by contacting developers (WAWTTAR) (Fig. 4, supplementary materials Table S4). WAWTTAR has a wide range of technologies to input, despite being developed in 1998 (Fig. 2). Although CWIS CP is in beta version and QSDSan's software is still in development, it enables users to input technologies, models, and data through open-source coding. Inserting new options is always possible, still, it is limited to users with proper programming knowledge. As eSOSview™ aims to achieve the most sustainable FFM for SS and NSS at city level, it covers the most significant number of technologies along the SVC. Some SFTs cover or have been applied only to NSS (FAT, QSDSan), while others focus on treatment plants and reuse (Poseidon, BioWATT). It has been found that when the target of SFT is at the national level for financial planning (WASHCost and WSNAT), technology specification increases complexity and uncertainty, and analysis becomes extensive.

Digging into the list of technologies for each SVC component proposed by Tilley et al. (2014) (supplementary materials Fig. S2 and Table S4), it is remarkable how widely septic tanks are included in SFTs (73 %), followed by single pits (60 %). Initially, these options were designed for rural areas and then transferred to fast-growing urban contexts, in the beginning temporarily, but still, they remained permanent once sewers were not installed (Strande et al., 2023; Capone et al., 2021), leading to unsafe management causing leakage, water contamination and public health risks (Amin et al., 2020; Unicef, 2023). Therefore, high integration of these technologies into SFTs represents a positive finding, especially for assessing OPEX and achieving safe management. For safe and effective provision of sanitation services, conveyance is essential, and ideally, 67 % of SFTs consider motorized E&T and conventional gravity sewer systems. Human-powered E&T, which is quite common in many urban areas, is not widely included in SFTs (only 33 %), overlooking costs associated with delivering safe services in densely populated areas, where trucks cannot access, thereby risking safety of both users and workers due to leakage and unprofessional services. The (semi) centralized treatment technologies mostly considered by SFTs (53 %) are activated sludge and Anaerobic Baffled Reactor (ABR), followed by Upflow Anaerobic Sludge Blanket Reactor (UASB) and Waste Stabilization Ponds (WSP), both included in more than 40 % SFTs. Irrigation and sludge application are the most common reuse options in SFTs (40 %) as these are typical for SS consisting of a conventional sewer followed by activated sludge, UASB or ponds for treatment as well as for NSS comprising of septic tanks, emptied and transported by trucks (motorized E&T), followed by ABR, UASB, or ponds for FS treatment.

Table 1
Brief description of Sanitation Financial Tools (SFTs).

