Journal of
Water, Sanitation & Hygiene for Development

© 2024 The Authors Journal of Water, Sanitation and Hygiene for Development Vol 14 No 12, 1216 doi: 10.2166/washdev.2024.209

Review Paper

Evaluative criteria for least-cost economic analysis of citywide inclusive sanitation: A scoping review

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ABSTRACT

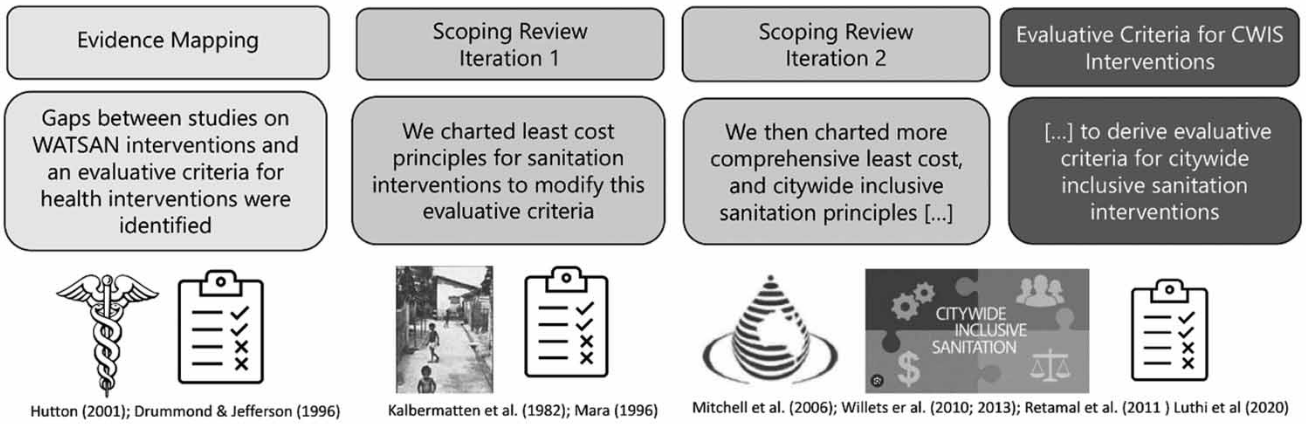
Compared to health interventions, where evaluative criteria have been established, uncertainty about how comparative economic analysis methodologies should be applied to heterogeneous urban sanitation interventions in cities of low- and middle-income countries persists. Gaps between least-cost principles and current approaches constrain emerging citywide inclusive sanitation (CWIS) planning frameworks. Furthermore, a lack of comparable evidence about the economic efficiency of service provision interventions impacts the delivery of urban sanitation as an inclusive public service. This review scopes how least-cost principles may be applied to methodologies for urban sanitation interventions in two iterations. We devise and discuss evaluative criteria, embodying CWIS principles, that will improve the quality of these methodologies. They include how (i) the inclusion of diverse cost perspectives, particularly populations with marginal access to sanitation, are accommodated within an analysis; (ii) a context-specific without-project case may be used as an appropriate basis for comparison; (iii) tangible and intangible costs and outcomes may influence decisions; and (iv) diverse mixtures of interventions at different scales may be compared with integrity. The resulting evaluative criteria define principles that may inform future systematic reviews of methods aimed at enhancing CWIS planning frameworks.

Key words: cost analysis, heterogeneity, integrated resource planning, least-cost planning, urban sanitation, urban water

HIGHLIGHTS

- Evidence of the allocative efficiency of context-specific sanitation investments is scarce in low- and middle-income countries.
- We devise least-cost principles for the comparative economic analysis of urban sanitation interventions.
- Evaluative criteria can inform methodologies for prioritising the right mix of service provision models for achieving citywide inclusive outcomes.

GRAPHICAL ABSTRACT



Proposed evaluative criteria for the comparative economic appraisal of citywide inclusive sanitation interventions

Study Design		Data Collection		Analysis and Interpretation	
1.1	A research question that balances economic efficiency and equity outcomes	4.1	The source of effectiveness data is specific to the without-project case	8.1	The time horizon and discount rate applied are stated and justified.
1.2	A societal cost perspective is disaggregated by subgroup cost perspectives	4.2	A justification for the comparison of data across different contexts is provided		
2.1	Options are compared against a least cost without-project standard	5.1	Unit costs expressed in TACH or TACC are used to measure cost-effectiveness.	9.1	Confidence intervals are presented for stochastic data.
2.2	Consistent and appropriate system boundaries are applied	5.2	Benefit valuation methods are described and justified for the study population	9.2	Sensitivity and scenario analyses are used to enhance the use of modelled data.
		5.3	Intangible benefits are reported separately and appraised deliberatively	9.3	Deliberative methods are used to allow for epistemic uncertainty
3.1	An appropriate economic analysis methodology is adopted	6.1	Average incremental costing is used to structure life cycle costs over time.	10.1	Reported outcome measures (TACH/TACC) align with the basis of comparison
		6.2	Adjustments for inflation and currency conversion are made explicit.	10.2	Outcome measures are presented in an aggregated and disaggregated format
		7.1	Assumptions within the costing model are justified and contextually relevant	10.3	Conclusions arise from multiple cost perspectives informed by multiple criteria

INTRODUCTION

The *Kalbermatten model* of least-cost sanitation planning (Mara 1996) was developed from World Bank guidance in the 1980s about the comparative economic analysis of sanitation projects (Kalbermatten *et al.* 1980, 1982). It embodied a *theory of economic costing* used to select public infrastructure projects at the World Bank (Squire & van der Tak 1975; Julius 1979). Kalbermatten *et al.* (1980) promoted prioritising cost-efficient, intermediate sanitation interventions that directly responded to demands for improved sanitation service outcomes within cities of low- and middle-income countries (LMICs). Governments with limited capacity to use taxation and subsidies to finance projects might instead select least-cost interventions that leverage local factors of production to distribute the benefits of economic development projects more equitably (Squire & van der Tak 1975; Perard 2018).

In a review paper, Kennedy-Walker *et al.* (2014) describe the influence of the *Kalbermatten model* in shaping the economic aspects of urban sanitation planning frameworks in LMICs (Schertenleib *et al.* 2021). For instance, it drove a shift in focus from economic to allocative efficiency and challenged an *induced bias* towards the selection of conventional waterborne sewerage (Squire & van der Tak 1975; Rosenqvist *et al.* 2016; Mills *et al.* 2020). However, the diverse range of paradigms about the inclusive planning of urban sanitation services that have emerged since has not been used to adapt comparative economic analysis methodologies for urban sanitation projects (Rosenqvist *et al.* 2016). For instance, the least-cost approach promoted by Kalbermatten *et al.* (1982) is still applied in contemporary studies, e.g., Manga *et al.* (2020).

