Sustainability assessment of urban and peri-urban sanitation systems relevant in the Bolivian context

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Foreword

Challenges for planning, implementing, operating and maintaining the provision of sanitation services persist in Bolivia, particularly in the context of expanding urban areas and extreme climate events. Current national sector policies and goals for the period 2021–2025 are aiming to promote universal access to basic sanitation services in both urban and rural areas, including aspects of sustainability of services through better practices, strengthening capacities and community development. Moreover, efficient water use, sanitation reuse approaches, climate-resilient services and adequate management of wastewater to prevent deterioration of water quality are key sanitation aspects contemplated in Bolivia's nationally determined contributions (NDC) water sector goals for 2030, compatible with Sustainable Development Goal 6.

In this context, SEI has been working in the country to support a vision for sustainable sanitation systems in which human health, environmental protection, social adequacy, technical suitability and economic feasibility are all considered. In line with this vision, the following report was commissioned by SEI from a group of experts from Sweden and Bolivia, as part of the Bolivia WATCH (WASH Thinking Connected to Hydrology) programme. The method described by the authors could be of value to service providers, researchers, practitioners, and local and national government officials interested in a holistic and participatory approach to assessing the sustainability of different sanitation systems.

It is notable that the authors examine sustainability of different sanitation systems considering all stages of the sanitation chain, and they provide a broader picture of sanitation approaches in Bolivia, which tend to prioritize large infrastructure improvements at the collection or treatment stages that require higher investments. Nonetheless, with current national sanitation policies including better practices that improve sustainability of existing systems, the content of this report is timely. The illustrative case study in the city of Montero, with different sanitation systems simultaneously in place, and further comparison with an innovation scenario proposed by the authors, serve as examples worth exploring when planning, implementing and improving systems to achieve safe and equitable sanitation for all inhabitants of growing cities in Bolivia, but also in other countries in Latin America.

The authors would like to extend a special thank you to Malin Smith and Ylva Geber, who both carried out work for their MSc theses in El Alto and Montero, respectively, on sustainability assessment of sanitation systems in 2019, providing background material and groundwork for the assessment presented in this report.

Executive summary

Introduction

The proportion of the global population who have access to safely managed sanitation services is steadily increasing, albeit too slowly to meet Sustainable Development Goal (SDG) 6, *"Ensure availability and sustainable management of water and sanitation for all"*, by the year 2030. Bolivia faces significant challenges securing access to safe sanitation for its entire population. Joint Monitoring Programme (JMP) data from 2020 indicate that about 53% of the total population have access to safely managed sanitation in Bolivia, but with a higher level for urban areas (60%).

Even in cities and neighbourhoods with sanitation infrastructure in place, the sustainability of both the infrastructure and the services can be put into jeopardy, for example by floods. Floods not only cause direct infrastructural damages but can also result in the uncontrolled spread of disease from existing but overflowing sanitation systems. To move towards a higher level of sustainability in its sanitation services a city needs not only to address extension of services to previously underserved communities, but also to critically examine its existing sanitation systems and services from a sustainability perspective; in other words, a city needs **sustainable sanitation systems** as well as sustainable planning and management routines to ensure the long-term function of the systems.

For a sanitation system to be sustainable, we must consider the three established pillars of sustainability (*Social*, *Environmental* and *Economic*) but also the sector-specific pillars of *Health and hygiene* and *Technical/institutional* sustainability. To understand a sanitation system's full sustainability, all these pillars/dimensions need to be assessed; there is complexity involved in achieving sustainable sanitation. Included in the complexity is the stakeholder perspective, where priorities between stakeholder groups are likely to vary widely. ***Sustainability assessments*** can be used as a decision-support tool to help systematically choose between alternatives. These assessments can also be used to illustrate strengths and weaknesses of different sanitation systems on a more general level, which can be useful earlier on in planning processes, or to generate an understanding of the sustainability of existing sanitation services.

With this report we have the following objectives.

1. To present a sustainability assessment method that will identify strengths and weaknesses of different sanitation alternatives along the service chain from different co-defined sustainability perspectives.

2. To act as an inspiration to improve and optimize existing sanitation systems.

3. To act as an inspiration to introduce sanitation innovations to improve environment and health sustainability.

The method

In this report we present a sustainability assessment method that can identify strengths and weaknesses of different sanitation systems across the sanitation service chain. The method can be used at different levels in the planning process – from early on and at an overarching level, to decision-making before implementation, to post-implementation – to understand the sustainability of different existing systems.

The method is ***technology-neutral*** and makes use of a ***multi-criteria assessment approach*** coupled with strong ***stakeholder involvement***. Different sustainability assessments building on this approach have been conducted in many different settings, for example in sanitation planning situations in northern Europe. It is important to underline that the method helps with illustration of sustainability of the systems. It is, however, not a full sanitation planning tool in itself; the approach needs to be fitted into a full sanitation planning process.

A sustainability assessment with strong stakeholder involvement helps create transparency in the decision-making process and it makes trade-offs between different technical solutions visible in the process. The technology-neutral starting point (the focus in the beginning is on criteria the sanitation systems will be assessed against) helps create a constructive dialogue around the merits and shortcomings of different sanitation systems, which we think can widen the technology options in urban sanitation to improve sanitation service sustainability. The stakeholder involvement together with the transparency of the process increase understanding of the results.

The steps in the sustainability assessment method and the stakeholder involvement are shown in Table ES 1.

Table ES 1: The sustainability assessment steps and stakeholder involvement.

Sustainability assessment steps	Involved in step	
	Relevant stakeholders	Sanitation experts
Step 1: identify the system boundaries	X	X
Step 2: identify criteria and indicators for each pillar/dimension of sustainability	X	X
Step 3: choose sanitation systems to include in the assessment	X	X
Step 4: assign weights to each criterion	X	X
Step 5: sustainability assessment		X
Step 6: sensitivity analysis		X
Step 7: stakeholder feedback on the results	X	X

The method is presented in detail in Section 2 of this report.

Sustainability assessment of sanitation systems in Montero, Bolivia

In Sections 3 and 4 of the report we apply the sustainability assessment method to existing sanitation systems in Montero, Bolivia, to *illustrate the strengths and weaknesses of different sanitation systems in a systematic and transparent manner.* In these sections the decision-making steps are not included, for example the weighting of criteria and the ranking of systems. Instead, the method is used to show strengths and areas for improvement for each system type. For a city-wide inclusive sanitation approach there will often be a need to use a combination of systems for a number of reasons.

We chose to apply the method using Montero because it is a city that already has three of the four sanitation systems considered in this report implemented and managed within its jurisdiction. The Montero water cooperative, COSMOL, and Montero municipality together provide a good example of a true city-wide inclusive sanitation approach. Therefore, we believe that, for a city like Montero and other Bolivian cities interested in a city-wide inclusive sanitation approach, it could be useful to get an overall understanding of the strengths and weaknesses of different sanitation systems for future improvements in sanitation service delivery.

Steps 1 to 3 and 5 to 7 in Table ES 1 were carried out using data and information from Montero and stakeholder input, complemented with literature data and expert knowledge. The functional unit used for the analysis was the management of all the sanitation flows generated by one person in one year. The criteria and indicators, co-defined with relevant stakeholders, used in the sustainability analysis (Step 2) are presented in Table ES 2.

Table ES 2: The criteria and indicators used for the sustainability assessment in Montero.

Sustainability dimension	Criteria used in the sustainability assessment	Indicators
Health and hygiene	Health risks along the service chain	11: Average number of hazardous events, (see Appendix 5.1 for details)*.
Environmental sustainability	Release of eutrophying and oxygen-demanding substances to water	3: Release of total nitrogen (TN), total phosphorous (TP) and biological oxygen demand (BOD_5) to the environment (kg/cap,yr).
	Water use	1: Consumption of water (L/cap,yr).
	Ease of collection and reuse of resources	1: Degree of separation of different sanitation flows (stormwater, industrial wastewater, greywater, blackwater/urine and faeces).
Social sustainability	Social acceptability	1: How much the household is expected to be engaged in the system.
	Affordability of system	1: System cost in relation to a percentage of minimum wage.
Technical function/ institutional	Appropriate system design	3: How many population densities the system works for, vulnerability to water scarcity, vulnerability to flooding.
	Integration of systems in policies and urban planning	1: National and municipal policies in place, municipal regulation of construction and operation in place, design and construction guidelines in place, operation guidelines in place.
	Technical complexity	2: Energy and level of mechanization and supervision needed; level of integration with other sectors.
Economic sustainability	Capital costs and operation and maintenance (O&M)	1: Annualized cost/cap,yr.
	Financial sustainability of systems	1: % of the system's costs covered by today's tariff.
	Costs of changing habits (considered included in Social acceptability above)	-.

* Different sanitation systems pose a different number of risks due to different operational and management requirements. When necessary for normalizing a grading scale, the average number of indicators for all systems, 11, has been used.

For each indicator we identified a scoring scale, with scores from 1 (poor performance) to 5 (high performance), using a colour-coding system, shown in Figure ES 1.

Figure ES 1: Colour and scoring scale used throughout the report.

We chose to look at four different sanitation system types (Step 3 in Table ES 1), three that exist today in Montero (Systems 1, 3 and 4 in Table ES 3) and one (System 2 in Table ES 3) that exists elsewhere in Bolivia. We looked at the system types as they function today, how they would function if they were operated at their potential and innovations for each system type (Table ES 3).

Table ES 3: Sanitation systems included in the sustainability assessment: existing and optimized versions and innovations considered for each system type.

	Existing	Optimized	Innovations
System 1	WC, conventional gravity-fed sewers and waste stabilization pond treatment	Existing + addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes + proper use of personal protection equipment (PPE)	Up-flow anaerobic sludge blanket (UASB) before the pond system Chemical precipitation
System 2	WC, condominial sewers and anaerobic primary treatment	Existing + change of Imhoff to anaerobic baffled reactors (ABR) and addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers + proper use of PPE	Submerged aerated filter
System 3	WC, household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant	Existing + addition of formal collection service in place (e.g. scheduled), sludge treatment (drying) + proper use of PPE	Replacement of soak pit with infiltration trenches Urea treatment of faecal sludge
System 4	Urine-diverting dry toilets (UDDTs), local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant	Existing + addition of collection and treatment of urine and faeces (Sumaj Huasi's model) + proper use of PPE	Urine stabilization at household level Urine drying at wastewater treatment plant (WWTP) Addition of urea to faecal compost

Results – sustainability assessment of existing and optimized systems in a Bolivian context

We believe that cities that are taking their mandate of sanitation service extension seriously could learn a lot from the sanitation experiences in Montero. Montero is a forerunner and a good example when it comes to using a mix of sanitation approaches to meet its citizens' sanitation service needs: Montero already uses three of the four system types investigated in this report, and several system types are being considered in the planning of sanitation services extensions in Montero.

For municipalities that want to engage in a sustainability analysis we recommend using this report as an inspiration for guiding the process as well as for choice of criteria, indicators and systems. However, it is important that the actual choice of criteria and systems is made in a participatory fashion with relevant stakeholders. It is also advisable that the sanitation experts identify the indicators and carry out the assessment during a concentrated and limited time, to keep stakeholder engagement and the process more alive and efficient.

Table ES 4 summarizes the results of the ***sustainability analysis for the existing systems***, without weighting and without a summary score, since the intention with the use of the method in this section is to show where the systems perform well, and where there is a need for improvement in settings similar to Montero's. For a city-wide inclusive sanitation approach there will often be a need to use a combination of systems for a number of reasons.

System 1 scored high on *Social acceptability, Technical complexity* and level of *Integration with other sectors*. This is not surprising, given that System 1 can be considered as part of the conventional centralized wastewater treatment paradigm, with high acceptance in the sector and among citizens. System 1 scored low on *Household affordability*, *Appropriate system design*, *Vulnerability to flooding* and *Water scarcity* and also on *Economic sustainability*. These low scores reflect that gravity-fed sewer systems with centralized treatment are expensive, suitable in a limited urban context and with a vulnerability to too little and too much water.

System 2 also scored high on *Social acceptability*, *Technical complexity* and level of *Integration with other sectors*. System 2 can also be said to be part of the centralized wastewater treatment paradigm, albeit with lower costs than in System 1. Hence, System 2 scores higher for *Household affordability* and *Economic sustainability* than System 1. The weakest aspects of System 2 are *Release of nutrients and organic matter* and its *Vulnerability to water scarcity*.

System 3 is the alternative with most medium scores (all technical/institutional and social indicators). The medium scores can be related to the fact that the system as such is well known and established but has limited engagement from authorities in terms of proactive service provision, which could improve its performance. Furthermore, it scored high on *Separation of sanitation flows* and *Economic sustainability* and low on *Release of nutrients and organic matter*.

System 4 has the highest number of indicators with high scores, notably the only one with a high score for *Health and hygiene*, *Water use* and *Vulnerability to water scarcity*. However, like the other systems it scored low on *Release of nutrients and organic matter*.

As the systems can be assumed to function today, each system has its strengths and weaknesses. System 4 has most indicators with high scores, having scores of 4 or 5 related to one or more of the indicators in each sustainability pillar. System 1 has the highest number of indicators with the lowest score, mainly related to affordability and economic sustainability and dependence on water.

Given the merits of the sanitation systems demonstrated in this study, even as they function today, it is reasonable that a mixture of sanitation solutions should be included for a city-wide inclusive sanitation approach in contexts similar to those in Montero.

Overall, it can be concluded that none of the systems as they are assumed to work today are removing nutrients and organic matter to a satisfactory level – Systems 2, 3 and 4 scored 1 on TP and BOD_5 release, and no system scored 4 or 5 for these indicators. Therefore, *Release of nutrients and* BOD_5 are common areas for development of all these systems.

In Table ES 5 we present the ***results for the optimized systems*** (see Table ES 3 for details) alongside those for the existing systems, to show the potential improvement in sustainability if the systems were slightly tweaked technically and improved in their O&M.

The optimization of the systems has a few overarching effects. *Environmental* and *Health and hygiene sustainability* are generally increased for the optimized systems, which are the primary functions desired from sanitation systems. Improvements to *Health and hygiene* within the optimized systems were achieved with little additional operating costs. The use of PPE by sanitation workers reduced the likelihood of risk events along the service chain for Systems 1, 2 and 3, as did the improvement of operation and maintenance routines, all of which can be considered low-cost interventions.