Author	Tool	Main objective(s)	Financial description	Target	Software
GWSP – Global Water Security & Sanitation Partnership World Bank (2023)	IBNet	Promotes sharing of data on key financial, technical, and process performance indicators and management practices, capturing utilities' operating performance in the provision of water and sewerage services for cross-utility and cross-country comparisons.	The user inputs costs for new investments, OPEX, tariffs, operating revenues, and billings to create indicators for utility performance, vulnerability analysis, and worldwide benchmarking.	Utility/ National	Excel and online portal
Finney et al. (1998)	WAWTTAR	A decision support platform designed to assist in the early-stage selection of suitable water and wastewater treatment processes, thereby minimizing impacts and system failures by selecting technologies that are appropriate for each country's specific resource capabilities. Feasible options can be ranked based on performance and annualised costs.	Each process's CAPEX, OPEX, and land cost is drawn from the cost vs. flow/loading curves stored in 1992 US dollars, multiplied by the percentage contribution of each cost category, summed, and adjusted by the inflation rate input. The total cost is the sum of all processes in the treatment train. The capital recovery factor for the interest rate and planning period amortises the annual cost.	City/TP	Non-online software
UN Millennium Project, 2005.	WSNAT	Estimates costs to support water and sanitation interventions for meeting the Millennium Development Goals to help countries identify resources needed annually to meet Target #10 by 2015 through required inputs such as demographic data, coverage targets, and unit costs.	Users must input total cost of installing one unit of a particular technology, costs for rehabilitating existing infrastructure, and their OPEX. The tool develops intervention estimates of resource requirements to achieve outcomes and coverage targets.	National	Excel
Peal et al. (2014)	FAT	To improve planning and design for faecal sludge management (non-sewered sanitation), provide number of trucks, treatment options, and evaluate cash flow and financial viability from investments, expenses, revenues and taxes.	The tool estimates cost based on the technology chosen by the user, considering site and resource criteria. Alternatively, the user can provide their estimates of costs for faecal sludge treatment plant and trucks CAPEX and OPEX. Projections of FS volume, number of trucks, costs, revenue, and taxes are made from household, commercial, and institutional.	City/ District	Excel
Langergraber and Weissenbacher (2014)	CLARA	To compare cost of different water and sanitation systems in the early planning stage (with limited data available) based on their Net Present Value (NPV) for investment, reinvestment, OPEX, and revenue for selected countries in Africa.	Each technology has three distinct cost functions: CAPEX, reinvestment costs (for an expired lifetime), and OPEX, which are calculated based on Bills of Quantities (BOQ) for each partner country. The user inputs flow, or people served, to find cost projections for comparing alternatives.	City	Excel
SaniPlan – CEPT University PAS Project (2016)	Sani Plan	To provide cities with sanitation and service improvement action plans for funding, as well as a financing framework and performance assessment for a municipality using benchmarks.	The tool develops a feasible financial plan for CAPEX and OPEX, considering grants, private sector, household, and government contributions, as well as loans. Five-year financial information is used to project the next ten years, with revenues and expenses impacted by financially sustainable improvements chosen by users.	City	Excel
Global Methane Initiative and World Bank Group (2016)	BioWatt	A tool for preliminary assessment (not a substitute for a feasibility study or project design) of wastewater-to-energy projects, focusing on biogas and electricity production potential, avoided greenhouse gas emissions, and OPEX.	It assesses wastewater treatment plant's electricity cost demand that can be met through biogas-generated electricity and impact on its OPEX by investing in energy generation technology.	TP	Excel
Author	Tool	Main purpose or objective	Financial description	Target	Software
Hutton and Varughese (2017)	WASH Cost	A cost estimation model for achieving the SDG WASH targets in 140 countries, focusing on households, assessing universal and equitable, safe and affordable drinking water, sanitation, and hygiene for all, ending open defecation.	Cost data were gathered from secondary sources and by the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (WHO & UNICEF, 2015), updated at the Sanitation and Water for All High-level Meetings em 2017 to access unit costs per capita of services for populations remaining to be served in different levels (high uncertainty)	National	Excel
World Bank (2019)	CWIS CP	To compare and monitor CAPEX and OPEX of different types of sanitation solutions along the whole SVC at component, system, and city levels.	The user inputs CAPEX and OPEX at SVC component level, which are combined at system and citywide levels using life cycle cost analysis for total and per capita costs.	City/ District	Online software
Oertlé et al. (2019)	Poseidon	To compare different wastewater treatment and reuse techniques based on their pollutant removal efficiencies, costs, country-specific standards, and weightage criteria.	Cost curves were developed per cubic meter of reclaimed water for each treatment and distribution in local currency from 2006 in the same unit. It provides first-figure cost approximations for comparison-making between different options at the pre-feasibility stage (uncertainty between 30 % and 50 %),	TP	Excel
Furlong et al. (2020) Waziri (2020) Akbar et al. (2022)	eSOSview™	To build 6 FFMs along SVC and evaluate financial sustainability for sanitation systems, and lead to the most financially sustainable model for each city.	Disaggregated cost inputs are used to calculate CAPEX, OPEX, and Revenue for each component of SVC. Sanitation tax, licences, fees, and incentives build 6 FFMs to calculate net profit/loss.	City/ District	Excel

(*continued on next page*)

Table 1 (*continued*)