Methodological constraints to producing comparable evidence of how urban sanitation interventions distribute costs and benefits at a municipal scale persist (Mills *et al.* 2020). Available data on the economic performance of competing options and their capacity to respond to Sustainable Development Targets 6.1 and 6.2 exist on a global (Hutton & Varughese 2016) or national scale (Hutton *et al.* 2014). However, these data are not suited to informing decisions about the most appropriate mix of municipal-level projects (Hutton 2016). The scarcity of cost-effectiveness data for the mixed sanitation options used in practice at this scale has been widely reported (Hutton *et al.* 2014; Hutton & Chase 2016; Daudey 2018; Mills *et al.* 2020; Sainati *et al.* 2020).

Thus, comparative economic analysis methodologies for urban sanitation interventions in these heterogeneous contexts are attracting growing interest (Carrard *et al.* 2021). The transition from the Millennium to the Sustainable Development Agenda has prompted the development of different ways of conceptualising urban sanitation systems, with the intent to facilitate the more equitable distribution of the costs and benefits of interventions (Kennedy Walker *et al* 2014; Rosenqvist *et al*. 2016; Scott *et al.* 2017; Schertenleib *et al.* 2021). Recent iterations of urban sanitation planning frameworks have highlighted the importance of mitigating the negative societal impacts of not providing appropriate sanitation services to everyone in a city. The need for heterogeneous service models that match the diverse service demands and cost preferences across different population clusters in cities has been highlighted (Hutton & Andrés 2018).

To date, these frameworks have yet to be applied as effectively as they might have been to inform decisions in practice (Scott & Cotton 2020). The scale at which safely managed sanitation services are needed tends to drive rule-of-thumb comparisons between existing feasible options (Sainati *et al.* 2020; Willetts *et al.* 2010). Current economic and financial analysis approaches promote what Spuhler & Lüthi (2020) describe as a persistent *one-size-fits-all approach* to decision-making, where novel, cost-effective approaches are less likely to be compared evenly. The depth of analysis required within comparative economic analysis methodologies to understand the complexity of context-specific drivers of cost-effectiveness within an urban LMIC context is rarely achieved (Daudey 2018; Hutton & Andrés 2018).

This situation makes the findings of Hutton (2001), who mapped gaps between comparative economic analysis methodologies for water and sanitation interventions and the available evaluative criteria that might improve them, increasingly salient. Such criteria are essential to developing a capacity to compare the economic performance of heterogeneous mixtures of sanitation configurations with variable service outcomes. The methodological uncertainty about how to compare heterogeneous urban sanitation interventions has been identified as a key constraint to the delivery of *citywide inclusive sanitation* (CWIS) as a municipal public service (Lüthi *et al.* 2020; Mills *et al.* 2020; Schrecongost *et al.* 2020).

To address this uncertainty, methodologies enhanced by more comprehensive least-cost principles are needed to assist urban sanitation planners in interpreting the complex economic relationships that exist within cities of LMICs (Scott *et al.* 2017). As Scott & Cotton (2020) observes in presenting the emerging *sanitation cityscape* framework, the extent to which the complexity of the household demand for urban sanitation services has been embraced in planning frameworks is limited. Thus, how the bottom-up demand for services from women, girls, and those who are poor or experience marginal living environments can be poorly understood by planners (Hutton & Andrés 2018; Spuhler & Lüthi 2020). Understanding the complex interface of mixed service provision typologies and household demand profiles is critical to distributing the costs and benefits of seemingly fragmented urban sanitation configurations more equitably (Scott & Cotton 2020).

While this *sanitation cityscape* may be interpreted in different ways, the conceptualisation is well aligned with the four principles of the evolving CWIS planning framework (Scott & Cotton 2020; Schertenleib *et al.* 2021). Namely to (i) prioritise urban sanitation as an equitable and inclusive human right; (ii) achieve safely managed sanitation service outcomes across an entire urban water cycle via a diverse, adaptive, and incremental mix of service provision models; (iii) recognise the tangible and intangible contributions of sanitation to economic development; and (iv) commit to partnerships between formal and grassroots actors to transparently deliver integrated urban services (Lüthi *et al.* 2020).

With this background in mind, this paper has three objectives: (i) to establish evaluative criteria for the comparative economic analysis of sanitation interventions based on principles embodied in the *theory of economic costing* (Julius 1979) promoted in the *Kalbermatten model*, as a reference case; (ii) to chart evidence from a more comprehensive set of least-cost, Integrated Resource Planning principles for urban water systems (Mitchell *et al.* 2007; Willetts *et al.* 2010, 2013) about how comparative economic analysis methodologies may better analyse and interpret how urban sanitation configurations distribute costs and benefits across a *sanitation cityscape*; (iii) to scope and discuss enhanced evaluative criteria for the economic analysis of CWIS interventions.

METHOD

Evaluative criteria for the comparative economic analysis of CWIS interventions have the potential to (i) facilitate the selection of least-cost urban sanitation configurations, (ii) provide a consistent lens for assessing the quality of studies, (iii) assist with making coherent comparisons across different contexts within cities, and (iv) enhance the capacity of municipal authorities, civil society, and grassroots actors to make inclusive and evidence-based decisions (Lüthi *et al.* 2020). We build on the gap analysis presented by Hutton (2001) to conduct a scoping review examining how least-cost planning principles may enhance comparative economic analysis methodologies. Our objective is to inform methodologies that compare urban sanitation configurations more meaningfully.

Hutton (2001) applied a deductive review to map evidence about gaps in existing evaluative criteria for the comparative economic analysis of water and sanitation interventions. *Twenty-four* methodologies were used to compare these interventions and mapped against existing evaluative criteria for health interventions. In this case, those used to appraise studies in the *British Journal of Medicine* (Drummond & Jefferson 1996). While it was identified that these principles were not sufficiently comprehensive for the comparison of water and sanitation interventions, they would be useful in understanding the additional principles that would be necessary to apply. The rationale used was that they represented consensus among health economists about what had a demonstrated capacity to improve the quality of studies. By identifying the gaps, Hutton (2001) intended for future work to shape more fit-for-purpose methodologies.