This increased *Environmental* performance comes at a cost: increased *Technical complexity* and *Integration with other sector*s as well as decreased *Economic sustainability*. This fact was most clearly demonstrated with System 4, where the optimized system, with urine collection services in place, increased its scores on nutrient and organic matter release from 1 to 4 or 5 (the highest scores of all systems on *Environmental sustainability*), but with a drop in *Economic sustainability* from 4 to 2. It can, however, also be noted that the optimized System 4 still costs less than System 1 and provides the highest levels of environmental protection of all systems. Given its high

Table ES 4: A summary of the sustainability assessment of the sanitation systems for the Montero case as they function today.

		System 1	System 2	System 3	System 4
Health and hygiene	**Health and hygiene**	2	3	3	4
Environmental sustainability	**TN release**	3	2	1	1
	TP release	2	1	1	1
	BOD5 release	3	1	1	1
	Water use	3	3	3	5
	Separation of sanitation flows	2	3	4	5
Social sustainability	**Social acceptability**	5	5	3	4
	Household affordability	1	2	3	3
Technical and institutional sustainability	**Appropriate system design**	1	2	3	4
	Vulnerability to water scarcity	1	1	3	5
	Vulnerability to flooding	2	3	3	4
	Integration into urban planning	3	3	3	4
	Technical complexity	4	4	3	3
	Integration with other sectors	4	4	3	4
Economic sustainability	**Financial sustainability**	1	3	5	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment;
System 2: condominial sewers and anaerobic primary treatment;
System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant;
System 4: urine-diverting dry toilets, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

performance on *Environmental sustainability*, it is reasonable that dry, urine-diverting systems with collection services should be included as a regular sanitation service option.

To provide sustainable sanitation services is costly for all system types. To achieve long-term financial sustainability for a utility, it is necessary to cover all costs including capital expenditure (CAPEX) and operating expenses (OPEX) for the system option in question. Costs can be covered via different financial mechanisms, notably the four Ts: tariffs, taxes, transfers (i.e. development aid) and trade, where trade sometimes can offset some costs if the system produces products that can be sold. An example of such products for "trade" can be biogas if it is collected and sold from Systems 1 or 2, or fertilizers from optimized System 4 (urine and safe compost). In our analysis we looked only at how much of the cost is covered by the tariff applied. It is clear that System 1 needs to rely heavily on taxes and transfers to cover its financial sustainability, which is also what happens for centralized sewered systems across the world today. System 1 is subsidized to a level that none of the other systems are. We would like to underline that all sanitation system types should have access to the same financing mechanisms and subsidy levels as centralized sewered systems. The individual household should not be expected to carry the full costs for on-site systems along the full service chain, especially when more prosperous parts of cities are served by highly subsidized centralized sewered systems. To address the issue of *Affordability*, cross-subsidies between different customers are needed to guarantee access to sanitation services for families with lower incomes.

It is worth noting that safe resource reuse (water, nutrients, energy), which is desired from the perspectives of a circular economy and long-term sustainability, will require an increased *Integration with other sectors*. Therefore, the water sector will have to adapt and cooperate with other sectors to achieve long-term resource sustainability. A low score on *Integration with other sectors* therefore does not mean that the system itself is unsustainable; it only means that additional effort is necessary to cooperate outside the water sector.

Some of the lower scores for the sewered systems (Systems 1 and 2) are difficult to improve with optimization efforts (*Vulnerability to flooding, Vulnerability to water scarcity, Appropriate system design, Household affordability* and *Economic sustainability*) because of the inherent inflexibility in the technical design of sewered systems.

Integration into municipal and urban planning can be improved for all systems; for example, municipal regulation is needed for all alternatives.

Table ES 5: Summary of the sustainability analysis of existing and optimized systems for the context of Montero.

		System 1		System 2		System 3		System 4	
		Existing	Optimized	Existing	Optimized	Existing	Optimized	Existing	Optimized
Health and hygiene	Health and hygiene	2	4	3	4	3	4	4	4
Environmental sustainability	TN release	3	4	2	3	1	3	1	5
	TP release	2	3	1	1	1	1	1	4
	BOD5 release	3	4	1	5	1	3	1	4
	Water use	3	3	3	3	3	3	5	5
	Separation of sanitation flows	2	2	3	3	4	4	5	5
Social sustainability	Social acceptability	5	5	5	5	3	4	4	4
	Household affordability	1	1	2	2	3	3	3	2
Technical and institutional sustainability	Appropriate system design	1	1	2	2	3	3	4	4
	Vulnerability to water scarcity	1	1	1	1	3	3	5	5
	Vulnerability to flooding	2	2	3	3	3	3	4	4
	Integration into urban planning	3	3	3	3	3	3	4	4
	Technical complexity*	4	3	4	3	3	3	3	3
	Integration with other sectors**	4	4	4	3	3	2	4	3
Economic sustainability	Financial sustainability	1	1	3	3	5	4	4	2

System 1: WC, conventional sewers and waste stabilization ponds + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes + {use of PPE}};
System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE};
System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE};
System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model) + {use of PPE}}.

The importance of innovation

The innovations presented in this report differ in their technology readiness levels (TRLs). Some, especially in Systems 1 and 2, are innovative in the Bolivian setting, but not generally in the world. Others, as in System 4, are truly innovative and therefore have lower TRLs. Innovations are, however, needed to improve the sector's protection of public health and the environment.

Innovations will generally increase sustainability of *Health and hygiene* and/or *Environment* at decreased *Economic sustainability* and increased *Technical complexity* across the different system types (Table ES 6).

Sustainable protection of health and the environment from poor sanitation is going to demand more resources for the sector than we are investing today.

Table ES 6: Qualitative assessment of effect of innovations in each system type on sustainability pillars.

	Health and hygiene	Environment	Social	Technical	Economic
System 1	0/+	+	-	-	-
System 2	0/+	+	-	-	-
System 3	0/+	+	-	-	-
System 4	0/+	0	-	-	-

Glossary

Anoxic: Environment conditions where oxygen cannot be found free (O_2) but only bound to nitrogen (NOx-N).

Blackwater: Mixture of urine, faeces and flush water.

BOD_5: Biological oxygen demand. A measurement of the amount of easily biologically degradable organic material measured after five days.

CAPEX: Capital costs.

COD: Chemical oxygen demand.

EAC: Equivalent annual cost.

Excreta: Descriptive term for urine and faeces that is not mixed with flush water.

Greywater: The total volume of water generated from washing food, clothes and dishware as well as from bathing, but not from toilets.

JMP: Joint Monitoring Programme.

MCA or MCDA: Multi-criteria decision analysis.

OPEX: Operational costs.

PPE: Personal protection equipment.

TKN: Total Kjeldahl nitrogen. A measurement of organic (org-N) and inorganic N in the form of ammonium or ammonia (NH_x-N).

TN: Total nitrogen. A measurement of the total amount of nitrogen in a sample, usually measured as the sum of total Kjeldahl nitrogen (TKN) and nitrogen oxides (NO_x-N).

TP: Total phosphorus. A measurement of the total amount of phosphorus in a sample. Usually measured as the total amount of organic and inorganic phosphorus.

TRL: Technology readiness level.

UDDT: Urine-diverting dry toilet. A toilet type in which urine flow is diverted from the faeces, for collection or infiltration.

UASB: Up-flow anaerobic sludge blanket digestion. A form of anaerobic digester used for wastewater treatment.

WSP: Waste stabilization pond.

WWTP: Wastewater treatment plant.

Contents

1. Background

1.1 The sanitation challenge in Bolivia

The proportion of the global population who have access to safely managed sanitation services is steadily increasing. Between 2007 and 2017, access to safe sanitation has risen from 28% to 45%, and during this period some of the greatest increases in access have been in Latin America. Although this increase is positive from the perspective of reaching Sustainable Development Goal (SDG) 6, *"Ensure availability and sustainable management of water and sanitation for all"* (Box 1.1), the rate of progress would need to increase by a factor of four in order to reach the goal by the year 2030 (Economic and Social Council, United Nations, 2019). As the poorest country in Latin America Bolivia faces significant challenges securing access to safe sanitation for its entire population (World Bank, 2020). In the latest census data compiled by the Bolivian National Institute of Statistics from 2012, 47% of the Bolivian population lacked access to basic sanitation services, with large regional variations across the country's different departments ranging from 65% in Beni to 28% in Tarija (INE, 2015).

BOX 1.1: SUSTAINABLE DEVELOPMENT GOAL 6 – *ENSURE AVAILABILITY AND SUSTAINABLE MANAGEMENT OF WATER AND SANITATION FOR ALL*

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.

6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.

6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.

6.b Support and strengthen the participation of local communities in improving water and sanitation management.

Within the second-largest department in the country, Santa Cruz, Montero is the city that is experiencing the largest population growth, which is putting a significant strain on the city's infrastructure, including its water and sanitation systems. According to Montero's 2019 *Municipal Plan for Water and Sanitation*, only 36% of the population in the urban areas are connected to the sewage system, and the majority of the remainder of the population either use simple latrines or septic tanks (GAMM, 2019).

Even in cities and neighbourhoods with sanitation infrastructure in place, the sustainability of both the infrastructure and the services can be put into jeopardy, for example by floods. Montero, and Bolivia in general, is strongly affected by a changing climate, resulting in an increased frequency of both droughts and floods (Sida, 2019). Floods not only cause direct infrastructural damages but can also result in the uncontrolled spread of disease from existing but overflowing sanitation systems. To move towards a higher level of sustainability in its sanitation services a city needs not only to address extension of services to previously underserved communities, but also to critically examine its existing sanitation systems and services from a sustainability perspective; in other words, a city needs **sustainable sanitation systems** as well as sustainable planning and management routines to ensure the long-term function of the systems.

1.2 What is a sustainable sanitation system?

What constitutes a sustainable sanitation system, and even the term sanitation itself, is differently interpreted across the sector. In this report we are using the definitions by the Sustainable Sanitation Alliance (SuSanA) (Box 1.2).

BOX 1.2: DEFINITIONS OF "SANITATION", A "SANITATION SYSTEM" AND A "SUSTAINABLE SANITATION SYSTEM", AS DEFINED BY SUSTAINABLE SANITATION ALLIANCE

The Sustainable Sanitation Alliance[1] is a loose network of hundreds of organizations engaged in the promotion and implementation of sustainable sanitation worldwide. It has defined sanitation, sanitation systems and sustainable systems as follows.

Sanitation is the act or process of making sanitary; and the promotion of hygiene and prevention of disease by maintenance of sanitary conditions.

A **sanitation system** protects and promotes human health by providing a clean environment and breaking the cycle of disease. It encompasses the institutions regulating the system, the organizations and management, the users, the entire technical infrastructure, as well as all services required for the collection, transport, treatment and management of end products of human excreta, wastewater, solid waste and stormwater.

To be a **sustainable sanitation system** it must not only protect and promote human health by providing a clean environment and breaking the cycle of disease, but also be economically viable, socially acceptable, and technically and institutionally appropriate, while protecting the environment and the natural resource base.

(SuSanA, 2017)

For a sanitation system to be sustainable, in the understanding of the Sustainable Sanitation Alliance, we must consider the three established pillars of sustainability (*Social*, *Environmental* and *Economic*) but also the sector-specific pillars of *Health and hygiene* as well as *Technical/institutional* sustainability. To understand a sanitation system's full sustainability all these pillars/dimensions need to be assessed.

1 www.susana.org

1.3 Assessment of sustainability of sanitation systems

By acknowledging the definitions in Box 1.2, we understand that there is complexity involved in achieving sustainable sanitation systems. Not only are there five dimensions of sustainability to consider, but there are also several stakeholder groups, for which priorities are likely to vary widely. ***Sustainability assessments*** can be used as a decision-support tool to help systematically choose between alternatives. They can also be used to illustrate strengths and weaknesses of different sanitation systems on a more general level, which can be useful earlier on in planning processes, or to generate an understanding of the sustainability of existing sanitation services.

In Section 2 of this report we *present a sustainability assessment method that can be used for decision-making between sanitation alternatives in a planning situation*. The method is ***technology-neutral*** and makes use of a ***multi-criteria assessment approach*** coupled with strong ***stakeholder involvement***. Sustainability assessments building on this approach have been conducted in many different settings, for example in sanitation planning situations in northern Europe (Sweden, Finland, Poland, Estonia, Latvia and Lithuania) (WRS Uppsala AB, 2000; Bodik and Ridderstolpe, 2007; Johannesdottir et al., 2019). It is important to underline that the method helps with illustration of sustainability of the systems, which can be used for decision-making among alternatives. It is, however, not a full sanitation planning tool in itself; the approach needs to be fitted into a full sanitation planning process. A sustainability assessment with strong stakeholder involvement helps create transparency in the decision-making process and it makes trade-offs between different technical solutions visible in the process. The technology-neutral starting point (the focus in the beginning is on criteria the sanitation systems will be assessed against) helps create a constructive dialogue around the merits and shortcomings of different sanitation systems, which we think is a good starting point to widen the technology options in urban sanitation to improve sanitation service sustainability. The stakeholder involvement together with the transparency of the process increase understanding of the results, and therefore possibly also acceptance of the eventual selected technical options; this helps create ownership in decisions and can be an extra valuable tool in situations where conflicts exist or may happen. Stakeholder involvement and process-oriented tools demand investment in resources and time early in the process. However, given the improved understanding of the sustainability of different systems prior to investments, added transparency and understanding of results by stakeholders, we argue it is well worth adding sustainability assessments to the sanitation planning process.

In this report we also, in Sections 3 and 4, apply the sustainability assessment method to existing sanitation systems in Montero, Bolivia, to *illustrate the strengths and weaknesses of different sanitation systems in a systematic and transparent manner*. In these sections the decision-making steps are not included, such as the weighting of criteria and the ranking of systems. Instead, the method is used to show strengths as well as areas for improvement for each system type. For a city-wide inclusive sanitation approach[2] there will often be a need to use a combination of systems for a number of reasons. We hope that the results in Sections 3 and 4 of this report will inspire planners and engineers to make best use of existing technologies and to improve and innovate to increase each system type's sustainability to maximize sustainable sanitation service delivery to all. We chose to apply the method for Montero because it is a city that already has three of the four sanitation systems considered in this report implemented and managed within its jurisdiction. The Montero water cooperative, COSMOL, and Montero municipality together provide a good example of a true city-wide inclusive sanitation approach. Therefore, we believe that, for a city like Montero and other Bolivian cities interested in a city-wide inclusive sanitation approach, it could be useful to get an overall understanding of the strengths and weaknesses of different sanitation systems for future improvements in sanitation service delivery.