Author	Tool	Main purpose or objective	Financial description	Target	Software
Athena Infonomics (2020).	Equiserve	To assess safe sanitation and provide equitable services, enabling the focus on low-income households and on-site sanitation, and highlighting the gap between costs and investments, system safety, and regulations.	The tool calculates service providers' cost coverage ratio and net income. It helps analyse how tariff shifts affect the system's viability, with special emphasis on low-income households and on-site sanitation impacts. It also explores subsidies. Users can build scenarios for infrastructure, policy/regulatory, revenue models, and financing structures to review Life Cycle Cost (LCC) estimates and financing approaches.	City	Online software
Sainati et al. (2020)	CACTUS	To share data on cost, climate, and welfare effects for sanitation services by normalising and standardising metrics and empirical data collected from urban sanitation projects to create comparable cost estimates for various locations and enable informed decision-making for investment.	The costs are collected from existing and completed operational sanitation systems, and the total costs are calculated by capital and operational costs, annualised per capita (TACC) and per household (TACH) over the lifetime using discounting and normalised in the database to a single currency and date for comparisons.	City	Excel/ online software
Li et al. (2022)	QSDSan	Integrating sanitation system designs, waste streams, and financial simulations, and sustainability characterisation (Technical Economic Analysis and Life Cycle Assessment) under uncertainty for resource recovery.	LCC is calculated as a sum of CAPEX, OPEX, and sales of all units using a technical economic analysis (TEA) algorithm class.	City/ District	Code in Git Hub
Basyal et al., 2023	LCCA (No name specified by authors)	A LCC tool for economic analysis of SS, NSS, and hybrid sanitation systems at residential, commercial, and industrial city areas.	The tool assesses LCC by inputting disaggregated CAPEX, major maintenance costs, OPEX, and asset's residual value at the end of its life for SS, NSS, and hybrid systems.	City	Excel

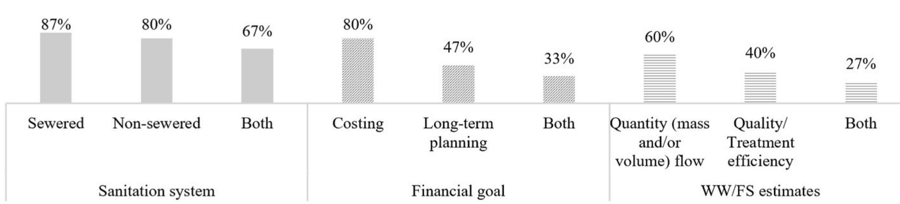

Fig. 3. Overview of SFTs prevalence in terms of sanitation systems, financial goal, and estimates of wastewater and faecal sludge.

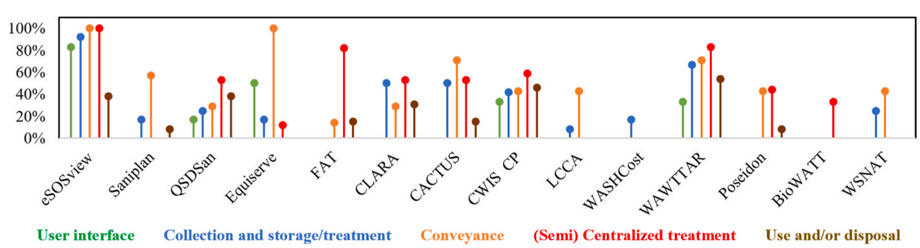

Fig. 4. SFTs' technologies prevalence for SVC components as per the Compendium of Sanitation Systems and Technologies.

3.4. SFTs' costing, revenue, and financial analysis

SFTs present two distinct financial approaches (supplementary materials Fig. S3): 1) to build CAPEX, OPEX and revenue from disaggregated cost data, which can be required as inputs from a user or included in the tool as cost functions of non-cost data, such as flow, load or people served; and 2) to calculate CAPEX, OPEX and revenue aside and input the amount (generally annuals costs) in the tool for planning and financing improvements or estimate costs/financial requirements to meet sanitation needs/targets (supplementary materials Table S1 and Table S5).

SFTs from group 1 require CAPEX inputs such as units and equipment prices, transport and storage, installation, land, labour, and project development (eSOSview™, FAT, LCCA) or more precise inputs, but more challenging to collect, such as construction materials, earthworks and excavations (QSDSan), sewer connections, pipe per diameter, manholes, pumping stations, cannon jets, grease traps, different size of vacuum trucks (Equiserve). To calculate OPEX, most SFTs require inputs such as water, electricity, fuel, maintenance (as in repair, spare parts, leasing for new equipment), consumables (cleaning materials, chemicals, tools), taxes, insurance, licenses and human resources (as in labour, skilled workers, engineers, managers, personal, staff, drivers, consultant, contractor, technician), emptying fee and utility fee (for motorized FS E&T), laboratory costs (for treatment plants), some also include costs for marketing and call centre services (CACTUS), training (CACTUS, LCCA, Equiserve), protective gear (CACTUS, Equiserve, LCCA, QSDSan), lubricant (CACTUS), garage rent (LCCA). Non-specific cost information, such as "miscellaneous," "overheads," or "others," may also be required for CAPEX, OPEX, and/or revenue in SFTs (supplementary materials Table S5).