To build upon this gap analysis, we apply an inductive scoping review with two iterations, as outlined in Figure 1 (Khalil & Tricco 2022). We aim to understand how more comprehensive, *least-cost* principles may enhance the allocative efficiency of emergent mixtures of heterogeneous CWIS interventions. The review acknowledges that we have selected evaluative criteria for health interventions as a point of reference that has since been subject to two major reviews (Drummond & Jefferson 1996; Husereau *et al.* 2022). However, the review by Hutton (2001) is useful as a pivot, as it clearly distinguishes gaps between the principles and practices relevant to the comparative economic analysis of water and sanitation interventions

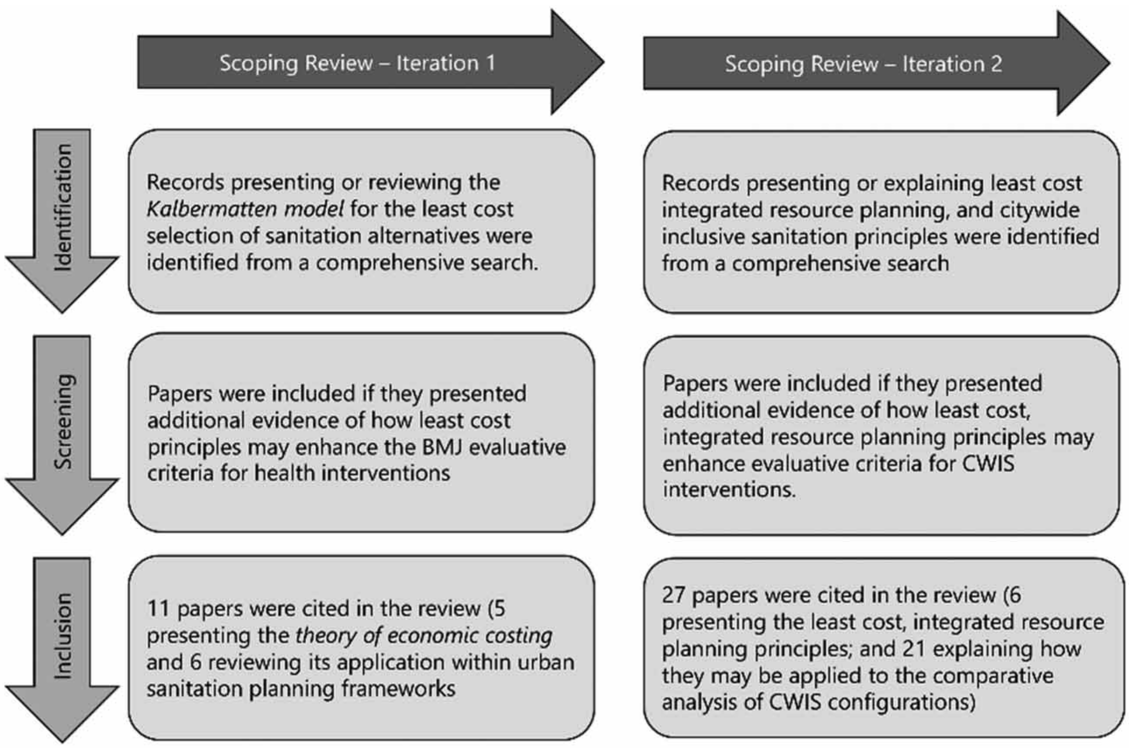


Figure 1 | Scoping review methodology.

from those of health interventions. This trait enables a discussion about how to scope how these limitations may be addressed in enhanced evaluative criteria for urban sanitation and, more specifically, CWIS.

The first iteration of the evaluative criteria for health interventions in Column 1 of Supplementary Table S1 is conducted by charting principles from the literature presenting the *theory of economic costing* (Squire & van der Tak 1975; Julius 1979; Kalbermatten *et al.* 1980, 1982; Mara 1996) that address gaps identified by Hutton (2001). To support this iteration, we also considered additional literature reviewing the application of this theory in planning frameworks retrospectively (Kennedy-Walker *et al.* 2014; Rosenqvist *et al.* 2016; Scott *et al.* 2017; Spuhler & Lüthi 2020; Schertenleib *et al.* 2021).

A second iteration of the evaluative criteria was conducted with an explicit objective of charting more comprehensive and up-to-date least-cost principles for sustainable urban water management and a related *cost-effectiveness analysis methodology* applying them to urban sanitation interventions (Mitchell *et al.* 2007; Willetts *et al.* 2010, 2013; Retamal *et al.* 2011). To support this iteration, we referred to related resources providing more in-depth coverage of particular concepts (Hanley & Spash 1993; Beecher 1996; Fane *et al.* 2003). We also extended the scope of the criteria to consider how they might embody CWIS principles (Lüthi *et al.* 2020; Scott & Cotton 2020). To do so, we sourced additional updated literature on least-cost principles for urban water and sanitation. We searched the titles, abstracts, and keywords of English language literature published between 2001 and 2021, recorded in the *SCOPUS* and *Google Scholar* databases, including any included papers' citations and reference lists. We applied the search terms *urban, sanitation*, permutations of the terms *plan**; *cost**, *economic*, *financial*, *citywide*, *inclusive*, as well as specific keywords from the least-cost planning framework, namely, *cost-effectiveness analysis*, *cost-benefit analysis*, *multicriteria decision analysis*, *sustainability assessment*, *resource efficiency*, *societal cost perspective*, *reference case, systems thinking*, *system boundaries*, *complex system**, *life cycle cost**, *average incremental cost**, *externalities; and uncertainty*.

Our inclusion criteria were based on the participant, concept, context mnemonic (Khalil & Tricco 2022). We defined the participant as the evaluative criteria and the concept as the least-cost principles. The context was defined as the application of a comparative economic analysis methodology to CWIS interventions in LMICs. As each included paper was read in full, relevant principles for the evaluative criteria were extracted. The intention of the scoping review was primarily to consolidate and tabulate fragmented literature about this complex and interdisciplinary context as a precursor to a systematic review. If applied comprehensively, the risk of bias from this method of scoping the literature is not significant (Khalil & Tricco 2022). An outline of the approach is provided in Figure 1.