2 This approach developed by the World Bank's Global Practice along with sector funding, research and implementing organizations is based on the idea that urban sanitation should consider a combination of solutions (e.g. on-site and sewered) centered on provision of services for all, instead of following a business-as-usual approach focused on building infrastructure. https://www.worldbank.org/en/topic/sanitation/brief/citywide-inclusive-sanitation

Lastly, we would like to point out that there are several ways of making sustainability assessments, including using computer programs for comparisons, ranking and weighting, such as the ELECTRE method (Rowley et al., 2012). In this report we have not used these types of tools but are focusing on a more "manual" approach to sustainability assessment, partly because the authors are used to working with the more manual approach but also because we think that this approach may be more accessible to a wider audience than computer-based tools.

1.4 Objectives of the report

This report has the following objectives:

1. To present a sustainability assessment method that will identify strengths and weaknesses of different sanitation alternatives along the service chain from different co-defined sustainability perspectives.

2. To act as an inspiration to improve and optimize available sanitation systems.

3. To act as an inspiration to introduce sanitation innovations to improve environment and health sustainability.

1.5 How to use the report

The method can be used for different purposes: to give a general overview of the sustainability of different sanitation systems in a given context, and to provide guidance as a decision-support tool in choosing between options.

For insights into the sustainability assessment method, see Section 2 of the report. In this section the different steps of the sustainability assessment method are presented.

In Section 3 we carry out a sustainability assessment to give an overview of the sustainability of different sanitation systems in the way they function today in the context of Montero in the Santa Cruz department of Bolivia.

There is room for improvement in how sanitation systems are designed and operated in Montero. In Section 4 we tweak the sanitation systems from Section 3 to see if optimizations can improve the sustainability of each system.

In Section 4 we also discuss the introduction of innovations for each system type and how that can change the sustainability of the systems.

There are several annexes to the report, including material from workshops (Annex 1), explanations of the methods used for the *Health* (Annex 2), *Environment* (Annex 3) and *Economic* (Annex 4) assessments, and finally detailed results from the assessments (Annex 5). The level of detail is high in the annexes; we want to share as much of our findings as possible to be transparent and to help readers who want to undertake similar sustainability assessments in the future.

2. Method – sustainability assessment

The two cornerstones of the sustainability assessment method used in this report are multi-criteria analysis (Box 2.1) and stakeholder engagement (Box 2.2).

BOX 2.1: MULTI-CRITERIA ANALYSIS

Multi-criteria (decision) analysis, MCA or MCDA, is a structured approach to decision-making in situations where several dimensions need to be considered simultaneously and trade-offs between alternatives identified and considered. There are numerous ways to perform MCA, including using several types of software. A general introduction to the subject of MCA can be found in Dodgson et al. (2009). A reader with a keen interest in MCA methods can look into the open access research paper by Wątróbski et al. (2019), where the authors present a review of 56 published MCA methods and describe the decision contexts where they may be suitable.

In this report we use an MCA framework based on the method presented by Malmqvist et al. (2006).

BOX 2.2: STAKEHOLDER ENGAGEMENT

Different stakeholder groups will have different expectations of a sanitation system and will therefore bring different aspects to the sustainability assessment. Stakeholder engagement/involvement is therefore of importance in several of the assessment steps. For example, there is often a difference in what a household and a utility engineer expect from a sanitation system. Affordable services and being easy to use and manage may be expectations from a household, whereas an engineer may be concerned with the system meeting discharge standards and its maintenance requirements. When identifying stakeholders to involve, it is important to think about the entire sanitation service chain, from the household level to the reuse/discharge level.

It is crucial that the criteria and indicators to be used in the sustainability assessment are identified together with the relevant stakeholder groups, and equally so for the step when weights are assigned to the criteria (some criteria may be considered more important to meet than others for the final assessment). The choice of sanitation systems to evaluate should also be made with stakeholders to the degree possible in the given situation. For example, households may have more to contribute on sanitation solutions at household level than on treatment methods. Depending on which level the sustainability assessment is performed at, stakeholder involvement may also be appropriate in the actual decision-making.

These two cornerstones are combined with sanitation knowledge and expertise to implement the sustainability assessment method described in this report. Sanitation experts (SE) work with relevant stakeholders (RS) as follows.

Step 1: identify the system boundaries (RS+SE).
Step 2: identify criteria and indicators for each pillar/dimension of sustainability (RS+SE).
Step 3: choose sanitation systems (RS+SE).
Step 4: assign weights to each criterion (RS+SE).
Step 5: sustainability assessment (SE).
Step 6: sensitivity analysis (SE).
Step 7: stakeholder feedback on the results (RS+SE).

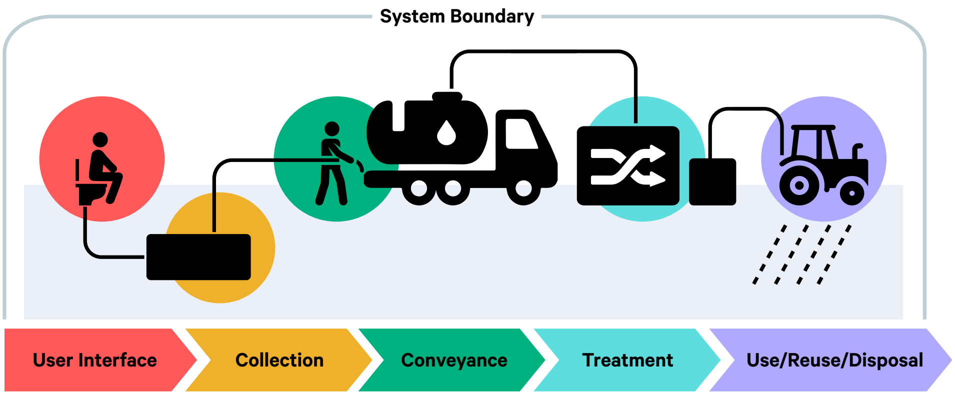
It is important to always keep in mind that a sustainability assessment is context-specific and an alternative that is found to be the most sustainable in one setting, area or region may not be the most sustainable in another setting. This can be due to geographic, resource and contextual factors, which may vary between locations.

The content of each step of the evaluation method is briefly described in the following sections.

2.1 Step 1: identify system boundaries and functional unit

A first important step is to identify the boundaries of the system that will be studied – that is, identifying the parameters within which the different alternatives will be analysed. By setting these boundaries, the different alternatives can be compared using the same "inputs"[3] into and "outputs"[4] from the sanitation system. When comparing different sanitation systems, it is particularly important that the same sanitation flows are considered for all different systems. For example, on-site systems managing faecal sludge only cannot be compared with sewered systems without including the greywater sanitation flow for the on-site system. Household inputs into the system that need to be considered are urine, faeces and greywater. These may be combined into wastewater in the system or enter the system separately. The outputs from the system will depend on the alternative analysed and its associated collection and treatment methods.

Figure 2.1: System boundaries



Source: Further developed from https://forum.susana.org/166-definitions-glossaries-dictionaries-mapping-tools/21715-definition-of-sanitation-value-chain

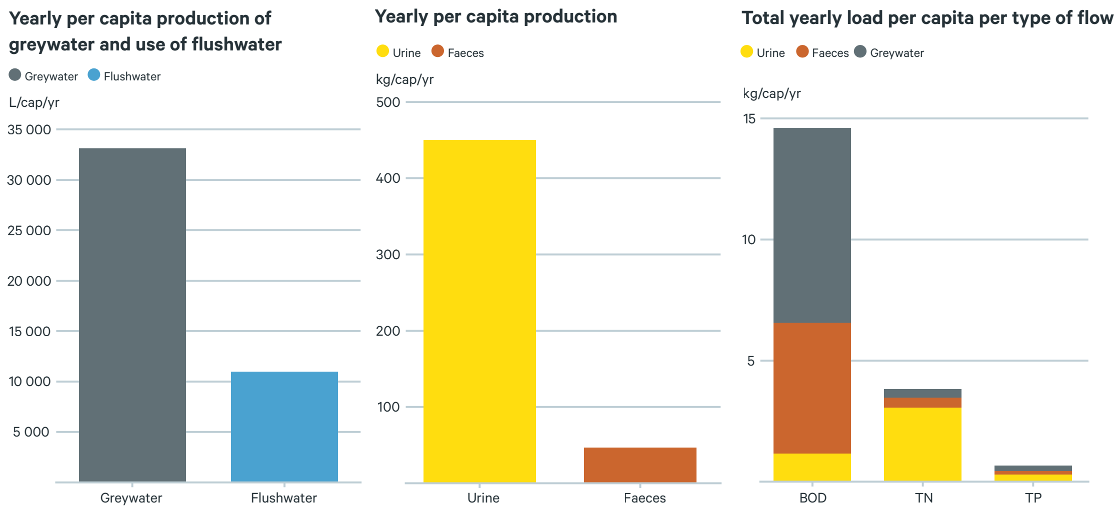
The next step is to identify the functional unit for the assessment of criteria so that comparisons are made in the same way to the largest extent possible (Box 2.3).

3 We use the "input" concept in "Compendium of sanitation systems and technologies" by Eawag-Sandec – the sanitation flows into the sanitation system.

4 We use the "output" concept in "Compendium of sanitation systems and technologies" by Eawag-Sandec – the sanitation flows out of the sanitation system.

BOX 2.3: FUNCTIONAL UNIT FOR QUANTITATIVELY ASSESSABLE INDICATORS

A relevant functional unit for assessment of household sanitation systems is the management of all the sanitation flows generated by one person in a year. The figure is based on the nutrient assessment that is presented in Annex 3.



Source : For calculations see Annex 3.

2.2 Step 2: identify criteria and indicators for each sustainability pillar/dimension

In Section 1.2 we talked about the five different sustainability pillars/dimensions for the sanitation sector (see Box 2.4). All these dimensions are important to understand the overall sustainability of a sanitation system. We use criteria and associated indicators to assess the sustainability of sanitation systems. A *criterion* describes an aspect of a sustainability dimension (example: *Household affordability*) and an *indicator* is a variable (or component) that can be used to determine the status of the specific criterion (example: *annualized per capita cost for the service).*

BOX 2.4: SUSTAINABILITY PILLARS/DIMENSIONS FOR THE SANITATION SECTOR

Sustainability pillars/dimensions that need to be considered within the sanitation sector.

- *Social sustainability*
- *Environmental sustainability*
- *Economic sustainability*
- *Health and hygiene sustainability*
- *Technical/institutional sustainability*

The criteria and indicators may vary between projects and contexts. The *selection of criteria for each sustainability pillar/dimension* should therefore preferably be made with the relevant stakeholder groups. This can be done in a workshop format, where the objectives of the study and the method are presented and the sustainability pillars/dimensions are introduced, after which the participants are divided into groups to identify important and relevant criteria. The results can be presented in a plenary, followed by regrouping and reformulation of overlapping criteria (it is important that the criteria chosen are distinct so that the same thing is not measured twice) and voting on which criteria to include in the sustainability study. This approach allows for a broad collection of everyone's input and a funnelling down to a consensus decision on which criteria to include.

Once the criteria are chosen, sanitation experts can identify suitable *indicators* to assess each criterion. The indicators can be either *quantitative* or *qualitative*. Quantitative assessments can be made for indicators that can be measured/quantified, such as costs, use of resources and discharge of pollutants. Qualitative assessments are needed for indicators that are harder to measure/quantify, such as social acceptance or risks in a work environment.

2.3 Step 3: choice of sanitation systems

The criteria selection workshop, as described in Section 2.2, will give guidance on the expected functions of the sanitation system from the relevant stakeholders across the sanitation service chain. This information, together with the local/national professional knowledge, will enable a sound selection of sanitation alternatives for the evaluation. The starting point for the assessment is technology neutrality. In cases where there are strong and technology-specific expectations in stakeholder groups, typically households and/or utility engineers, these solutions should be included even if unrealistic from a cost perspective. For transparency and consensus-building, the chosen alternatives should be presented and sanctioned by the relevant stakeholder groups. The selection of which alternatives to include in the evaluation could potentially be made at the criteria selection workshop.

2.4 Step 4: assign weights to each criterion

The sustainability assessment can be used to give an overview of the merits and areas for improvement of the alternatives, as is illustrated in Sections 3 and 4 in this report. It can also be used to make an actual choice of the most sustainable sanitation system. It is reasonable to assume that in a given context there will be some criteria that are more important to meet than others. In those cases, weights will need to be assigned to each criterion. This should preferably be done in cooperation with the relevant stakeholder groups at a workshop, once the indicators for each criterion have been defined.

There are different ways to assign weights, the one presented in the next section being but one approach.

Weighting

A relatively simple way of assigning weights to different criteria is to do it in two steps: first assign the relative importance of the sustainability pillars/dimensions, using 100% as the total score, then assign a proportion of the importance weights to each criterion under the sustainability pillars. See Box 2.5 for an example.

BOX 2.5: WEIGHTING OF SUSTAINABILITY PILLARS/DIMENSIONS

In this example, *Health and hygiene* sustainability was considered the most important, followed by *Social* and *Economic sustainability*, then *Environmental* and *Technical/ institutional sustainability*. A total of 100% was assigned between the sustainability pillars, reflecting the relative importance of each. An example of how this could look is given below.

Sustainability pillar/dimension	Assigned weight (%)
Social	20
Environmental	15
Economic	20
Health and hygiene	30
Technical/institutional	15

After the initial weight has been assigned to the sustainability pillars, that weight must be further subdivided based on the criteria for that sustainability pillar. In the example above, 30% of the weight was assigned to *Health and hygiene*. The stakeholder group together with the sanitation experts identified three criteria related to this dimension: *Risk of infection at household level, Risk of infection at community level* and *Workers' safety* (see table below). The 30% assigned to the pillar was divided up to reflect the relative importance of each criterion. Hence, of the overall 100% weighting available for all pillars, 15% was assigned to *Risk of infection at the household level* in this specific example.

Health and hygiene sustainability	Assigned weight out of 30% proportion
Risk of infection at household level	15
Risk of infection at community level	10
Workers' safety	5

This method is relatively straightforward but getting to the assigned weights may be less so. It is recommended to use a workshop format, with good representation of relevant stakeholders, and to work towards a consensus on the weights, as this will result in higher acceptance of the results of the sustainability analysis down the line. Changing of the weights can also be used as part of the sensitivity analysis, see Section 2.6.

The results presented for Montero in this report in Sections 3 and 4 do *not* include weighting. The objective of these sections is to demonstrate the sustainability of each system type, with optimizations and innovations, without prioritization between criteria. This approach makes the results in Sections 3 and 4 more generally applicable for situations similar to Montero than if the weighting would have been included.