The need for accurate cost data can be assessed by breaking down costs of materials for construction and installation, such as prices of bricks, steel, concrete, aluminum, wood, plastic, and others, as seen in QSDSan and WAWTTAR. QSDSan also aims to assess and minimize cost uncertainties by requiring maximum and minimum prices. Another method to obtain accurate data is found in CACTUS, where a user can input cost information from the perspective of unit user (as an OPEX to use a technology) or from equipment seller (as CAPEX to produce a technology), including maintaining offices, workers' training, vaccinations, health insurance, taxes and vehicle parking, customer support, and consulting services. On the other hand, more accessible but less precise data is usually needed for an early-stage decision-making tool, which can be achieved by SFTs working with in-built cost functions. User input data such as people served, flow rate, sludge volume, Chemical Oxygen Demand load, years, and discount rate could be used to estimate/update costs based on in-built cost functions in the tools (CLARA, Poseidon, FAT, WAWTTAR). Considering accuracy and accessibility, Equiserve, eSOSview™, FAT, and LCCA do not utilize cost functions and do not require numerous cost inputs to assess CAPEX, OPEX, and revenue of sanitation systems. FAT is the only tool that has an in-built cost function for estimating FSTP as well as allows user to input disaggregated costs, if desired. To achieve more straightforward ways to build cost information (but losing precision), Poseidon estimates WWTP OPEX as 4 % of CAPEX and taxes as 2 % of CAPEX; FAT calculates OPEX as 5 % of CAPEX, miscellaneous as 1,5 %, and trucks OPEX as 20 % of FSTP OPEX. WASHCost calculates costs for infrastructure rehabilitation or renovation to extend its lifespan, referred to as CAPMANEX, as 30 % of CAPEX at half the equipment lifespan, using a discount rate.

For revenue calculations, most SFTs require inputs from biogas, solids (sludge, compost, dry or raw FS), reclaimed or irrigation water, struvite, and urine sales. QSDSan calculates revenue from sale of Nitrogen, Phosphorus, and Potassium at a specific price in the country, discounted by a percentage of losses and an inconvenience factor for using FS as fertilizer. In eSOSview™, fees from previous SVC component are revenue for next one, and it also includes values from rent, toilet usage fees, advertising space, and paper sales. It is the only tool capable of creating different FFMs, offering numerous possibilities for money transfers, including sanitation taxes, emptying fees, discharge licenses, and incentives. BioWATT focuses on reducing OPEX by generating electricity from biogas, thereby reducing costs associated with aerated techniques and replacing them with anaerobic ones, while considering additional labour and maintenance requirements.

For SFTs from Group 2, total CAPEX, OPEX, and Revenue must be input by a user to calculate sustainability indicators (IBNet) or Net Present Value (NPV) for a period of 10–20 years, using population, WW, and FS growth with a discount rate. SFTs from group 1 can also make those long-term estimates (Equiserve, FAT, LCCA, CLARA) or calculate the baseline Net Present Value (eSOSview™, QSDSan). However, SaniPlan estimates costs of actions taken to improve performance (activated by users) and adds them to Business as Usual (BAU) costs. FAT calculates internal rate of return (IRR) based on CAPEX, OPEX, Revenue, depreciation, loans, and associated taxes. WASHCost estimates cost of ending open defecation and gradually achieving basic sanitation, while considering costs of maintaining current service, including expenses related to behavior change (10–20 % of CAPEX), and WSNAT considers costs of rehabilitating faulty equipment over its lifespan. Equiserve, SaniPlan, FAT, WASHCost, and IBNet work with revenues from grants, loans, equity, subsidies, and tariffs.