RESULTS AND DISCUSSION

The evaluative criteria for the comparative economic analysis of CWIS interventions derived from this methodology are presented in Supplementary Table S1. They are consolidated in Table 1 and interpreted in the discussion that follows. This discussion is supported by a companion paper that systematically reviews the application of the evaluative criteria to existing comparative economic analysis methodologies, citing practical examples of how they may be applied from relevant literature (Ross *et al.* 2024).

Defining urban sanitation from a societal cost perspective

While Drummond & Jefferson (1996) imply that a well-defined comparative economic analysis of health interventions may be designed from a single cost perspective, CWIS interventions require a societal cost perspective aggregating multiple viewpoints. The legitimacy of inclusive decisions is shaped by the capacity of analysis to accommodate the cost preferences of societal actors and related subgroups. This requirement is reflected by Kalbermatten *et al.* (1982), stating that '*all costs to the economy are included within the scope of an analysis, no matter who incurs them*' (Julius 1979).

Framing a comparative economic analysis from a societal perspective enables the financial costs and benefits of an intervention appraised to have the least societal cost to an economy to be disaggregated and distributed equitably (Squire & van der Tak 1975; Julius 1979; Kalbermatten *et al.* 1982). For instance, the allocative efficiency of interventions prioritising user convenience, such as conventional waterborne sewerage, will differ from those intended to provide basic, safely managed services at a low cost of ownership (Kalbermatten *et al.* 1980; Lawhon *et al.* 2017). In LMIC contexts, this might include options that extend to the use of formal, centralised interventions beyond their intended objectives or those informal services that arise in response to unmet demand (Lawhon *et al.* 2017).

A societal cost perspective differs from a conventional utility perspective, which selects options based on the capacity to recover costs from additional service users from a predetermined intervention (Willetts *et al.* 2013). Adopting multiple

Table 1 | Evaluative criteria for the comparative economic analysis of CWIS interventions

Study design	
Research question	
1.1	A research question is outlined that balances economic efficiency, equity, and sustainability outcomes inclusive of low-income households, women, girls, and those facing insecure land tenure
1.2	The study adopts a societal cost perspective, disaggregated by the cost perspectives of key societal actors and relevant subgroups
The rationale for the comparison of alternatives	
2.1	All alternative supply and demand-led interventions that might meet a defined service outcome are compared against the opportunity costs of forgoing the least-cost standard that would have emerged without a project
2.2	The without-project case and alternatives are framed within consistent and critically defined system boundaries that are explicit about the people, time, and service dimensions adopted in the analysis and relevant to key decision-makers
Economic analysis methodology	
3.1	The economic analysis methodology comprises (i) a comparable cost-effectiveness analysis, (ii) optimisation of each alternative, and (iii) end user(s), especially marginalised end users, making a final cost–benefit or cost-effectiveness determination of the least-cost alternative based on broad qualitative criteria
Data collection	
Effectiveness data	
4.1	Sources used to derive outcome measures are stated, and the study design is specific to the study context and the system boundaries of the comparative economic analysis
4.2	If outcome measures from multiple cost-effectiveness studies are compared, a method of synthesis or meta-analysis is provided, including a justification for why the results are comparable
Benefit valuation	
5.1	A primary outcome measure is reported in units of total annualised costs, or NPV per household or capita (TACH/TACC), along with an explicit account of the costs and outcomes included in the measure
5.2	If tangible and quantifiable benefits have been valued, the method adopted is relevant to the context in which the estimate is made explicit
5.3	Intangible and unquantifiable benefits are reported separately in a format that enables their relevance to be determined by decision-makers
Cost data	
6.1	Quantities of resources are reported separately from unit costs and used to determine relevant life cycle costs using average incremental costing
6.2	Currency and price data are recorded, and details of adjustments for inflation or exchange rates are given
Modelling	
7.1	A contextually relevant resource flow model is described and justified as the basis for estimating the economic costs over the time horizon of analysis for a hybrid mixture of service provision interventions, with any assumptions applied made explicit, recoverable, and testable
Analysis and interpretation of results	
Adjust for the timing of costs and benefits	
8.1	The time horizon and discount rate(s) used in the analysis are stated and justified
Account for uncertainty	
9.1	Details of statistical tests and confidence intervals are given for all stochastic data
9.2	Methods, such as sensitivity or scenario analysis, are used to explore and describe uncertainties, and their implications can be interpreted by diverse subgroups
9.3	Deliberative multistakeholder decision-making methods, inclusive of marginal users, address epistemic uncertainty as part of the design of economic analysis methodology and increase the likelihood that root causes of gender and social inequity shape decisions
Present results transparently	
10.1	Relevant, mutually exclusive alternatives optimised to meet the same service outcome are compared in incremental units of TACH/TACC against a cost-effective, without-project standard

(*Continued.*)

Table 1 | Continued

Study design	
10.2	An aggregate primary outcome measure is also presented in a disaggregated form for each stage of the sanitation service chain, life cycle cost component and for each cost and subgroup perspective
10.3	A non-prescriptive conclusion is presented in response to the study question arising from the reported data, accompanied by appropriate caveats describing uncertainties to enable societal actors, especially marginalised users, to interpret the study outcomes independently

perspectives within a societal lens enables service outcomes to be negotiated, accommodating a greater range of options within an analysis. However, adopting a societal perspective increases the complexity of comparative economic analysis and the data required to describe the economic impacts of interventions. The breadth of costs included expands and may include data not systematically collected in LMICs (Scott & Cotton 2020). For instance, data about social and environmental externalities, such as the climate impacts of service provision, which institutions may be reluctant to adopt within an analysis (Kalbermatten *et al.* 1980).

Data about subgroup cost perspectives, such as those of women and girls or those with marginal housing tenure, are also not typically considered for disaggregation by utilities in LMICs (Hutton & Andrés 2018). For instance, Danert & Hutton (2020) juxtapose the significance of household expenditure on the self-supply of sanitation services in many countries with the typical lack of inclusion of this knowledge in feasibility studies. Hutton (2001) identified the potential for *subgroup analysis* to enhance the capacity of comparative economic analysis to generate cost-effectiveness data for interventions that are more specific to clusters of households. This extends the capacity of analysis to consider equity outcomes of decisions in more detail (Squire & van der Tak 1975; Hutton & Andrés 2018; Narayanan *et al.* 2018; Kohli-Lynch & Briggs 2019).