2.5 Step 5: the sustainability assessment

Evaluating the indicators is the most time-consuming part of conducting a sustainability assessment. As we have previously discussed, five sustainability pillars/dimensions need to be considered for sustainability analyses within the sanitation sector. Several criteria/indicators per pillar/dimension for a number of systems in the sustainability assessment quickly generate many parameters to consider, demanding time and effort to evaluate.

The level of detail needed in the assessment is dependent on where in the planning process the method is used. For an overall understanding of the sustainability of different systems early in the planning process, a more general approach, as shown in Sections 3 and 4 of this report, may be used. For decision-making between alternatives in a feasibility study, a higher level of detail is needed, including preliminary designs of the systems, to really understand factors such as costs and environmental impacts.

There are different ways to score indicators, but the approach presented in this report is based around developing and applying a five-point scale for each indicator. For an example, see Box 2.6.

BOX 2.6: ASSESSING SUSTAINABILITY – SCORING AN INDICATOR

In this example, two systems are being assessed for their relative sustainability.

System 1: Gravity sewers and up-flow anaerobic sludge blanket (UASB) reactor.

System 2: Gravity sewers and activated sludge treatment with anaerobic digestion of sludge.

The involved stakeholders have determined that greenhouse gas emissions from the sanitation system is one of their main concerns and that it should be included as an environmental criterion in their assessment. One suitable indicator may be the amount of biogas that can be collected for reuse (or that can be flared if reuse is not an option).

Description	Score
Less than 20% of the biogas produced in the system is collected	1
Between 20% and 40% of the biogas produced in the system is collected	2
Between 40% and 60% of the biogas produced in the system is collected	3
Between 60% and 80% of the biogas produced in the system is collected	4
Between 80% and 100% of the biogas produced in the system is collected	5

In this example it is concluded, by consulting biogas process engineers, that a UASB with the proposed design would allow for about 40% of the biogas to be collected, and about 60% of the biogas from the anaerobic digestion of sludge could be collected. Using the proposed scale above, both System 1 and System 2 would score 3 points.

In this example, the identified indicator is *quantitative* in nature but it has been evaluated using a *semi-qualitative* method (i.e. asking experts for their professional opinion).

Compiling the evaluated indicators

Once the sustainability assessment is finished, the overall result can be compiled to get an overview of the results before applying the weights (see Box 2.7 for an example). This “objective” overview is always good to make; it illustrates the strengths and weaknesses of each system for the chosen indicators and on a system level where efforts to improve sustainability are needed.

BOX 2.7: EXAMPLE OF SUSTAINABILITY ASSESSMENT RESULTS WITHOUT WEIGHTING

In this example three different sanitation systems were assessed, using different indicators for each criterion (a to l in the table below). The overall result shows that Systems 1 and 2 are similar in the *Social* and *Environment* indicators, whereas System 2 scores higher for the *Economic* criterion. System 1, on the other hand, scores higher than System 2 for one *Health* indicator and for both *Technical/institutional* indicators. System 3 scores higher than both other systems in the *Environment* and *Health* indicators, but lower on *Social* and *Technical/ institutional*. Hence, the systems have different strengths from a sustainability perspective. The systems are similar in their overall average score, but it would seem like System 3 has a slightly higher level of overall sustainability than the other systems, given the choice of indicators and all criteria being considered equally important (i.e. without weighting).

	Indicator	System 1	System 2	System 3
Social	a	5	4	2
	b	3	3	2
Environment	c	2	2	4
	d	4	4	5
	e	1	1	3
Economic	f	2	4	2
	g	1	4	2
Health	h	3	2	3
	i	2	2	5
	j	2	2	4
Tech/Inst	k	4	3	2
	l	4	2	1
	Average score:	**2.75**	**2.75**	**2.92**

Determining weighted scores – an overall sustainability score

Once all the indicators have been evaluated and the weight for each indicator has been assigned, it is possible to rank the evaluated systems by calculating an overall sustainability score. The calculation is made by multiplying the indicator scores by the corresponding weights (see Box 2.8 and “Weighting” in Section 2.4) and then adding up the resulting products using the equation below:

$$S_i = \sum_{j=1}^{k} W_j C_j = W_1 C_1 + W_2 C_2 + \ldots + W_k C_k$$

BOX 2.8: EXAMPLE OF WEIGHTING OF RESULTS

In this example, we build on the examples in Boxes 2.5, 2.6 and 2.7. The three sanitation systems in Box 2.7 are assigned the weights in Boxes 2.5 and 2.6, which gives average weighted overall scores for the systems as below. As can be seen, the overall results are relatively similar between the systems, hovering between 2.7 and almost 3 when weighted. In this example, with more emphasis on the *Health*, *Economic* and *Social* criteria than *Environment*, System 3 comes out last, narrowly behind the other systems. Without the weighting, System 3 was rated narrowly higher than the other systems. This example illustrates how the weighting can shift the outcome of a sustainability analysis based on stakeholder engagement and feedback .

	Indicator	Relative Weight	System 1	System 2	System 3	Weighted score System 1	Weighted score System 2	Weighted score System 3
Social	a	**15**	5	4	2	0.75	0.6	0.3
	b	**5**	3	3	2	0.15	0.15	0.1
Environment	c	**5**	2	2	4	0.1	0.1	0.2
	d	**5**	4	4	5	0.2	0.2	0.25
	e	**5**	1	1	3	0.05	0.05	0.15
Economic	f	**15**	2	4	2	0.3	0.6	0.3
	g	**5**	1	4	2	0.05	0.2	0.05
Health	h	**15**	3	2	3	0.45	0.3	0.45
	i	**10**	2	2	5	0.2	0.2	0.5
	j	**5**	2	2	4	0.1	0.1	0.2
Tech/Inst	k	**5**	4	3	2	0.2	0.15	0.1
	l	**10**	4	2	1	0.4	0.2	0.1
					Weighted average score:	**2.95**	**2.85**	**2.7**

The assessed alternatives/sanitation systems can then be ranked according to their relative sustainability, with the highest-scoring alternative/system being the most sustainable given the chosen indicators and the chosen weights in the particular decision-making context. It is important, however, to remember that the numerical value of the sustainability score is only relevant for ranking the chosen systems in the given context and with the chosen weights; *it does not represent an absolute sustainability assessment of that sanitation system type*. For example, the choice of criteria/indicators and prioritization (weighting) of these criteria in one context may give results that would look different in another context with other criteria choices and prioritizations.

It is advisable to keep the results in a matrix form, before and after weighting, since the overall information matrix can allow for additional understanding of the sustainability of the systems.

As stated in Section 2.4, the results presented for Montero in this report (Sections 3 and 4) do *not* include weighting, since the objective was to demonstrate the sustainability of each system type, with optimizations and innovations, without prioritization between criteria. This approach makes the results in Sections 3 and 4 more generally applicable for situations similar to Montero than if the weighting would have been included.

2.6 Step 6: the sensitivity analysis

The purpose of this analysis is to determine the sensitivity of the outcome of the sustainability assessment and score to the included indicators (Section 2.2) and weights (Section 2.5). The sustainability assessment is a useful tool to gain understanding of the merits of different options, but it is important to remember that it includes a number of assumptions and uncertainties, which will be specific to each sustainability assessment. Therefore, a sensitivity analysis can give answers as to how robust the results are if different factors change. For example, what would the results in Boxes 2.7 and 2.8 be if the scores and weights are changed to reflect new regulations on effluent values likely to come into place in the coming five years? Or maybe there is disagreement among the stakeholders about how the criteria should be weighted, in which case the sensitivity analysis can include the alternative weighting scenario. Maybe there is uncertainty about the operation and maintenance (O&M) cost estimations of one of the systems. What difference in the results will we see if we apply a different O&M cost estimate for the system in question? Maybe the use of a different source of information, such as new research data, for a specific indicator will change the scoring of the indicator? As shown here, there are several aspects that can be relevant to each specific case, and these need to be identified and included in the sensitivity analysis for a case.

In Sections 3 and 4 of this report we use scoring tables for the sustainability assessment where qualitative or quantitative results are given a score from 1 (poor) to 5 (excellent). There are numerous assumptions and estimations behind each scoring table, and the threshold values between scores can at times be arbitrary. Therefore, it is important to keep an eye on values that are close to the scoring thresholds in the analysis.

The results of the sensitivity analysis should be included when presenting the results of the assessment to involved stakeholders.

2.7 Step 7: stakeholder feedback on the results

Once the sustainability assessment is finished it is important to present its results to the stakeholders, which can be done in a workshop format. It is advisable to go through the outcomes of the first and second workshops (decisions on criteria and weights per criteria and indicator), the systems assessed, the sustainability analysis results and what the effects of critical weights and other factors identified in the sensitivity analysis mean for the sustainability assessment results. This workshop gives the stakeholders a chance to understand the strong and weak points of the different systems, based on the criteria and weights originally determined by them. Furthermore, it gives the stakeholders an opportunity to provide feedback on input data and discuss the methods used and thresholds for scoring.

Even if the method allows for the calculation of a “hard” ranking (see “Determining weighted scores”, Section 2.5) it is advisable also to show the results in the form of matrices (e.g. with colour codes, as in Box 2.8) to illustrate the sustainability results of the different systems in a more comprehensive fashion.

A sustainability assessment with its sensitivity analysis provides a transparent starting point for sustainable sanitation provision decision-making and, further down the line, implementation.

3. Results – applying the sustainability assessment in Montero

In this section we illustrate the method described in Section 2, with the exception of Step 4 (assigning weights), using Montero as a case study. We chose to apply the method to Montero because it is a city that already has three of the four sanitation systems considered in this report implemented within its jurisdiction in a city-wide inclusive sanitation approach, and it has a water cooperative that has embraced a multi-system approach to sanitation service delivery. Montero has a sanitation plan for future expansions/improvement with a multi-system approach. Therefore, we believe that, for a city like Montero and other Bolivian cities interested in city-wide inclusive sanitation, it could be useful to get an overall understanding of the strengths and weaknesses of different sanitation systems for future improvements in sanitation service delivery within their jurisdiction. Currently, Montero is in the process of upgrading its sanitation services, such as with improvements at the treatment plant and with extended faecal sludge management. The results from this sustainability assessment fit into that upgrade process and provide useful information for communication with stakeholders.

Four different sanitation systems, all existing in one form or another in Bolivia today, were analysed. The analysis was made at three different levels: (1) a full sustainability analysis as the sanitation systems function today (Section 3), (2) a full sustainability analysis for the same systems but where they are "optimized" to function at their full capacity/potential (Section 4) and (3) a qualitative discussion around the positive and negative effects when innovations are introduced in each sanitation system (Section 4).

3.1 Case study area – Montero

To illustrate the sustainability assessment method, we use data and information from Montero in the Santa Cruz department of Bolivia. Montero is one of the most populous and fastest-growing municipalities in the department with a population of approximately 135 000 inhabitants.[5] Table 3.1 shows the mean annual income for men and women in quintiles for the Santa Cruz department. Box 3.1 gives background on the geography and climate of Montero.

Table 3.1: Mean annual income for men and women over the age of 18 in the Santa Cruz district in Bolivia (Geber, 2020).

Mean annual income in the Santa Cruz department, Bolivia [USD/yr]		
Quintile	**Men**	**Women**
1st (0–20%)	3,861	2,318
2nd (21–40%)	6,308	5,053
3rd (41–60%)	8,561	7,811
4th (61–80%)	11,833	12,763
5th (81–100%)	25,033	28,541
Average	**11,119**	**11,297**

5 https://www.ine.gob.bo/index.php/montero-es-el-cuarto-municipio-mas-poblado-de-santa-cruz/ [2020-09-29]

BOX 3.1: MONTERO – BACKGROUND INFORMATION

Geography and climate

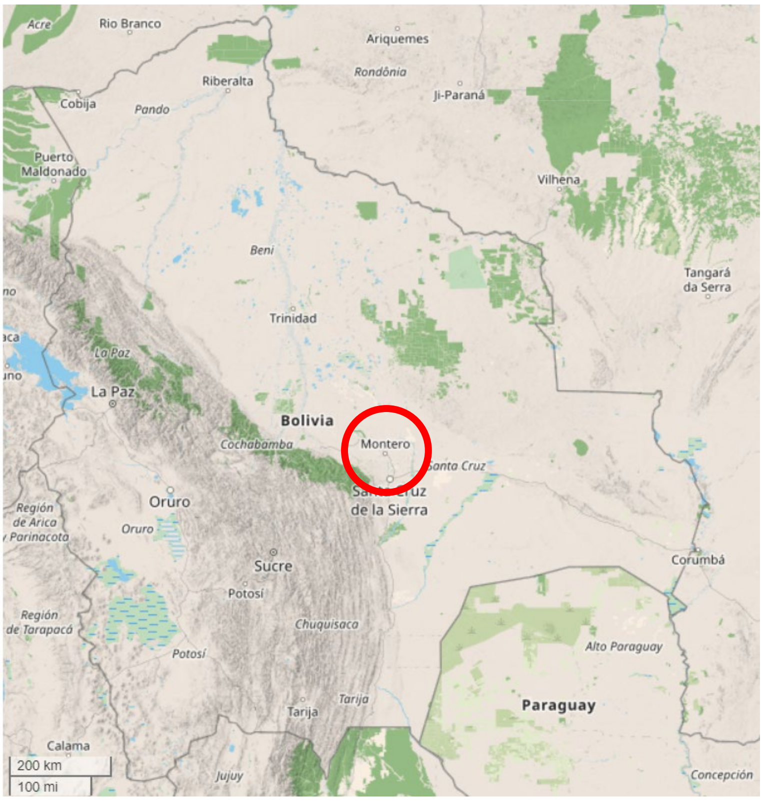
The municipality is situated 230–390 m above sea level and the annual precipitation averages above 1250 mm, with more humid weather during the summer and drier weather during the winter (GAMM, 2019). The climate in Montero is classified as "tropical" according to the Köppen-Geiger climate classification scale with annual average temperatures of 24°C, providing suitable conditions for growing many types of crops.

Soils

The soils in and around Montero consist mostly of sand with smaller proportions of silt. Due to generally acidic soil conditions, the soil pH is commonly increased by spreading ash from burnt leftover agricultural residues. The groundwater table is located around 1.8 m below the soil surface during normal dry conditions but can be situated as shallow as 20–30 cm below the soil surface after rainfall events, and sometimes even reaching above the surface (Geber, 2020).

Crops

Sugar cane accounts for almost 90% of the crops that are harvested during summer (INE, 2013). Corn and soy are commonly grown all year round, while yuca and wheat are alternative crops that are grown during the winter. The cultivations that are most closely situated to Montero are located about 15 km north of the city around the small city of Saavedra.