SFTs utilize various financial metrics (see supplementary materials, Fig. S3 and Table S6), with Net Present Value and total annual cost being the most used metrics. Most SFTs capture cost per capita, while cost per household is 20 %, and 27 % distinguishes government costs from users. In 67 % of SFTs, revenue is calculated, but less than half (7) consider taxes and tariffs. Less than 30 % of SFTs aim to finance sanitation with grants, sales, and cost recovery, or evaluate cash balance. Less than 20 % calculate specific financial metrics such as Weighted Average Cost of Capital (WACC), Earnings Before Interest, Taxes, Depreciation and Amortization (EBITDA), and Return on Investment (ROI).

3.5. SFTs addressing CWIS outcomes

Using (Athena Infonomics, 2021) indicators for equity, safety, and sustainability as an established set of standardized CWIS indicators, missing costs and gaps in SFTs' achieving CWIS outcomes are explored. It is important to understand which CWIS indicators are included in SFTs and which ones are missing for the three CWIS outcomes (Fig. 5 and supplementary materials Table S7).

80 % of SFTs include at least one equity-related indicator, focusing on fair cost distribution between NSS and SS, affordability for LICs vs. non-LICs, gender and minority equity among workers, and women's access to sanitation. While nearly 70 % of tools assess costs between NSS and SS, only one-third highlight disparities between users in LIC and non-LIC. Limited or inadequate information on these might result in unfair charges for safe sanitation services, which often leads to situations where LIC, primarily using NSS systems, bears the majority of costs. In contrast, NLIC, which typically relies on SS, may only pay taxes

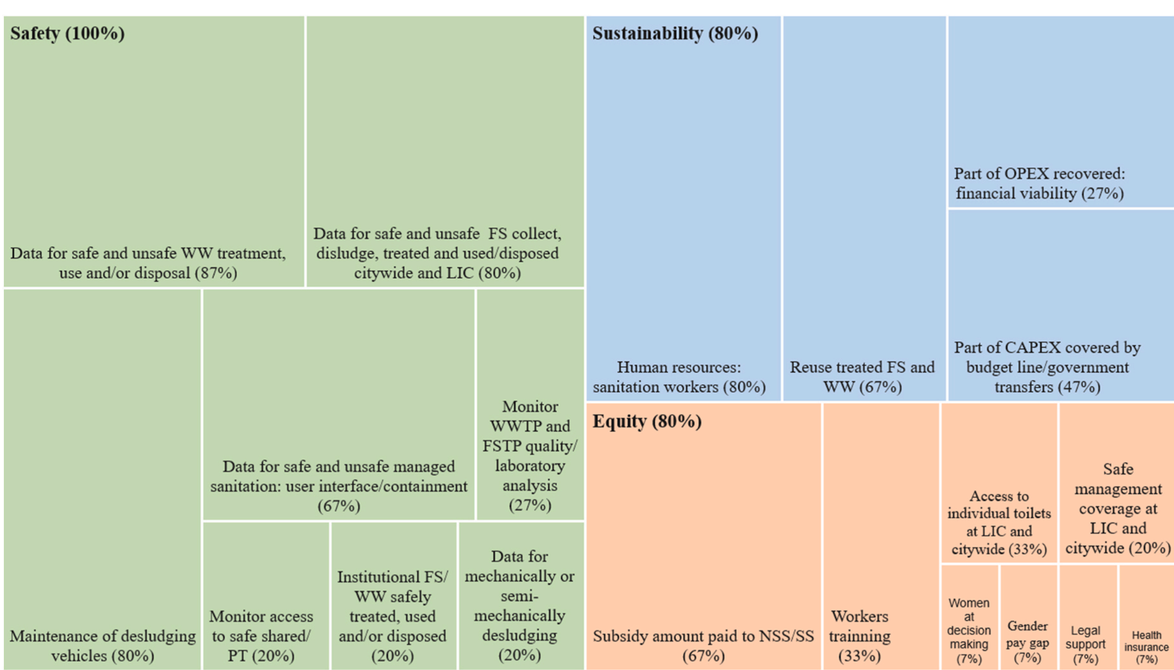

Fig. 5. CWIS outcomes and indicators prevalence in SFTs (size of each rectangle corresponds to the percentage value).

or tariffs that are usually less than fees for emptying NSS containments (excluding construction of containment system) (Dodane et al., 2012). SFTs should consider these in the financial analysis, such as incentives for NSS businesses and cross-subsidized tariffs among regions in the city (Acey et al., 2019).