Comparative economic analysis methodologies for CWIS interventions may use data about disaggregated subgroups to develop more robust models to better understand the performance of urban sanitation configurations from a societal lens. For instance, *multiple technical approaches that are adaptive, mixed, and incremental and operate under different ownerships at different economies of scale* (Schrecongost *et al.* 2020) may be compared iteratively to consider different financial trade-offs that may work towards outcomes where everyone benefits (Schrecongost *et al.* 2020). Residential end-use modelling approaches, as discussed later in this paper, are one approach that may be used to facilitate data collection and analysis that might enable subgroup analysis (Retamal *et al.* 2011). Others are articulated in a companion paper presenting a systematic review of the evaluative criteria (Ross *et al.* 2024).

A consistent basis for comparing alternative CWIS interventions

Kalbermatten *et al.* (1982) referred to two key findings from studies about the cost-effectiveness of sanitation alternatives in Asia and Africa to support their model. The first was that at least two feasible low-cost alternatives to conventional waterborne sewerage could provide universal access to adequate sanitation service outcomes. Second, incrementally sequencing the implementation of these interventions over time is typically more cost-effective than conventional waterborne sewerage due to the capacity to employ local labour and resources.

Both of these observations make the basis of the comparison of alternatives important. For comparing health interventions, *a before and after* basis is often used for comparing mutually exclusive alternatives to enable an assumption that the opportunity costs of forgoing the existing intervention are *doing nothing* and negligible (Drummond & Jefferson 1996). However, this is rarely, if ever, the status quo for water and sanitation interventions and makes the basis for comparison of alternative service provision models more uncertain (Hutton 2001). For this reason, Julius (1979) asserted that, in principle, sanitation intervention should instead be compared to a *without-project scenario* to represent the local opportunity costs of existing service provision approaches. Sacristán *et al.* (2020) further clarify this principle by defining a *without-project reference case* as representing the most cost-effective situation that would have otherwise emerged without an intervention.

While it is more complex to define this without-project situation, it is important to ensure the integrity of an economic analysis that claims that '*no alternative use of resources consumed by a project would secure a lower societal cost*' (Squire & van der Tak 1975). A comparison with a local cost-effective standard is essential for understanding the local resource implications arising from all possible options that may be selected. These include supply-led interventions that enable access to additional resources and demand-led or behavioural approaches that distribute the benefits of existing resources more equitably (Beecher 1996; Fane Robinson & White 2003; Mitchell *et al.* 2007; Willetts *et al.* 2010; Spuhler & Luthi 2020).

Defining a without-project case as the basis for comparison significantly impacts the outcomes of comparative economic analysis, but it is also subjective. This situation means scoping the *system boundaries* of an appraisal of sanitation alternatives should be conducted with a critical lens (Mitchell *et al.* 2007; Willetts *et al.* 2010). Historically, institutional preferences for conventional waterborne sewerage have led to default decisions about the costs and benefits that should be included or excluded from an analysis of sanitation interventions (Hutton 2001). For instance, household investments and the costs of water for flushing or treating greywater have typically been excluded from least-cost analysis despite the greater relevance of these factors in LMICs (Kalbermatten *et al.* 1980; Danert & Hutton 2020).

Willetts *et al.* (2010) advocate for an explicit justification of the *system boundaries* regarding a study's *people*, *time*, and *service* dimensions. The people dimension refers to a consistent definition of the population considered in a study, including their behaviours and values. The time dimension refers to the time horizon of a study and whether it appropriately accounts for how the life cycle costs of alternative interventions are sequenced over time (Fonseca *et al.* 2011). The service dimension refers to a consistent definition of which components of a sanitation service chain are being considered by a study. CWIS frameworks are purposive in shifting how system boundaries of comparative economic analysis are defined so that safely managed service provision is universal and inclusive (Schrecongost *et al.* 2020). For instance, the *sanitation cityscape* framework proposed by Scott & Cotton (2020) advocates for the *living environment* to be explicitly included within the system boundaries of analysis, encompassing the diverse typologies of demand for services that exist within households (Danert & Hutton 2020).

Selecting an appropriate comparative economic analysis methodology

Comparative economic methodologies for water and sanitation interventions are described as less developed than health interventions (Hutton 2001). This contributes to there being scarce evidence of the economic efficiency of sanitation alternatives in cities of LMICs (Hutton *et al.* 2014; Hutton & Chase 2016). Available data are framed at a global or regional level and is limited to a general conclusion that the economic benefits of urban sanitation outweigh the costs rather than informing decision-makers about how options might be optimised towards CWIS outcomes (Hutton *et al.* 2014; Hutton & Varughese 2016; Perard 2018). A broad range of methodological limitations exist that are specific to comparing the costs and outcomes of water and sanitation interventions at a municipal scale (Hutton 2001).

Kalbermatten *et al.* (1982) assert that all comparative economic analysis methodologies are only partially satisfactory for comparing sanitation alternatives. A common approach is to make a *cost minimisation assumption* that the interventions being compared are mutually exclusive and provide equivalent service outcomes to justify the selection of the alternative with the lowest net present value (NPV) as the least cost. However, as this assumption rarely manifests in practice, uncertainty prevails about any quantitative measure of cost-effectiveness arising from this assumption (Squire & van der Tak 1975; Julius 1979).

An implication of not applying this assumption is that it becomes necessary to monetise the benefits of sanitation alternatives to compare them either in (i) absolute terms within a *cost-benefit analysis*, where tangible benefits are valued by a market or a proxy measure, or (ii) as a standard outcome measure to conduct a *cost-utility analysis*, where costs are defined in relation to a broadly accepted proxy measure of benefit, such as disability-affected life years. Benefit valuation is contentious and has been identified as a significant constraint to the comparative economic analysis of water and sanitation interventions (Hutton 2001). Well-established methodologies applying these approaches report difficulties in accounting for all intangible and non-monetisable benefits and a lack of local data with which to model valuations at a resolution at a sub-national scale with integrity (Hutton *et al.* 2014; Hutton & Chase 2016).

In response to these limitations, Kalbermatten *et al.* (1982) proposed a multi-method approach to the appraisal of sanitation alternatives, comprising (i) a comparable *cost-effectiveness analysis* of direct and tangible indirect costs; (ii) optimisation of each alternative aligned with the objective of the analysis; and (iii) a process enabling service users to make the final cost–benefit determination to deal with the intangible and non-monetisable impacts of alternatives. Willetts *et al.* (2013) extend the idea of service users making a final cost–benefit determination by framing deliberative sustainability criteria as an alternate means of dealing with externalities. This work could be further adapted to include households, particularly vulnerable users, in decisions in alignment with CWIS principles.