The sanitation system in Montero

Currently, only 36% of the population in the urban areas of Montero are connected to the conventional sewer and wastewater treatment system (GAMM, 2019). This system is operated by the local water cooperative COSMOL. The collected wastewater is led to a centralized wastewater treatment plant (WWTP) where it passes through a coarse bar screen that removes larger solids before entering an anaerobic pond, the first in a series of three waste stabilization ponds (WSP). Currently, no fine solids separation system exists at the WWTP. Nevertheless, two automatic revolving screens and a grit separation and removal system are currently under construction (Geber, 2020).

About 63% of the population use simple latrines, soak pits or septic tanks. Faecal sludge from septic tanks is collected at the owner's request, transported by truck to the WWTP and discharged at the inlet of the centralized WWTP.

Approximately 1% of the city's population use urine-diverting dry toilets (UDDTs), from which the urine is infiltrated on-site at the households where they are installed. The faeces are collected in containers at the household level and are regularly emptied by COSMOL for transport and treatment at the centralized WWTP. The faeces treatment consists of primary storage before burial at the WWTP grounds. The households having UDDTs at home also have on-site greywater gardens for local greywater management.

The overall sanitation system therefore has basically two main approaches: (1) conveyance by gravity sewers and centralized treatment and (2) on-site collection, conveyance by trucks and a combined centralized treatment. Figure 3.1 gives an overview of the sanitation system in Montero today.

Figure 3.1: Illustration of the existing sanitation system in Montero.

WSP in Montero (Source: Aguatuya)

Septic tank, sludge collection and treatment at WWTP in Montero (Source:Gustavo Heredia)

Dry, urine-diverting toilet and greywater garden in Montero (Source: UNICEF Bolivia)

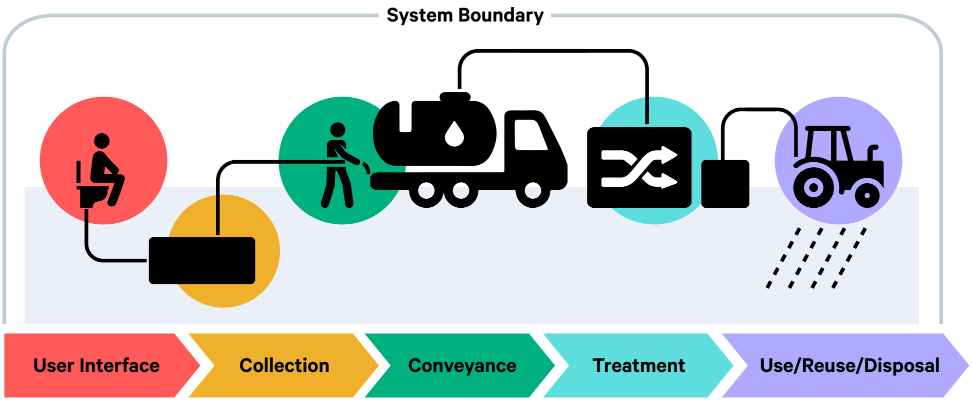
3.2 Sustainability assessment of sanitation systems in Montero

In this section we go through the steps of the sustainability analysis, as described in Section 2.

Step 1: identify system boundaries

For this study, we have included the toilets at household level, the collection, transport and treatment of all sanitation flows from a household (greywater, urine and faeces), as shown in Figure 3.2. We have used the typical inputs into the sanitation system mentioned in Section 2.1 (the sanitation flows going into the system). The inputs are dependent on type of sanitation system used. For a UDDT system the inputs are urine, faeces, cleansing material and greywater, which in turn are transported and treated within the system. For a septic tank system, the inputs are excreta, flush water, cleansing material and greywater. The flows leaving the system (the outputs) depend on the inputs and the treatment method used in each system.

Figure 3.2: The system boundary for the study.



Source: Further developed from https://forum.susana.org/166-definitions-glossaries-dictionaries-mapping-tools/21715-definition-of-sanitation-value-chain

The functional unit in Box 2.3, the management of sanitation flows generated by one person during one year, was used in this study for the indicators, allowing for quantification.

Step 2: identify criteria and indicators

The criteria used for the assessment in this study were identified in a one-day stakeholder workshop in Montero where important stakeholders were represented, including the municipality of Montero, COSMOL, civil society organisations, the national government, NGOs and UNICEF. During the workshop the methodology was presented, after which the participants decided on relevant criteria for each sustainability pillar. The sanitation systems that we proposed to include into the study were presented. The workshop programme and the full list of criteria are available in Annex 1.

After the workshop, the authors of this report, a small group of sanitation experts from Bolivia and Sweden, developed the stakeholder-identified criteria by regrouping to allow for qualitative or quantitative assessment via indicators as shown in Table 3.2. One or more indicators were identified for each criterion.

We assessed and rated each indicator on a five-point integer scale, where a low score indicates lower sustainability performance and a higher score indicates a higher performance (see Figure 3.3).

Table 3.2: Breakdown of the criteria that have been applied throughout the report.

Sustainability dimension	Stakeholder-identified criteria	Regrouped criteria	Indicators
Health and hygiene	Risk of illness in vulnerable groups	Health risks along the service chain	11: Average number of hazardous events (see Appendix 5.1 for details)*.
	Risk of spreading of disease		
Environmental sustainability	Protection of water supplies (surface and groundwater)	Release of eutrophying and oxygen-demanding substances to water	3: Release of total nitrogen (TN), total phosphorous (TP) and biological oxygen demand (BOD5) to the environment (kg/cap,yr).
	Water use	Water use	1: Consumption of water (L/cap,yr).
	Ease of collection and reuse of resources	Ease of collection and reuse of resources	1: Degree of separation of different sanitation flows (stormwater, industrial wastewater, greywater, blackwater/urine and faeces).
Social sustainability	Social acceptability	Social acceptability	1: How much the household is expected to be engaged in the system.
	Need to change habits		
	Affordability of system	Affordability of system	1: System cost in relation to a percentage of minimum wage.
Technical function/ institutional	Appropriate system design	Appropriate system design	3: How many population densities the system works for, vulnerability to water scarcity, vulnerability to flooding.
	Integration in urban planning	Integration of systems in policies and urban planning	1: National and municipal policies in place, municipal regulation on construction and operation in place, design and construction guidelines in place, operation guidelines in place.
	Need for technical and organizational capacity and supervision	Technical complexity	2: Energy and level of mechanization and supervision needed; level of integration with other sectors.
	Capacity at the treatment plant		
Economic sustainability	Capital and O&M costs	Capital and O&M costs	1: Annualized cost/cap,yr.
	Costs sustainability	Financial sustainability of systems	1: % of the system's costs covered by today's tariff.
	Costs of changing habits	-	Considered included in social acceptability above.

* Different sanitation systems pose a different number of risks due to different operational and management requirements. When necessary for normalizing a grading scale, the average number of indicators for all systems, 11, has been used.

Figure 3.3: Colour and scoring scale used throughout the report.

1	2	3	4	5

Below is a description of the applied indicators for each sustainability pillar/group.

Indicators for health and hygiene

The *Health and hygiene* assessment was conducted using a risk framework developed by the WHO (World Health Organization, 2015), in which hazardous events (health risks) along the entire sanitation service chain are identified and assessed. Potentially hazardous events, related to exposure to pathogens, gases and elevated levels of nitrates in groundwater, were identified for the different sanitation systems along the different steps of the sanitation service chain; see Annex 2 for details of the method and Annex 5.1 for the identified hazardous events. Note that the number of hazardous events will differ between systems due to different technical setups and differing O&M demands and activities. The average number of health risks in the systems assessed in this study was 11.

The potential risks in each step of the service chain were assessed, using the likelihood (L) and severity (S) descriptions that are presented in Annex 2 and calculating a risk score (R) according to the following equation.

Risk score (R) = Likelihood (L) x Severity (S)

The calculated risk score for each hazardous event was then assigned a risk level (low, medium, high or very high). The total risk score for each sanitation system was calculated as a sum, as well as the number of risks in each risk level, which both contributed to the final score for each system, as recorded in Table 3.3 (see Annex 2 for details). Note that if there are any "very high" risk hazards present in a system its overall score can never be higher than 1.

Table 3.3: Scoring system used to determine the health score for each system.

Description	Overall number of risks rated very high or high	Total score requirement	Overall score
Very high total risk	> 0 risks rated very high	-	1
High total risk	> 4 risks rated high, no risks rated very high	Total risk score ≥ 143	2
Medium total risk	≤ 4 risks rated high, no risks rated very high	Total risk score < 143	3
Low total risk	≤ 3 risks rated high, no risks rated very high	Total risk score < 110	4
Very low total risk	0 risks rated high or very high	Total risk score < 66	5

Indicators for environmental sustainability

Three indicators were chosen for assessment of environmental sustainability: (1) *Release of total nitrogen (TN), total phosphorus (TP) and biological oxygen demand (BOD_5) to the environment* (i.e. receiving water bodies or soils), (2) *Water use* and (3) *Degree of separation of different sanitation flows*, which are all explained below.

Release of nitrogen, phosphorus and BOD_5

The importance of limiting the release of nitrogen, phosphorus and BOD_5 to water bodies is explained in Box 3.2.

BOX 3.2: WHY IS RELEASE OF NITROGEN, PHOSPHORUS AND BOD_5 IMPORTANT FOR ASSESSMENT OF ENVIRONMENTAL IMPACT?

While urine and faeces make up a relatively small volume (excreta, approx. 1,5 kg/cap,d), they contribute most of the loads of TN, TP and BOD in wastewater.

If insufficiently treated wastewater is infiltrated into soils with shallow groundwater tables it can contribute to elevated risks of pollution of groundwater aquifers. In particular, elevated levels of nitrates can be harmful when using the aquifer as a source of drinking water. Babies, particularly infants, are sensitive to high levels of nitrates and can fall ill with a potentially fatal disease commonly known as "blue baby syndrome" that hampers the blood's ability to oxygenate tissues.

The release of TN and TP from insufficiently treated wastewater to receiving water bodies can contribute to significant eutrophication issues, among which are harmful algal blooms (HABs) affecting entire water-based ecosystems. HABs can produce several different potent natural toxins that reduce the surface water quality and cause harm to humans (who use the water body as a source of freshwater), fish and other aquatic organisms. Following a HAB, the die-off and subsequent degradation of the algae will lead to a significant consumption of dissolved oxygen, which in turn can result in anoxic conditions in the water body. Anoxic conditions can lead to massive die-offs of fish and other aquatic organisms as dissolved oxygen is crucial for most types of aquatic organisms. The release of BOD_5 from insufficiently treated wastewater contributes to the same oxygen depletion issues and is harmful to aquatic environments. As such, the less TN, TP and BOD_5 that are released into receiving water bodies or are infiltrated into soils with shallow groundwater tables the better from an environmental standpoint.

For centralized waterborne systems, release to the environment of TN, TP and BOD_5 can be assessed by the wastewater effluent concentrations, and how well they meet effluent regulation.[6] For sanitation systems that divert nutrient-rich substances, like urine, and therefore reduce the nutrient load to wastewater, effluent concentrations in wastewater and effluent regulation do not work as appropriate indicators. Instead, an *annual per capita load to the environment* can be used, which was done in this study. Descriptions of how the loads in Tables 3.4 to 3.6 were determined can be found in Annex 3. In systems scoring 1 point a high level of the mass load is discharged (more than approximately 90%, 69% and 39% for TN, TP and BOD_5, respectively). Conversely, for systems scoring 5, low levels of the mass load are discharged (less than approximately 21%, 16% and 9% for TN, TP and BOD_5, respectively).

Table 3.4: Scoring of nitrogen release.

Description	Score
Annual TN load on the environment is more than 3.42 kg/cap,yr (*more than appr. 90% of the mass load is discharged*)	1
Annual TN load on the environment is less than 3.42 but more than 2.76 kg/cap,yr (*between appr. 72% and 90% of the mass load is discharged*)	2
Annual TN load on the environment is less than 2.46 but more than 1.45 kg/cap,yr (*between appr. 38% and 72% of the mass load is discharged*)	3
Annual TN load on the environment is less than 1.45 but more than 0.79 kg/cap,yr (*between appr. 21% and 38% of the mass load is discharged*)	4
Annual TN load on the environment is less than 0.79 kg/cap,yr (*less than appr. 21% of the mass load is discharged*)	5

Table 3.5: Scoring of phosphorus release.

Description	Score
Annual TP load on the environment is more than 0.46 kg/cap,yr (*more than appr. 69% of the mass load is discharged*)	1
Annual TP load on the environment is less than 0.46 but more 0.37 kg/cap,yr (*between appr. 55% and 69% of the mass load is discharged*)	2
Annual TP load on the environment is less than 0.37 but more than 0.19 kg/cap,yr (*between appr. 28% and 55% of the mass load is discharged*)	3
Annual TP load on the environment is less than 0.19 but more than 0.11 kg/cap,yr (*between appr. 16% and 28% of the mass load is discharged*)	4
Annual TP load on the environment is less than 0.11 kg/cap,yr (*less than appr. 16% of the mass load is discharged*)	5

6 Provided that the regulation is reflecting the risk of eutrophication, which is not always the case.

Table 3.6: Scoring of BOD_5 release.

Description	Score
Annual BOD_5 load on the environment is more than 5.69 kg/cap,yr (*more than appr. 39% of the mass load is discharged*)	1
Annual BOD_5 load on the environment is less than 5.69 but more than 4.60 kg/cap,yr (*between appr. 31% and 39% of the mass load is discharged*)	2
Annual BOD_5 load on the environment is less than 4.60 but more than 2.41 kg/cap,yr (*between appr. 16% and 31% of the mass load is discharged*)	3
Annual BOD_5 load on the environment is less than 2.41 but more than 1.31 kg/cap,yr (*between appr. 9% and 16% of the mass load is discharged*)	4
Annual BOD_5 load on the environment is less than 1.31 kg/cap,yr (*less than appr. 9% of the mass load is discharged*)	5

Water use

To assess the water use we looked at how the different sanitation systems would impact the water use at household level. The Montero average water use is 120.7 L/cap,day, which was used as the starting point for the mid-point in score 3 in Table 3.7. To achieve a score 3, a variation in water use of plus or minus 12.5% around the average of 120.7 L/cap,day was allowed. If more than 125% of the average water use is necessary at household level, the system scored 1. Equally, if less than 75% of the average water use is necessary at household level then the system scored 5.

Table 3.7: Scoring of water use.