Gender inequality in workforce persists worldwide, and it is not an exception in the field of sanitation. These gaps are computed only in IBNet, where number of women workers, or holding engineer positions and their salaries are required as input. The workforce bridges provision of safe sanitation services and gender is a decisive factor; for instance, men usually work cleaning sewers and manually emptying septic tanks, while women are responsible for carrying buckets and dumping waste, or involved in toilet cleaning, sweeping streets and railways, and sorting municipal waste, which affects their income (Bhakta et al., 2022; Cawood et al., 2021). Recognizing and addressing contributions and challenges of women in sanitation work is key to provide quality and safe sanitation services. It has been documented that women's mobilising skills are more effective in changing community behaviours to sustain WASH improvements, due to their relational approaches and success in delivering appropriate messages (Anderson et al., 2021). Therefore, SFTs must address costs to solve specific reasons hindering gender equality in sanitation workforce, like: 1) design PPE for women; 2) compute costs for health care, once carrying high loads and walking long distances while menstruating or going through perimenopause can result in discomfort and gynaecological problems; 3) include legal support costs for maternity leave and safe childcare spaces (Bhakta et al., 2022); 4) training for gender-based social dynamics in workplace; and 5) psychological care to face stigma associated with women working outside homes, which can be associated with mental health disorders (Dery et al., 2023; Monteiro and Nalini, 2021; Anderson et al., 2021). Moreover, transgender sanitary workers' needs are rarely discussed, and this scenario is further complicated by factors such as age, caste, and religious minority status (Bhakta et al., 2022).

All SFTs assess at least one safety indicator (Fig. 5; supplementary materials Table S7), yet only three consider FS/WW from non-domestic sources, overlooking significant volumes generated in schools, hospitals, industries, and commercial areas (Strande et al., 2018). In urban areas, non-domestic sources can account for up to 50 % of faecal sludge, as observed in Kampala (Schoebitz et al., 2016). Excluding these sources from financial planning can compromise half of the city's sanitation management, potentially leading to leakage and inappropriate discharge sites, which jeopardize safety. Therefore, SFTs must estimate non-domestic FS and WW streams to include those volumes in the city's technological and financial planning.

Safe management of user interfaces is also under-evaluated in SFTs, especially in shared and public toilets (20 % of SFTs). Neglecting shared and public toilets can lead to abandoned facilities, lack of cleanliness, odour, crowding, conflicts between landlords and tenants (Antwi-Agyei et al., 2020; Simiyu et al., 2020), and insufficient resources for managing menstruation (Maroko et al., 2021), open defecation, and women's safety risks (Gibbs et al., 2021; Panchang et al., 2022). Costs for public and shared toilets should be addressed in SFTs to improve maintenance and accessibility (Vu et al., 2022; Maroko et al., 2021) and create policies and incentives for improving users' behavior (Antwi-Agyei et al., 2020; Simiyu et al., 2020).

Most SFTs address E&T safety by considering vehicle maintenance, and only a few include semi-mechanical methods, such as manually operated pumps (e.g., Gulper, Rammer), or basic tools like buckets and shovels. Overlooking these methods in financial planning may neglect FS management in densely populated low-income areas, as they are widely used, affordable, and can reach areas without truck access (Lerebours et al., 2022). Considering for exposure to workers unsafe environment due to possible human contact with FS and increased health risks, it is essential to include workers' health insurance and protective gear costs in financial planning of SFTs. Furthermore, semi-mechanical emptying is usually cheaper (and less profitable) than mechanical, which can result in users' preference for unsafe and informal desludging methods. The profitability can be severely affected if corporate taxes or utility fees are same for both emptiers. In such cases, evaluating costs and profits of each type of emptying is essential for studying cross-subsidizing semi-mechanical emptying (Wilcox et al., 2024).

While most SFTs address treatment and reuse or disposal of WW and FS, only 27 % include costs related to monitoring TP outputs, such as lab analyses or expenses to meet effluent quality standards. An existence of TPs does not guarantee safe reuse or disposal of their products, which can still lead to public health risks, due to water and soil contamination (Shende and Pophali, 2023; Bonetta et al., 2022; Butte et al., 2021).