Generating context-specific effectiveness data

A significant difference between the comparative economic analysis of health interventions and water and sanitation interventions is that randomised controlled trials generate data for the latter, where it is less certain which drivers of change effectiveness data for water and sanitation represent (Hutton 2001). A reliable, standardised methodology that produces robust, cost-effective data is necessary to improve the capacity to make evidence-based decisions about selecting least-cost urban sanitation configurations. However, the current focus of the literature is on increasing the volume of available financial unit cost data (Daudey 2018) and standardising how it is reported to enable a meta-analysis of the costs of established urban sanitation interventions (Sainati *et al.* 2020). This approach applies broad-brush parametric estimation methods to develop *heuristics* or rules of thumb that may be used to support decisions about infrastructure decisions.

Higher quality and more robust effectiveness data are necessary if the cost determinants of complex mixtures of CWIS interventions are to be understood (Willetts *et al.* 2010) and a more appropriate basis for comparing interventions established (Hutton *et al.* 2014). Very few comparative economic analyses of urban sanitation interventions specify a context-specific, least-cost standard as a basis for generating and comparing cost-effectiveness data. This limitation impedes more detailed and flexible analyses that accommodate multiple perspectives and inform more context-specific decisions about CWIS interventions and the systemic causes of inequitable service provision (Willetts *et al.* 2010).

For this to occur, costing models that are capable of meaningfully representing the least-cost standard, or without-project case need to be developed. Such models require all existing service provision configurations to be defined so that their unit costs and quantities of resources consumed over time can be estimated at their current service level. While these data may or may not be available for formal service provision models from utilities or other service providers, conceptual models that meaningfully represent informal service provision will be required. Furthermore, cost models should attempt to account for the heterogeneity of how services are provided. This will necessitate that the data collected about unit costs and resource consumption used to support a cost model be sampled in a way that holistically represents a citywide water and sanitation system.

Assumptions embedded within costing models associated with concept designs, bills of materials, household and community surveys, or resource flow models need to be made transparent (Ross *et al.* 2024). Cost-effectiveness models should be considered to be iterative, with built flexibility to test different scenarios over time, whereby significant shifts in the without-project situations are able to be accounted for to facilitate a more robust understanding of the diversity of cost determinants within the least-cost analysis. Multiple methods specific to a city and its heterogeneous contexts, including ongoing household and community surveys in situations where data collection cannot be automated, will be necessary to improve the inclusiveness, flexibility, and certainty of cost estimates (Hutton *et al*. 2014; Retamal *et al*. 2011).

Addressing limits to benefit valuation

The selection of an outcome measure for least-cost analysis that compares the costs of sanitation alternatives with their outcomes is determined by the method of benefit valuation adopted. For example, *benefit-cost ratios* attempt to monetise the value of defined service provision outcomes by collecting empirical data about the price users are willing to pay (Julius 1979). However, this economic value, especially in LMICs, can be an unreliable indicator of true value or resource costs to the economy due to uncertain social and environmental externalities (Squire & van der Tak 1975). The *Kalbermatten model* proposes that the costs of projects should be adjusted by a range of shadow factors defined for a national economy. Governments often define shadow rates to account for contextual factors that cause financial variables, such as interest rates, the price of labour, or critical resources such as water, land, or energy, or exchange rates, to vary from their actual economic value (Squire & van der Tak 1975).

However, this approach is contentious and subject to various objections regarding its accuracy, rigour, impact, feasibility, and desirability. When proposed by Julius (1979), there was awareness of these limitations in accounting for the value of sanitation projects. The rationale for disregarding these concerns was that merely accounting for the variation was sufficient to counter-induced biases within least-cost analysis methods and was preferable to doing nothing (Squire & van der Tak 1975). When considering the heterogeneity of demand and the weakness of the market for sanitation services in cities of LMICs, the relevance of such an approach to municipal-level studies is questionable.

The same problems apply to all direct and indirect, or proxy methods, for valuing the benefits of urban sanitation projects based on willingness to pay for a service outcome, such as contingent valuation or hedonic pricing (Julius 1979; Hanley & Spash 1993; Hutton 2001). Significant practical and theoretical constraints limit their use as a standard measure of benefits arising from water and sanitation interventions *at a project scale* (see Hutton *et al.* (2014)). In particular, the intangible nature of benefits arising from sanitation, such as dignity, comfort, prestige, security, gender equality, household cleanliness, or aesthetics, is challenging to quantify comprehensively within a study (Ross *et al.* 2021). A single measure is unlikely to be representative or consistent across a population (Hutton 2001). The partial nature of benefit valuation and its tendency to misrepresent the scale and distribution of benefits of sanitation limits its use in general decisions about allocating economic resources, at best, to a national scale. This limit applies to the *Economics of Sanitation Initiative* methods, which remain the most rigorous methodology for benefit valuation for urban sanitation (Hutton *et al.* 2014; Hutton & Chase 2016).

For these reasons, outcome measures contingent on benefit valuation to any extent are less relevant to decisions about CWIS. Cost-effectiveness measures of total annualised cost per household (TACH) or per capita (TACC) basis are better suited to municipal-level studies (Julius 1979; Kalbermatten *et al.* 1982; Sainati *et al.* 2020). In this case, benefits are defined for the NPV of providing an incremental unit of a service outcome (i.e., treating the next litre of wastewater or cubic metre of faecal sludge) at the scale of a household. Focusing on a clearly defined service outcome enables a robust, quantifiable comparison of the tangible costs, including those that may be avoided, in a way that is clearly distinguished from intangible and non-monetisable outcomes (Beecher 1996). This knowledge allows intangible costs to be recorded separately and analysed via broader qualitative decision-making processes such as multicriteria decision analysis or a deliberative sustainability assessment (Mitchell *et al.* 2007; Willetts *et al.* 2013).

Representing cost data appropriately

Comparing the costs of alternative sanitation projects involves collecting or estimating both unit costs and the quantities of resources used to supply services over the time horizon of an analysis. This task can be challenging in cities of LMICs, where reliable cost data for urban sanitation configurations can be scarce and difficult to project in the future (Daudey 2018; Mills *et al.* 2020; Sainati *et al.* 2020). Gaps in knowledge related to the units, currency, or year costs were incurred, and other contextual factors are common. For new or innovative approaches to sanitation service provision, context-specific cost data may need to be derived via detailed design work, technology transfer processes, or the endogenous development of service configurations. For example, Willetts *et al*. (2010) and Retamal *et al*. (2011) provide a detailed account of how this may be achieved in an urban LMIC context.