Description	Score
The per capita water use is more than 125% of the average in Montero	1
The per capita water use is less than 125% of the average in Montero but more than 112.5%	2
The per capita water use is less than 112.5% of the average in Montero but more than 87.5%	3
The per capita water use is less than 87.5% of the average in Montero but more than 75%	4
The per capita water use is less than 75% of the average in Montero	5

Degree of separation of different sanitation flows

The separation of different sanitation flows facilitates environmental protection, increases treatment efficiencies and improves the ability of resource recovery (see Box 3.3). There is an analogy with the development in the solid waste sector, where collection of different waste fractions (organics, paper, glass etc.) at the source has improved the possibilities of recycling as well as the quality of recycled fractions.

BOX 3.3: THE IMPORTANCE OF KEEPING DIFFERENT SANITATION FLOWS SEPARATE FROM EACH OTHER

Separation of sanitation flows facilitates both nutrient recovery and treatment efficiency. Sanitation flows that can be collected separately are stormwater including roof drainage, industrial wastewater, greywater, urine and faeces/blackwater/faecal sludge.

A first level of separation in a centralized waterborne system is to keep *stormwater* away from the household wastewater (duplicate systems) to lower risks of flooding with untreated wastewater, keeping the hydraulic loading rate on wastewater treatment processes stable, to avoid dilution and to decrease the pollutant content in the wastewater sludge. *Industrial wastewater* typically contains more harmful chemicals than the typical/average household wastewater and can therefore contaminate the recoverable products such as sludge or treated wastewater if it is mixed in with “cleaner” household fractions. Hence, a second level of separation is to keep industrial wastewater from the household wastewater.

For higher quality of recovered nutrients and of treated wastewater/greywater it is advisable to separate the *greywater* from the *blackwater* from the toilets. Greywater contains some small amounts of nutrients, dish soap, detergents and other household chemicals. Its separation from blackwater will facilitate reuse of the water resource, since greywater contains comparatively fewer pathogens than the blackwater, and therefore can be reused/infiltrated into soil with less treatment compared with a mixed household wastewater. Moreover, when not mixed with greywater, the recovery of nutrients in the blackwater becomes easier (the nutrient content is not diluted with greywater, nor is it contaminated by household chemicals found in greywater). It is worth noting, however, that on-site systems that produce faecal sludge, such as septic tanks, are not efficient in recovering nutrients since most TN and TP infiltrate in soils via the liquid effluents from these systems.

For highest quality and efficiency of nutrient recovery, *urine* should be collected separately from the faeces.

Based on the information presented in Box 3.3, the indicator scale in Table 3.8 was developed.

Table 3.8: Scoring of degree of separation of different sanitation flows.

Description	Score
No separation of sanitation flows at all	1
Wastewater and stormwater are separated	2
Wastewater, stormwater and industrial wastewater are separated	3
Blackwater, greywater, stormwater and industrial wastewater are separated	4
Urine, faeces, greywater, stormwater and industrial wastewater are separated	5

Indicators for Social sustainability

Social acceptability

The two initially identified criteria, *Need to change habits* and *Social acceptability*, from the criteria selection workshop (described in Section 3.2 Step 2) were regrouped together into *Social acceptability*. As an indicator of this criterion we chose how much a household is expected to engage in the management of the sanitation system (Table 3.9). Systems that demand a high level of engagement from the household to function are likely to have a low acceptability.

Table 3.9: Scoring of *Social acceptability*.

Description	Score
The household is expected to manage the system to ensure its function. There is no collection/ emptying service.	1
There is an informal service available for parts of the system (e.g. informal emptying services).	2
There is a collection service available for management of the excreta after the household level. The household needs to engage in calling in the service.	3
There is a collection and management service available (e.g. scheduled emptying and maintenance).	4
Minor household management of the user interface, no household management after the user interface.	5

Affordability (system cost in relation to percentage of minimum wage)

International experience suggests that the costs for water and sanitation services should not exceed 5% of the family income in order to be accessible. In this assessment we have based the *Accessibility/affordability* of the sanitation systems on the total costs of the systems and the Bolivian minimum wage. Estimates suggest that 40% of the cost of water and sanitation services corresponds to safe drinking water and 60% corresponds to safe sanitation. Hence, to score 5, CAPEX and OPEX costs for the sanitation system should not exceed 3% (60% of 5%) of a minimum wage (see Table 3.10). For the CAPEX and OPEX calculations, see below.

Table 3.10: Scoring of *Affordability*.

Description	Score
CAPEX and OPEX of the system are covered by more than 12% of a minimum wage	1
CAPEX and OPEX of the system are covered by 12% of a minimum wage	2
CAPEX and OPEX of the system are covered by 9% of a minimum wage	3
CAPEX and OPEX of the system are covered by 6% of a minimum wage	4
CAPEX and OPEX of the system are covered by 3% of a minimum wage	5

Indicators for Technical/institutional sustainability

Technical/institutional sustainability was assessed via six separate criteria: (1) *Appropriate system design*, (2) *Vulnerability to water scarcity*, (3) *Vulnerability to flooding*, (4) *Integration of systems in urban planning and policies*, (5) *Technical complexity* and (6) level of *Integration with other sectors*. A description of each of the criteria and the applied indicators are presented in the sections below.

Appropriate system design

The criterion *Appropriate system design* was prioritized at the initial workshop in Montero. It was a difficult criterion to find already established and appropriate indicators for. The indicator chosen in the end was a matrix in which flexibility was applied in terms of population density levels that the particular type of sanitation system can accommodate (very low, low, intermediate, high and very high) and the level of planning needed for construction and operation of the system as intended (low, intermediate and high), as shown in Figure 3.4. Depending on how many of these population densities and planning contexts the systems were deemed appropriate for, they were scored as shown in Table 3.11. Box 3.4 provides an illustrative example of the evaluation of this indicator.

Figure 3.4: Scoring matrix for *Appropriate system design*.

Density			
Very high			
High			
Intermediate			
Low			
Very low			
	Low	**Intermediate**	**High**
	Level of planning needed		

Table 3.11: Scoring of *Appropriate system design*.

Description	Score
Applicable in 3 or less density and planning contexts	1
Applicable in more than 3 but less than 6 density and planning contexts	2
Applicable in more than 6 but less than 9 density and planning contexts	3
Applicable in more than 9 but less than 12 density and planning contexts	4
Applicable in 12 or more density and planning contexts	5

BOX 3.4: EVALUATING THE INDICATOR APPROPRIATE SYSTEM DESIGN

To illustrate the evaluation of this indicator, consider a conventional gravity sewer system with centralized treatment. This system is suitable to construct in areas with high population densities and in areas that are highly planned/formal. Outside these contexts conventional gravity sewer systems are not appropriate due to technical, access and cost constraints. Hence, the *Appropriate system design* matrix would look like below, showing that the system is applicable in three or less density and planning contexts, thus scoring 1 point on the indicator according to the scoring system in Table 3.11.

Density	Gravity sewers with centralized treatment		
Very high			
High			
Intermediate			
Low			
Very low			
	Low	**Intermediate**	**High**
Level of planning needed			

Vulnerability to water scarcity

Water serves two main purposes in most common types of waterborne sanitation system: (1) it is used as flush water in toilets and (2) it enables the use of piped conveyance to the wastewater treatment plant. The lack of water during times of increased water scarcity can affect the ability to flush toilets, as well as the conveyance function. For the criterion *Vulnerability to water scarcity* the scoring table was reduced to three levels of scores, because of the difficulty of determining five different/distinct levels of vulnerability, as in Table 3.12.

Table 3.12: Scoring of *Vulnerability to water scarcity*.

Description	Score
Neither the toilet part of the system nor the rest of the system can function at all without water	1
-	2
Toilet needs water, but conveyance does not	3
-	4
The system can function fully without access to water	5

Vulnerability to flooding

Vulnerability to flooding was qualitatively assessed based on the impact on households, conveyance and the treatment capacity if the sanitation system is experiencing a flood. The systems were scored based on the average impact, rounded to the nearest whole number, along the sanitation service chain, as detailed in Tables 3.13 and 3.14.

Table 3.13: Scoring matrix for *Vulnerability to flooding* along the service chain.

	Very high impact (1 point)	High impact (2 points)	Medium impact (3 points)	Low impact (4 points)	Very low impact (5 points)
Household	Very high frequency of household flooding during heavy rainfall	High frequency of household flooding during heavy rainfall	Medium frequency of household flooding during heavy rainfall	Low frequency of household flooding during heavy rainfall	Very low frequency of household flooding during heavy rainfall
Conveyance	Conveyance capacity is close to 0% during heavy rainfall (i.e. conveyance system overflowing)	Conveyance capacity is low during heavy rainfall	Conveyance capacity is moderate during heavy rainfall	Conveyance capacity is high during heavy rainfall	Conveyance capacity is close to 100% during heavy rainfall
Treatment	Efficiency is close to 0% during heavy rainfall	Efficiency is low during heavy rainfall	Efficiency is moderate during flooding event	Efficiency is high during flooding event	Efficiency is close to 100% during flooding event

Table 3.14: Scoring of *Vulnerability to flooding* along the service chain.

Description	Score
On average very high impact	1
On average high impact	2
On average medium impact	3
On average low impact	4
On average very low impact	5

Integration of systems in policies and urban planning

The integration of different sanitation systems in policies and urban planning is a difficult indicator to objectively measure or assess, but it is nevertheless an important factor in order to sustainably plan, manage and operate the systems. In this study we considered the availability of different "governing documents" (e.g. policies, plans, strategies, regulations, guidelines and standards) at the national and municipal levels as an indicator of how well integrated a sanitation system is into urban planning. The systems included in this case study were rated based on how many of the following types of governing documents are available that include or mention the sanitation system in question (Table 3.15):

- national policies, plans and/or strategies are in place
- municipal policies and plans are in place
- municipal regulation on construction and operations exists
- design and construction guidelines/standards are available
- operational guidelines/standards are available.

Table 3.15: Scoring of *Level of integration* in policies and planning.

Description	Score
System included in 0–1 relevant governing documents	1
System included in 2 relevant governing documents	2
System included in 3 relevant governing documents	3
System included in 4 relevant governing documents	4
System included in 5 (or more) relevant governing documents	5

Technical complexity

The more mechanical and technical components the sanitation systems contain, the more technically complicated they become to operate, which will increase the demand for a more specialized and experienced workforce. The technical complexity of the sanitation systems included in this study largely depends on to what degree the systems need to be actively supervised, and to a lesser degree on how technologically advanced they are (all of the included systems can be considered relatively "low-tech"). In this study we included energy demand, level of mechanization and need for active supervision as indicators for *Technical complexity* (Table 3.16).

Table 3.16: Scoring of *Technical complexity*.

Description	Score
Energy-intensive, technically complex, demands highly skilled workers	1
Technically complex, active supervision needed of system	2
Some mechanization needed in system, some labour needed	3
Passive system, low mechanization but more labour-intensive than 5	4
Entirely passive system, low labour need	5

Level of integration with other sectors

The different sanitation systems in the study have different demands on engagement/involvement with actors and other sectors to function as intended. This necessary *Integration with other sectors* and/or actors can add to the complexity of system management. We therefore used the total number of interacting actors in the system as the basis for scoring this indicator (Table 3.17). The outcome of the evaluation of this indicator is largely affected by the intention to recycle resources.

Table 3.17: Scoring of *Integration with other sectors*.

Description	Score
More than four actors are involved in making the system function	1
Not more than four actors are involved in making the system function	2
Not more than three actors are involved in making the system function	3
Not more than two actors are involved in making the system function	4
There is not more than one actor involved in making the system function	5

Indicators for Economic sustainability

To assess *Economic sustainability*, we needed to determine the true costs of each of the four sanitation alternatives. For this purpose, the equivalent annual cost (EAC) methodology was used (see Box 3.5).

BOX 3.5: EAC OF A SANITATION SYSTEM

EAC is used to analyse and/or compare all the costs of a project or a technological alternative. EAC is the annual cost of owning, operating and maintaining an asset over its entire life. In other words, EAC takes into account not only investment costs (CAPEX) but also all operation and maintenance (OPEX) costs, such as labour costs, energy, supplies and routine maintenance. EAC also factors in a discount rate (5% was adopted for the study) to incorporate the "cost of capital".

EAC is calculated as follows:

$$\text{EAC} = \frac{\text{Asset Price} \times \text{Discount Rate}}{1 - (1 + \text{Discount Rate})^{-n}}$$

where:

Discount Rate = Return required to make project worthwhile

n = Number of periods

For the study, this calculation was performed for each link of the sanitation service chain including interface and containment, collection and transport, treatment and disposal or reuse. All the EAC values for these components were added in order to obtain the total annualized CAPEX and OPEX for each sanitation alternative.

The difference with this methodology as compared with the classic net present value methodology commonly used for infrastructure projects is that the final result is an annualized value (expressed in USD/year), which is more useful and relevant from the service-operator perspective, since this annualized value can be easily compared with other annual revenue streams such as tariffs, transfers and subsidies.

Finally, the total EAC can be expressed on a per capita basis (USD/capita*year), which facilitates the relationship of costs and tariffs applied to households.

To determine the per capita EAC, the number of people per household used was five. This value was used for all on-site components. For centralized wastewater treatment facilities, a scale of a plant between 50 000 and 100 000 people equivalents (pe) was used; for decentralized treatment facilities (DEWATS) a scale up to 10 000 pe was adopted.

Once the per capita EAC for each alternative was determined, we compared the total annualized costs of the sanitation systems (including CAPEX and OPEX) with the current tariffs and the investments made by the households.

The difference between the total EAC and the costs covered by the households via tariff and investment is considered a subsidy. The score for *Economic sustainability* was calculated based on the thresholds presented in Table 3.18. For more details of the method, see Annex 4.

Table 3.18: Scoring of *Economic sustainability*.