Despite the fact that sanitation workforce connects infrastructure with service provision with an increased exposure to health risks and expenses. Only CACTUS requires health insurance and legal support as input. Neglecting these costs of health and social security of sanitation workers might lead to exposure to occupational health and safety risks such as gastroenteritis, respiratory and musculoskeletal disorders, mental distress, discrimination, and social issues (especially those working on manually emptying pits and tanks, transporting FS, and maintaining sewers). Additionally, their pay or income could be insufficient and unstable, with little legal protection from the regulatory system (Philippe et al., 2022; WHO, 2019). They are also exposed to high solar radiation intensity, wind speed, and low humidity (Oza et al., 2022). These effects are often heightened by inadequate Personal Protective Equipment (PPE) and lack of training; however, less than 35 % of SFTs compute PPE costs, and workers' training is included in just one-third of SFTs. Workers' vulnerability also represents a vulnerability in service provision, as high staff turnover can result in poorer service quality (ILO - International Labour Organization, 2019)).

To ensure sustainability, the focus is on two indicators: availability of human resources for sanitation services and financial viability. 80 % of SFTs compute at least one of the indicators for sustainability; most of them calculate cost of human resources for sanitation, including skilled and unskilled workers, drivers, and consultants, which directly impacts OPEX. Financial sustainability often relies on revenue from using or selling sanitation by-products in many SFTs (10), however, it is recognized that sanitation businesses cannot rely solely on sales of by-products to be financially sustainable, leading to financial losses and service disruption (Russel et al., 2019). Therefore, SFTs should cover OPEX from other sources, such as tariffs and taxes. Half of SFTs cover CAPEX through budget lines or government transfers, and as a matter of fact, government funds, loans, and grants often support investment costs, as municipalities rarely have these resources.

The prospect of creating a SFT that integrates CWIS indicators and outcomes is challenging, as it requires co-development with both hardware and non-hardware elements. Reviews on sanitation frameworks and tools highlight that appropriate tools need to integrate businesses and stakeholders (Dwipayanti et al., 2017), include many technological options, be flexible to innovation, considering sustainability, allow for participation, while dealing with uncertainties (Spuhler and Lüthi, 2020), include knowledge/expertise from fields with natural organizational and sustainability synergy, be extensively tested and adapted by businesses in practice (Grainger-Brown and Malekpour, 2019), quantify demand for resource recovery products and its value, address retrofitting of existing infrastructure, and assess social impacts from a life cycle perspective (Ddiba et al., 2023), aiming to increase tools' impact in low and middle-income countries (Furlong et al., 2020).

3.6. Way forward and implications

This paper critically analyzes the usage and limitations of existing Sanitation Financial Tools (SFTs) in achieving safely managed sanitation, as outlined in the Citywide Inclusive Sanitation (CWIS) framework, focusing on equity, safety, sustainability, and core outcomes. It has been

Table 2
Elements to be integrated in SFTs for achieving CWIS outcomes.

CWIS Outcome	Elements to be integrated in SFTs
Equity	Evaluate cost fairness among NSS/SS. Evaluate cost fairness between LIC and Non-LIC. Number of women and minority workers Gender and minority pay gaps Women's access to shared toilets
Safety	WW/FS non-domestic inputs and estimates Consider the user interface costs, including public and shared toilets. CAPEX, OPEX, and Revenue analyses for human-powered/semi-mechanical E&T Costs for monitoring treatment plants' by-products and disposal Workers' health care, training, and PPE access costs
Sustainability	Human resources support at OPEX Cover OPEX from all possible sources: tariffs, fees, sales, and savings from resource recovery. Budget lines to cover CAPEX: national, external, loans

discussed and recognized that various elements are lacking in current SFTs, hindering CWIS outcomes for inclusive sanitation service provision, and highlighting the fragmented nature of current financial tools, underscoring key gaps in addressing gender disparities, health risks, and financial sustainability. By identifying these shortcomings, the study lays groundwork for development of a more comprehensive and CWIS-aligned financial tool, thereby contributing to more effective planning and resource allocation in support of achieving Sustainable Development Goal 6 (SDG 6). Table 2 outlines recommended elements for assessing each CWIS outcome.