Where sufficient data are available for comparative economic analysis, it should be used to define incremental costs defined in TACH or TACC to help compare assets within a sanitation service configuration over their entire lifetime. An authentic comparison of alternative interventions requires these units to enable costs to be scaled and sequenced over a common time horizon. There can be significant differences in how the costs and benefits of interventions with different asset lives are incurred and benefits, or service outcomes, are realised (Julius 1979; Hutton 2001). For this reason, when comparing alternatives against a least-cost, standard, or without-project case, life-cycle-cost analysis (LCCA) should be applied. Fonseca *et al.* (2011) provide a detailed account of an LCCA methodology, while the evaluation of Criterion 10.2 (see Table 1) by Ross *et al.* (2024) provides examples of studies that have meaningfully applied LCCA.

LCCA helps to optimise the sustainability of options compared within an analysis by explicitly defining how the total costs of investment and ownership of assets are structured over their lifetime, measured as a NPV. LCCA enables the capacity to account for costs as they occur up to the time when the asset with the longest asset lifetime is replaced (Mitchell *et al.* 2007). While frameworks for characterising these costs have been promoted for water and sanitation interventions (see Fonseca *et al.* 2011), they are yet to be universally adopted. Developing a benchmark for reporting life cycle costs would help improve the generalisability of cost data for CWIS interventions (Daudey 2018; Sainati *et al.* 2020).

The approach by which costs are discounted over time is equally essential to applying LCCA. In practice, *annualised unit costs* are commonly reported for this purpose. This method spreads the *capital costs* of infrastructure linearly, on an annual basis, over its anticipated lifetime, before being combined with an estimate of annual operating costs and then discounted (Fane *et al.* 2003; Fonseca *et al.* 2011). The problem with this measure is that it disproportionately favours centralised alternatives with high initial investment costs and excess capacity for planned growth. Conversely, demand-led options that are more adaptive to changing demand over time and are commonly used to provide CWIS outcomes are disadvantaged (Kalbermatten *et al.* 1980). The reason for this is that the benefits of matching a service's supply to the demand for that service are not accounted for with *annualised costs* (Fane *et al.* 2003). Examples of demand-led options include decentralised options that respond directly to specific gaps in service provision or programmes that extend the use and purpose of existing infrastructure.

To counter this potential bias, the *Kalbermatten model* adopts *average incremental* or *levelized costs* (Fane *et al.* 2003). In this case, the sum of the NPV of all life cycle costs is divided by the sum of the present number of households serviced or the volume of water supplied (or wastewater treated) to provide that service (Julius 1979; Willetts *et al.* 2010). Using an average incremental cost as the basis for discounting life cycle costs provides a more context-specific, future-oriented, and equivalent basis for comparing all possible options for providing the same service outcome (Fane *et al.* 2003).

Meaningfully modelling economic costs over time

Drummond & Jefferson (1996) outline how models used within a comparative economic analysis extend the limits of what can be observed using empirical data. In the case of decisions about sanitation interventions, models are used to understand relationships between key determinants of resource consumption and the distribution of costs over time. Within many LMIC contexts, the quality of available data that may be used as input parameters for a model can be limited, fragmented in nature, and typically focused on institutional forms of service provision, where material and financial flows are more likely to be monitored (Lawhon *et al.* 2017).

The integrity of future decisions about how sanitation alternatives are prioritised is shaped by the level of detail in which a model selected can represent the complexity of the interactions between different approaches to service provision. This extent depends on how effectively the *without-project case* of a comparative economic appraisal represents its context and the parameters that determine how the urban sanitation configurations will interact. An ideal model would represent this situation as it exists and include the influence of all relevant cost and subgroup perspectives in any forecast (Mitchell *et al.* 2007; Lawhon *et al.* 2017; Kohli-Lynch & Briggs 2019).

Urban sanitation infrastructure configurations are complex systems because of the heterogeneous demands for service outcomes that emerge from a study population, arising from the diverse mix of interrelated approaches for supplying service outcomes of varying quality (Mitchell *et al.* 2007; Willetts *et al.* 2010; Schrecongost *et al.* 2020). Infrastructure configurations are layered with multiple and partial service provision approaches applied at different scales, comprising '*different coverage, technologies, operations, logics, and ownerships*' (Lawhon *et al.* 2017). Their integrated behaviour is inherently complex to forecast spatially and over time in a way that accounts for these differences.

The essential requirement for any model used within a comparative economic analysis is that the modelling method adopted is explicit and aligned with the objective of an appraisal. The assumptions used to extend available empirical data should fit the context in which the appraisal is conducted and be reported transparently (Drummond & Jefferson 1996). Regarding CWIS interventions, decisions about the definition of system boundaries have uncertain implications. The potential impact of including and excluding perspectives, preferences, and behaviours of different cost and subgroup perspectives at different scales can result in significant variation in how a *without-project case* is defined (Beecher 1996; Mitchell *et al.* 2007; Willetts *et al.* 2010; Retamal *et al.* 2011).

A model might structure different infrastructures, costs, and subgroup perspectives within an urban sanitation configuration as part of different sub-systems within broader system boundaries (Narayanan *et al.* 2018). Systemic modelling approaches require a robust and flexible basis for building up projections of the behaviour of the without-project case and sanitation alternatives from disaggregated empirical data. End-use analysis and modelling approaches effectively represent incremental cost-effectiveness and have been applied successfully to this task (Mitchell *et al.* 2007) in cities of LMICs (Retamal *et al.* 2011). End-use models enable material flows to be shaped by the behaviour of different costs and subgroup perspectives. They enable assumptions about interactions between CWIS service provision models to be tested iteratively and made explicit to promote shared knowledge with which to inform decisions. The benefits and disadvantages of a range of other less robust modelling approaches applied to urban sanitation contexts in LMICs are discussed in Ross *et al.* (2024).