Description	Score
< 60% of system costs are covered by current tariff and household investments	1
60–70% of system costs are covered by current tariff and household investments	2
70–80% of system costs are covered by current tariff and household investments	3
80–90% of system costs are covered by current tariff and household investments	4
> 90% of system costs are covered by current tariff and household investments	5

Step 3: choice of sanitation systems

As described in Section 3.1, Montero's existing sanitation system has two main approaches: centralized collection, conveyance and treatment or on-site collection with truck conveyance, or a hybrid of on-site and centralized treatment. Four types of sanitation systems are suggested for inclusion in the analysis, of which Systems 1, 3 and 4 exist in Montero:

- System 1: WC, conventional gravity-fed sewers and waste stabilization pond treatment
- System 2: WC, condominial sewers and decentralized anaerobic primary treatment
- System 3: WC, household connection to an on-site septic tank with a soak pit, treatment of faecal sludge at treatment plant
- System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

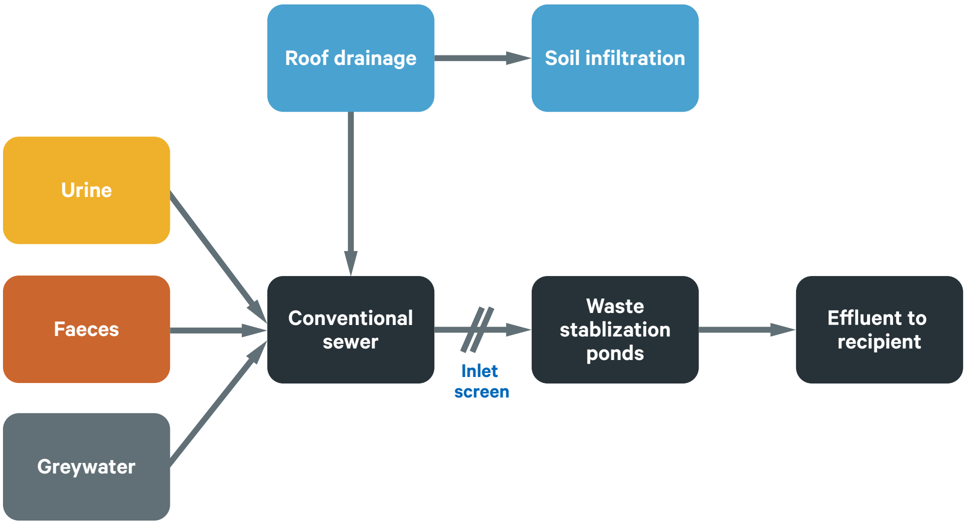
Short descriptions of the technical function of each of the systems are presented below.

System 1: conventional gravity-fed sewers with treatment in WSP

The wastewater from households (including greywater and water from flushing toilets) is connected to a gravity-fed sewer system that collects and transports the combined wastewater. The collected wastewater is led to a centralized WWTP where it passes through a coarse bar screen, which removes larger solids, before entering an anaerobic pond, the first in a series of three WSP. Currently, no fine solids separation system exists at the WWTP. Nevertheless, two automatic revolving screens and a grit separation and removal system are currently under construction. The stabilization ponds have never been emptied of accumulated sludge, and there is no designated sludge treatment process. Hence, organics and other settleable solids are allowed to settle and are left to accumulate in the ponds. The treatment system is primarily designed to reduce BOD_5 and N in the treated effluent. The treatment can also contribute to some TP removal, through the settling of organic material, particulate P and P-rich algae that grow in the pond system.

Household roof drainage infiltrates on-site (at the household level) into nearby soil, but it is frequently found that the drainage pipes are directly connected to the conventional sewers. The system is illustrated in Figure 3.5.

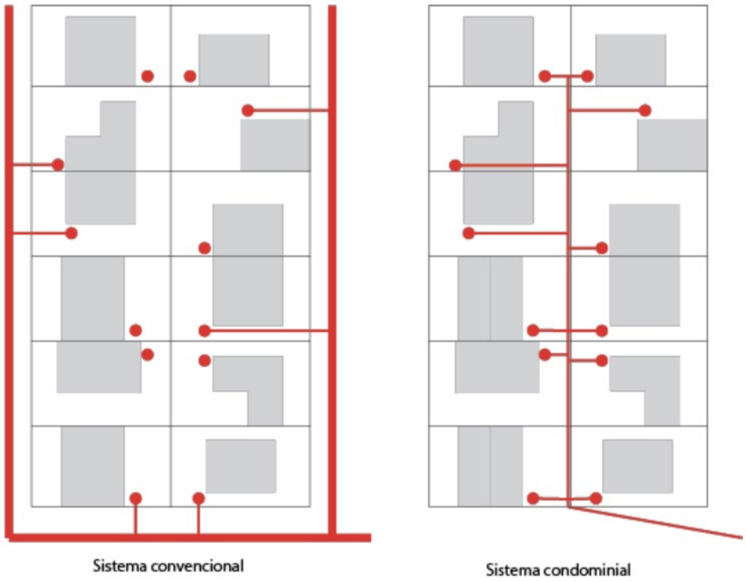
Figure 3.5: Simplified schematic representation of system 1: conventional gravity-fed sewers with treatment in WSP.



System 2: condominial sewers with anaerobic primary treatment
Wastewater from the households (including greywater and water from toilets) is collected by a condominial sewer system (Box 3.6).

BOX 3.6: A CONDOMINIAL SEWER SYSTEM

The *condominial* sewer network is similar to a conventional sewer network but with some specific differences. A *condominial* sewer is based on the concept that the sewer network should start at the houses (even within the plots) with small diameter pipes (normally ø100 mm) and collect the water from houses in a block, optimizing the total length and following a "sewer shed" approach before they reach a main sewer line. These are called *condominial branches*. These pipes can be installed at shallow depth and on a flatter gradient, allowing for a more flexible design at a lower cost (Tilley et al., 2014). This type of sewer has been successfully installed in countries such as Brazil, Peru and Bolivia (Lampoglia and Rolim, 2006).



The total investment cost of a condominial sewer system can be between 20% and 40% lower than a conventional sewer. Also, shallower pipes and inspection chambers result in lower operation and maintenance costs because the equipment needed is simpler and cheaper.

Condominial sewers favour the use of prefabricated components such as inspection chambers, which lowers the total investment costs even more and reduces the construction times.

On the management side of the solution, the greatest advantage is that, since a condomial system "starts at every house", all houses are connected from the beginning of the project. This is contrary to the conventional approach in which the project starts with the installation of sewer lines along every street and the households are expected to connect afterwards, resulting frequently in connection rates as low as 30%.

The condominial sewer system can either lead the wastewater to a main collection sewer line, which in turn will transport wastewater to a centralized facility, or it can be directly connected to a nearby treatment plant. This is called "distributed" wastewater treatment (see Box 3.7 for definition).

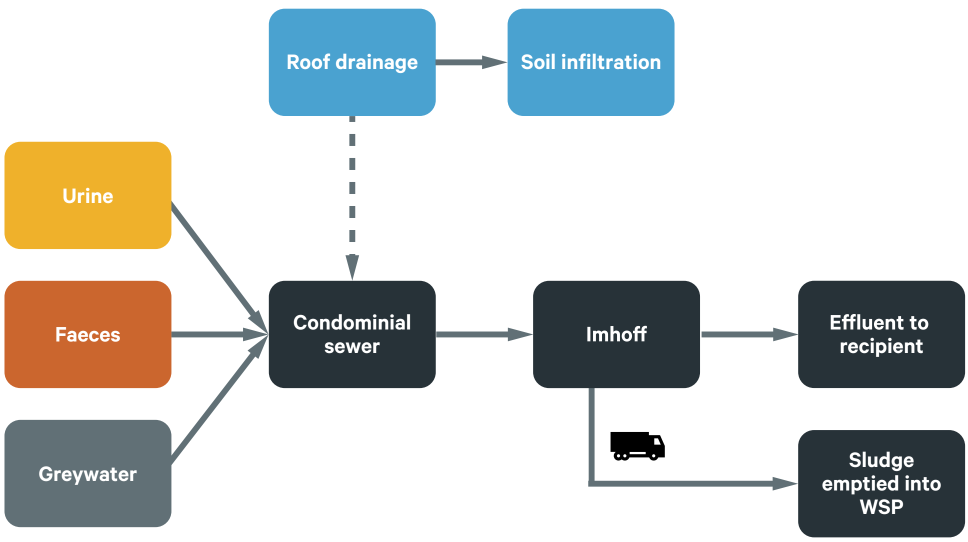
BOX 3.7: DISTRIBUTED WASTEWATER TREATMENT

In computer networking and other fields, "decentralized" is a subset of "distributed". In water and wastewater treatment, these terms are often used interchangeably, but there is a key distinction. Decentralized treatment is characterized by independent, small- or medium-scale treatment plants placed next to a source of water or wastewater. Decentralization offers physical and managerial autonomy to local entities. While distributed treatment systems share the same scaling and siting characteristics – and often the same modular, containerized technologies – as decentralized systems, the difference is that distributed systems are physically or managerially linked to a larger system.

For System 2, we have considered that the condominial sewers are connected to a large-scale Imhoff tank, which provides treatment that primarily removes BOD_5 (settleable organics and solids) while also providing some removal of settleable TN and TP. The effluent from the primary anaerobic treatment is discharged into open channels or can be infiltrated depending on the local conditions. The sludge that is accumulated in the primary anaerobic treatment is periodically collected and moved by truck to a centralized treatment facility where it is discharged into the facility inlet (usually stabilization ponds) for further treatment.

Household roof drainage infiltrates into nearby soil, and occasionally the drainage pipes are directly connected to the condominial sewers. The system is illustrated in Figure 3.6.

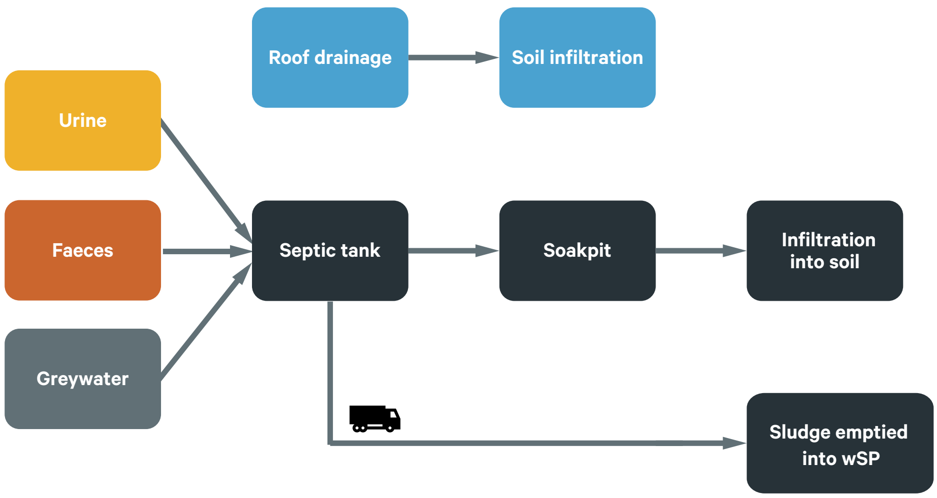
Figure 3.6: Simplified schematic representation of System 2: condominial sewers with primary anaerobic treatment.



System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge at treatment plant

The greywater and the household's flush toilets are connected to an on-site septic tank where the septic tank effluent feeds into an adjacent soak pit for diversion and disposal. Negligible supplementary treatment is achieved through shallow soil infiltration in the soak pit due to high load on a small infiltration area and the proximity to groundwater (high groundwater table). The septic tanks are infrequently emptied of sludge (commonly only once issues or overflows occur) by vacuum trucks. The collected sludge is trucked to a centralized wastewater treatment plant where it gets discharged at the inlet. The septic tanks provide treatment that primarily removes BOD_5 (settleable organics and solids) while providing some removal of settleable TN and TP. The system is illustrated in Figure 3.7.

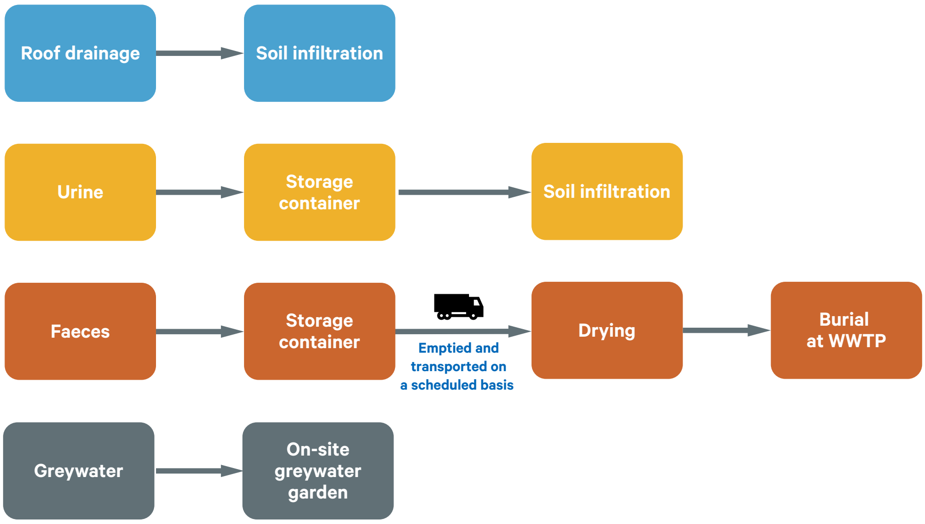
Figure 3.7: Simplified schematic representation of System 3: household urine, faeces and greywater are collected in a septic tank where the effluent is led to a soak pit for infiltration into the soil on-site. The accumulated sludge in the soak pit is emptied once issues occur and the sludge is trucked to a nearby WWTP where it is dumped at the inlet. Household roof drainage infiltrates into nearby soil.



System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant

The household greywater is piped to an on-site greywater treatment system, typically a greywater garden, where the water infiltrates into the soil. The greywater typically contains a small amount of the household's total TN, TP and BOD_5. The household excreta (urine and faeces) are collected in single-vault UDDTs that allow for the separate collection and treatment of urine and faeces, without the use of any flush water. Currently the collected urine is infiltrated on-site by the users/households, and the faecal storage containers are collected and moved by truck to a centralized treatment facility where the faeces are stored for some weeks, in lid-covered containers before being buried on-site. On-site urine infiltration and burial of faeces provide no direct treatment for nutrient removal and this adds risks for nutrient (TN and TP) leaching to groundwater. The system is illustrated in Figure 3.8.

Figure 3.8: Simplified schematic representation of System 4: household urine and faeces are separated in double-vault UDDTs and collected separately. The urine is infiltrated into soil on-site and the faeces are trucked to a nearby facility to be dried before being buried at the local WWTP. The household greywater is infiltrated in an on-site greywater garden. Household roof drainage infiltrates into nearby soil.



Step 4: weighting

No weighting was made of the criteria in the Montero case study. The objective of Sections 3 and 4 in this report is to demonstrate the sustainability of each system type, with optimizations and innovations, without prioritization between criteria. This approach makes the results in Sections 3 and 4 more generally applicable for situations similar to Montero than if the weighting would have been included.

Step 5: results – sustainability assessment as the systems function today

In this section we illustrate the assessment results of the four different sanitation systems as they are estimated to function today, either in Montero (Systems 1, 3 and 4) or in Bolivia in general (System 2).