The findings of this study have significant implications for all stakeholders, including donors, city planners, and others, who are engaged in urban sanitation. For example, the study emphasizes the importance of costing and funding not only for infrastructure, but also non-infrastructure elements, as mentioned in Table 2, to provide equitable and sustainable sanitation service provision. Donors have traditionally funded large infrastructure sanitation projects, many of which have failed to deliver change (Asian Development Bank, 2021), and should recognize the need to include funding for non-infrastructure costs/investment. For city planners, the study highlights the importance of utilizing comprehensive financial tools that incorporate the needs of underserved populations, safeguard sanitation workers, promote gender equity, and support long-term service delivery. For international agencies promoting Sustainable Development Goal 6, the study provides evidence to support policy guidance that moves beyond infrastructure coverage metrics toward inclusive and sustainable financial planning frameworks. In addition, this paper provides an opportunity for sanitation stakeholders to select a proper tool as per their needs.

4. Conclusion and recommendation

This review offers a novel contribution by systematically examining the extent to which existing sanitation financial tools align with CWIS outcomes. While prior tools have explored technical or financial aspects of sanitation systems, few have critically assessed how to incorporate non-infrastructure aspects for financing safety and inclusivity. Since 1994, 15 SFTs have been developed for carrying out financial analysis targeting national, city, or utility levels with different goals, such as planning for financing improvements, comparing NSS and SS, building FFMs, evaluating revenue from resource recovery, and collecting and sharing data. Only four SFTs utilize SFD outputs. Depending on the decision-making stage and level of uncertainty, SFTs could be used with available/accessible data for early-stage planning and with more accurate data/cost inputs for project design, or a combination of these. Most SFTs capture cost per capita, and less than half consider taxes and tariffs in their financial calculations. Regarding SVC, only one-third of SFTs include user interface technologies, which represents a risk to access to toilet and its operation and maintenance, and ultimately affecting the latter components of the SVC. Most SFTs compute collection/storage (especially septic tank and single pits), and conveyance (predominantly motorized E&T and conventional gravity sewer). All SFTs include (semi)/centralized treatment technologies (frequently activated sludge, ABR, UASB, and ponds), and nearly 70 % evaluate reuse and/or disposal options (such as irrigation and sludge application).

None of the SFTs could fully address all the outcomes of CWIS approach. Regarding equity outcomes, costs of providing workers with occupational health and safety, legal support, and evaluating gender inequities are not adequately addressed. This fails to address vulnerability of sanitation workforce and risks compromising service provision. Differentiation between low-income and non-low-income areas is neglected in most SFTs. Regarding safety outcomes, most SFTs overlook a significant portion of urban FS/WW from non-domestic sources, including access to shared and public toilets, semi-mechanical emptying, and monitoring of TP quality and costs. This oversight can lead to public health risks, particularly for women using shared toilets, as well as unsafe emptying and unsafe use or disposal. Sustainability can be found in most SFTs; however, most consider only revenue generated from sales of sanitation reuse by-products, which is insufficient to meet all financial needs for sanitation service provision. An opportunity to cover OPEX from tariffs/taxes and CAPEX from capital budget support as well as costs associated with sanitation workforce is largely missing.

To achieve CWIS outcomes, a holistic SFT must estimate WW/FS from non-domestic sources, address costs of maintaining toilets and containments separately for low-income and non-low-income users, highlight women using shared facilities, compare SS and NSS costs in the city, evaluate gender and minority gaps at the workforce, support them with training, legal support and health care, especially women and human-powered services, monitor the quality of TP products to provide safe reuse and disposal of sanitation by-products, and plan to cover CAPEX and OPEX from various sources.

To achieve safely managed sanitation and SDG6, usage of SFTs should be complemented by favorable policies and some of the key policy recommendations include: 1) integrating CWIS principles and framework in sanitation planning and strategies; 2) developing standard guidelines/indicators for evaluating equity, safety and sustainability and associated costs to achieve these outcomes; and 3) including capacity-building initiatives that enable local governments to adopt and adapt CWIS principles and SFTs.

CRediT authorship contribution statement

Camila Silva Franco: Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shirish Singh:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Damir Brdjanovic:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Camila Silva Franco reports financial support was provided by National Council for Scientific and Technological Development, Brazil. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

Data is at supplementary material.

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