Adjusting for the timing of costs and benefits

Discounting the future costs and outcomes of water and sanitation interventions is more complicated than health interventions (Squire & van der Tak 1975; Hutton 2001). First, urban sanitation configurations comprise interdependent components with diverse asset lives. This variation means there is a trade-off necessary between including the life cycle costs of these components within the system boundaries of analysis and the certainty in which they can be estimated over an extended time horizon (Ilg *et al.* 2017). Second, discount rates that are appropriate to a household cost perspective are likely to be different from those of investors in infrastructure, with the opportunity cost of capital being much lower for households (Fonseca *et al.* 2011). Historically, central governments set discount rates strategically at a national level and are rarely questioned within a comparative economic analysis at a municipal scale (Hanley & Spash 1993). As such, a heterogeneity of cost perspectives concerning the discount rate is rarely, if ever, tested in sensitivity analyses (Ilg *et al.* 2017) for appraisals of urban sanitation interventions, and a greater focus on testing a range of rates and then on justifying the choices made is required for CWIS interventions.

Dealing with uncertainty

Drummond & Jefferson (1996) emphasise the importance of considering how decision-makers might interpret risk and uncertainty associated with the outcomes of a comparative economic analysis (Willetts *et al.* 2013). Risk and uncertainty perceptions are different. Both are associated with deciding about an unknown future consequence of a scenario. However, risks are associated with probabilities that may be known or measured. At the same time, uncertainty is related to aspects of a decision where the probability of a consequence cannot be known (Ilg *et al.* 2017). Urban sanitation configurations in LMICs have many uncertain cost determinants (Daudey 2018; Mills *et al.* 2020), characterised by heterogeneity related to access to water resources, sanitation service provision models, experiences, and aspirations.

Because of this, the outcomes of urban sanitation interventions may not be known at a citywide scale, as they are inherently unpredictable, particularly over the time horizon adopted for comparative economic analysis. In existing practice, most studies focus on the *aleatoric* aspects of uncertainty that may explain what is known and unknown statistically, e.g., by specifying confidence intervals for empirically collected data or by conducting a sensitivity analysis to test uncertain relationships between model parameters (Ilg *et al.* 2017). This type of uncertainty is accounted for in existing evaluative criteria.

However, this is different for *scenario uncertainty*, which relates to ambiguity about how a comparative economic analysis is designed. For example, decisions about the costs and outcomes included in a without-project case or the system boundaries of analysis. This type of uncertainty is e*pistemic* and relates to whether the right questions are being asked to make all relevant knowledge available to inform a decision (Ilg *et al.* 2017). Epistemic uncertainty is not easily measurable, and efforts to manage it often result in decision-makers applying intuitive or subconscious reasoning derived from known past experiences (see Sclar *et al.* 2018). Decisions about the design of a study may draw on intangible social, cultural, or political biases to derive greater confidence in predicting an unknown future outcome.

A critical gap in the evaluative criteria for CWIS is the need to include more diverse knowledge of costs and outcomes in the without-project case or system boundaries used as a basis of comparison in a study. Deliberatively including the preferences, aspirations, and worldviews of people without formal access to land tenure or access to safely managed services and the cost perspectives of subgroups, including women and girls, in the design of a comparative economic analysis is well aligned with the principles of CWIS (Lüthi *et al.* 2020; Schrecongost *et al.* 2020). Including criteria prompting epistemic or scenario uncertainty is thus an essential addition to evaluative criteria (Willetts *et al.* 2013).

Studies should be explicit about how social equity and gender objectives are designed into planning processes and how this might lead to more inclusive outcomes. For instance, economic analysis models may be designed with the capacity to disaggregate the cost perspectives of subgroups representing differences in the social and behavioural determinants of sanitation interventions, in addition to physical determinants (Mitchell *et al.* 2007; Lambe *et al.* 2020). Such an approach helps to make the assumptions and biases underpinning an analysis more explicit and mutually understood to transform how outcomes are interpreted.

Presenting results transparently

Hutton (2001) identified that few published economic evaluations had reported the economics of selecting alternative water and sanitation interventions comprehensively or satisfactorily, with implications on how decisions are shaped. Transparent reporting of the outcomes of a comparative economic analysis is indicated in three main ways. First, aggregated results for the cost-effectiveness of different options should also be presented in a disaggregated format. Ideally, an analysis would be documented clearly, including details about how alternative interventions were selected for comparison and optimised and then how they may be interpreted from all key cost and subgroup perspectives (Kalbermatten Julius & Gunnerson 1982). Transparent reporting also assists in determining how outcomes may be interpreted in other comparable contexts to support decisions beyond the scope of the objectives of the appraisal. Second, outcome measures should not be reported prescriptively or imply consensus about a least-cost outcome from a societal perspective. While outcome measures may help broadly rank interventions, decisions should consider whether outcomes have disproportionate impacts from different financial cost and subgroup perspectives (Kalbermatten Julius & Gunnerson 1980). Ideally, economic outcome measures should be interpreted collaboratively, incorporating broader sustainability criteria representing intangible social, environmental, and political impacts not able to be included within an appraisal (Willetts *et al.* 2013). Third, decision-makers should be made explicitly aware of any caveats arising from the design of a study. In addition, outcome measures should only be validated by the results of other studies if similarity in the methods and the study context can be demonstrated (Drummond & Jefferson 1996).

CONCLUSIONS

Compared to methodologies for the comparative economic analysis of health interventions, those for water and sanitation, and in particular urban sanitation interventions, remain underdeveloped. This scoping review considers evidence about how least-cost economic principles may address identified gaps in evaluative criteria intended for health interventions to make them more fit for purpose for urban sanitation interventions in LMICs.

The results of this scoping review are intended to clarify and provide insights into how least-cost analysis methodologies might better reflect CWIS principles, including (i) the inclusion of diverse cost perspectives, particularly those with marginalised access to the benefits of urban sanitation investments in prioritising urban sanitation interventions (ii) the representation of the existing *without-project case* across an entire citywide sanitation service chain as the basis of comparison; (iii) distinguishing tangible and intangible economic costs and outcomes and integrating both into sanitation planning frameworks; and (iv) the projection of costs and outcomes of mixtures of formal and grassroots sanitation service provision models into the future in a disaggregated form so context-specific impacts of decisions about urban sanitation interventions are more visible.

The resulting evaluative criteria are not claimed to be consensus-based. The review scopes comprehensive, up-to-date, least-cost economic principles to enhance the application of comparative economic methodologies to CWIS interventions in practice. We recommend that researchers and practitioners further review and iterate these criteria. For instance, the criteria may be applied as a charting tool in a systematic literature review to highlight gaps in existing best practices for the least-cost analysis of urban sanitation interventions and provide more specific guidance on how these principles may be applied in practice.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 7 September 2023; accepted in revised form 30 October 2024. Available online 8 November 2024