Health and hygiene assessment

As a reminder, the scoring is based on the number of high-risk events and on an overall scoring of the identified risks (see Annex 5 for the full results). A summary of the results for all four system types is shown in Table 3.19. System 4 was assessed as the safest of the included systems, scoring 4 points, and System 1 as the least safe system, scoring 2 points.

Table 3.19: Summary results of the *Health and hygiene* sustainability assessment.

	System 1	System 2	System 3	System 4
Health and hygiene	2	3	3	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment;
System 2: condominial sewers and anaerobic primary treatment;
System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant;
System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

The scoring of System 4 was based on the system having no high-level risk events and a low overall risk score. The most hazardous events for System 1 are *Gases: exposure to dangerous levels of H_2S in pumping stations* and *Pathogens: exposure to wastewater when released*, which are two high-risk events that significantly contribute to the total risk score for the system. Both risks were considered "not unlikely" and of at least major severity if they were to occur. System 2 and System 3 both scored 3 points, suggesting comparable levels of health risks. The highest risk event for System 2 is *Pathogens: exposure to wastewater when released*, the only high-risk event identified for the system. System 3 has four high-risk events, of which the two highest health risks are *Pathogens: infiltration of septic tank effluent to groundwater* and *Nitrates: infiltration of septic tank effluent to groundwater.*

Environment

Table 3.20 summarizes assumptions of treatment efficiencies and other environmental aspects of the four systems.

Table 3.20: Assumptions that are made relating to the environmental aspects of how the systems function today in Montero. For additional details see Annex 3.

	System 1	System 2	System 3	System 4
TN reduction	WSPs: 50%	Imhoff tank: 20%	Septic tank:10% Soak pit: 0%**	Urine infil.: 0%** Faecal burial: 0%** Greywater infil.: 30%
TP reduction	WSPs: 50%	Imhoff tank: 25%	Septic tank: 20% Soak pit: 0%**	Urine infil.: 0%** Faecal burial: 0%** Greywater infil.: 30%
BOD5 reduction	WSPs: 80%	Imhoff tank: 35%	Septic tank: 30% Soak pit: 0%**	Urine infil.: 0%** Faecal burial: 0%** Greywater infil.: 80%
Water use [L/cap,d]	120.7	120.7	120.7	90.7*
Separated sanitation flows	(1), (2)	(1), (2), (3)	(2), (3), (4), (5)	(2), (3), (5), (6), (7)

TN, TP and BOD reduction: ** As the systems function today there is effectively no treatment by applying these practices as the groundwater table is highly situated and TN, TP and BOD can be expected to leach into the groundwater.

Water use: The additional/reduced per capita water use from using different water-conveying sanitation systems is assumed to be negligible. Hence, the only factor that has a large-scale impact on water use is the removal of flush water by having a dry system.

* *According to Heredia (2020), five flushes per capita and day at 6 L per flush can be assumed in Montero.*

Separated flowstreams: (1) wastewater, (2) stormwater/roof drainage, (3) industrial wastewater, (4), blackwater, (5) greywater, (6) urine, (7) faeces.

The full results from the environmental assessment are available in Annex 5 and a summary of the results for all four system types is shown in Table 3.21. Regarding *TN, TP and BOD_5 release* System 1 scored the highest. Systems 2, 3 and 4 were assessed similarly in nutrient and BOD_5 release. However, it can also be seen that none of the systems have high scores (4 or 5) on nutrients and BOD_5-removal, suggesting a real need to improve the function of the systems in order to provide meaningful environmental protection from nutrients and organic matter.

For the *Water use* indicator, Systems 1, 2 and 3 scored 3 points, while System 4 scored 5 points. Since System 4 is a dry system, without a need for flush water in toilets, significant amounts of water can be saved.

For the *Separation of sanitation flows* indicator, the score varies across all of the systems, indicating that they manage the sanitation flows collection very differently. System 4 scored 5 points, since it separates the largest number of sanitation flows, allowing for the greatest reuse possibilities of the included systems. System 1 separates the smallest number of sanitation flows, thus allowing for the smallest number of reuse possibilities of the included systems.

Table 3.21: Summary results of the *Environmental* sustainability assessment.

	System 1	System 2	System 3	System 4
TN release	3	2	1	1
TP release	2	1	1	1
BOD_5 release	3	1	1	1
Water use	3	3	3	5
Separation of sanitation flows	2	3	4	5

System1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Social sustainability

The full results from the *Social sustainability* assessment are available in Annex 5 and a summary of the results for all four system types is shown in Table 3.22. In terms of *Social acceptability,* Systems 1 and 2 scored the highest, as these systems require only minor household management of the user interface. System 3 scored the lowest of the included systems as there is an additional need for the household to manage the function of the system, for example by actively calling emptying services.

For the *Household affordability* indicator, System 1 sticks out as the least affordable system for households, scoring 1 point. System 2 scored 2 points and Systems 3 and 4 scored 3 points. Looking into the detailed assessment, there are, however, only small differences in the actual affordability between Systems 2, 3 and 4: 9.5%, 8.7% and 7.5% of minimum wage respectively.

Table3.22: Summary results of the *Social sustainability* assessment.

	System 1	System 2	System 3	System 4
Social acceptability	5	5	3	4
Household affordability	1	2	3	3

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Technical function

The full results from the assessment of *Technical function* are available in Annex 5 and a summary of the results for all four system types is shown in Table 3.23.

Table 3.23: Summary results of the *Technical function* assessment.

	System 1	System 2	System 3	System 4
Appropriate system design	1	2	3	4
Vulnerability to water scarcity	1	1	3	5
Vulnerability to flooding	2	3	3	4
Integration into urban planning	3	3	3	4
Technical complexity	4	4	3	3
Integration with other sectors	4	4	3	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

In terms of *Appropriate system design*, System 4 scored the highest, being a sanitation system that can function in the greatest number of population densities and planning contexts. System 1 scored the lowest since it is suitable only for intermediate to very high densities in highly planned areas.

For *Vulnerability to water scarcity*, only scores 1, 3 or 5 were given (see Section 3.2, Step 2). System 4 is a dry system, which can function without access to water and therefore scored 5 points. System 1 and System 2 both require access to water to operate the toilet and the conveyance systems, and if these systems lack access to water they cannot function as intended, thus scoring 1 point. System 3 does not need water for the conveyance and therefore scored 3 points.

System 4 was considered the least *Vulnerable to flooding*, scoring 4 points, since the average impact on households, conveyances and treatment efficiency of flooding was assessed to be low. On the other hand, System 1 was assessed as the most vulnerable to flooding, having on average high impacts on households, conveyance and treatment during heavy rainfall events.

Considering the *Level of integration into urban planning*, System 4 has the largest number of governing document categories, scoring 4 points. Systems 1, 2 and 3 all scored 3 points. It can be noted that municipal regulations on construction and operation are missing for all system types.

Systems 1 and 2 are mostly passive systems with low levels of mechanization, with some amount of manual labour needed for the systems to function, therefore both scored 4 points on the *Technical complexity* indicator. The operation of Systems 3 and 4 requires additional mechanization and labour compared with Systems 1 and 2. Hence, these systems both scored 3 points.

In terms of level of *Integration with other sectors*, Systems 1, 2 and 4 involve only two actors in the systems (one constructing the system and another operating the system), thus all three scored 4 points. System 3 scored 3 points, since three actors are involved (one constructing the system, another that empties the septic tanks and a third that provides treatment for the septage).

Economic sustainability

The full results from the *Economic sustainability* assessment are available in Annex 5 and a summary of the results for all four system types is shown in Table 3.24. For *Economic sustainability*, System 3 was assessed to be the most sustainable as more than 90% of the system's total costs are covered by today's tariffs and household investments, scoring 5 points. System 1 was assessed as the least financially sustainable system as less than 60% of the system costs are covered by today's tariffs and household investments, scoring 1 point.

Table 3.24: Summary results of the *Economic sustainability* assessment.

	System 1	System 2	System 3	System 4
Economic sustainability	1	3	5	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Summary of sustainability assessment for the Montero case as the systems function today

Table 3.25 summarizes the results presented in this section. It clearly shows that each system has its strengths and weaknesses. We have not added a summary score for each system type, since the intention with the use of the method in this section is to show where the systems perform well, and where there is a need for improvement, in settings similar to Montero's. For a city-wide inclusive sanitation approach there will often be a need to use a combination of systems for a number of reasons. We hope that the results in Sections 3 and 4 of this report will inspire planners and engineers to make best use of existing technologies and to improve and innovate to increase each system type's sustainability.

System 1 scored high on *Social acceptability*, *Technical complexity* and level of *Integration with other sectors*. This is not surprising, given that System 1 can be considered part of the conventional centralized wastewater treatment paradigm with high acceptance in the sector and among citizens. System 1 scored low on *Household affordability*, *Appropriate system design*, *Vulnerability to flooding* and *Water scarcity* and also on *Economic sustainability*. These low scores reflect that gravity-fed sewer systems with centralized treatment are expensive, suitable in a limited urban context and with a vulnerability to too little and too much water.

System 2 also scored high on *Social acceptability*, *Technical complexity* and level of *Integration with other sectors*. System 2 can also be said to be part of the centralized wastewater treatment paradigm, albeit with lower costs than in System 1. Hence, System 2 has a higher *Household affordability* and *Economic sustainability* than System 1. The weakest aspects of System 2 are *Release of nutrients and organic matter* and its *Vulnerability to water scarcity*.

System 3 is the alternative with most medium scores (all *Technical/institutional* and *Social* indicators). The medium scores can be related to the fact that the system is well known and established but with limited engagement from authorities in terms of proactive service provision, which could improve its performance. Furthermore, it scored high on *Separation of sanitation flows* and *Economic sustainability* and low on *Release of nutrients and organic matter*.

System 4 is the alternative with the highest number of indicators with high scores, notably the only one with a high score for *Health and hygiene*, *Water use* and *Vulnerability to water scarcity*. However, like the other systems it scored low on *Release of nutrients and organic matter*.

Overall, it can be concluded that none of the systems are removing nutrients and organic matter to a satisfactory level – Systems 2, 3 and 4 scored 1 on TP and BOD_5 release and no system scored 4 or 5 for these indicators.

Table 3.25: A summary of the sustainability assessment of the sanitation systems for Montero as they function today.

		System 1	System 2	System 3	System 4
Health and hygiene	Health and hygiene	2	3	3	4
Environmental sustainability	TN release	3	2	1	1
	TP release	2	1	1	1
	BOD_5 release	3	1	1	1
	Water use	3	3	3	5
	Separation of sanitation flows	2	3	4	5
Social sustainability	Social acceptability	5	5	3	4
	Household affordability	1	2	3	3
Technical and institutional sustainability	Appropriate system design	1	2	3	4
	Vulnerability to water scarcity	1	1	3	5
	Vulnerability to flooding	2	3	3	4
	Integration into urban planning	3	3	3	4
	Technical complexity	4	4	3	3
	Integration with other sectors	4	4	3	4
Economic sustainability	Financial sustainability	1	3	5	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Step 6: the sensitivity analysis

Choice of indicators, scoring thresholds (and weights if included) and assumptions needed to assign an indicator score will all influence the sustainability assessment results. We tried to reduce uncertainty to the largest degree possible in our assumptions of, for example, treatment capacity of different systems by consulting and reconsulting both literature and additional experts.

The choice of indicators will clearly influence the outcome of the assessment. One criterion we really struggled to find an appropriate indicator for was *Integration into urban planning* (see the technical function in Step 5 in Section 3.2 and the results in Section 3.3 for details of this criterion). Another relevant example may be *Social acceptance*, where we chose to look at the need for the household to engage with the system as a proxy for social acceptance. If we had done an analysis of people's perceptions towards the different systems, the results may have been quite different.

We considered the construction of the scales for indicator scoring as an important aspect for reducing uncertainty. We tried to have score 3 as the starting point (e.g. average water use in

Montero) and we then constructed intervals upwards and downwards from this. We used our own expertise and consulted literature to help create the scoring tables. This approach created scales for a semi-quantitative approach and for qualitative indicators, but it can of course be argued that the intervals were arbitrarily constructed for certain indicators. Therefore, we paid extra attention to system scores that were close to the upper or lower cut-off value of a score.

Section 4 of this report can be seen as a sensitivity analysis in itself, investigating what the outcome of the sustainability assessment would be if each system were optimized.

Step 7: stakeholder feedback

In this project stakeholders were able to give feedback twice, at the start of the project by identifying criteria and agreeing on systems to be assessed and at a second workshop (virtual) to give feedback on preliminary sustainability assessment results.

In general, participants were surprised to learn about the complexities of sanitation services once the whole sanitation chain is taken into account. The general recommendation was to support the implementation of the Municipal Sanitation Plan, which considers an integrated approach to sanitation.

Specifically, it was recommended that:

- COSMOL should treat faecal sludge from septic tanks in its area of service. Considering the current situation, in which sludge from septic tanks is collected by private operators and hauled all the way to the city of Santa Cruz for treatment, the implementation of local treatment by the cooperative would be an important step towards integrating different (and complementary) sanitation solutions in Montero as well as an opportunity to manage septic sludge in a more sustainable and integrated fashion.

- The municipality should have a more active role in monitoring progress of the implementation of the Montero Sanitation Plan using a GIS-based tool.

- A more effective coordination is needed between COSMOL, the municipality and national-level authorities in order to support innovative and more inclusive solutions to sanitation service provision.

Figure 3.9: Workshop on Zoom for presenting the results.

3.3 Discussion

The process

The Covid-19 pandemic happened during the implementation of this project and impacted the sustainability assessment process in different ways. For example, stakeholder engagement was limited to digital meetings from March 2020. The second workshop (Step 7 in Section 3.2 above) was held digitally, which limited stakeholder interaction and dialogue.

An important step in the process is the choice of indicators to assess sustainability of different criteria. For example, during the criteria selection workshop in Montero in September 2019 *Integration into urban planning* and *Appropriate system design* were prioritized by the stakeholders as two important technical function criteria. It was not easy to find appropriate indicators to assess these criteria! In the end we chose whether the system alternatives were mentioned in local and national policy documents to assess *Integration into urban planning*, which gave surprising results, not really reflecting the practical reality for the different systems (System 4 scored the highest but is implemented the least in reality). For *Appropriate system design* we chose, after many discussions, to look at the flexibility of the technical system in terms of a matrix using population density and level of planning needed.

As discussed in Section 3.2, Step 6, it can be argued that the scoring thresholds for some indicators are arbitrarily set; for example, the construction of the scoring table for the *Health and hygiene* criterion or for the *Environment* criterion, regarding release of nitrogen and phosphorus to the environment. With our choice of approach, to create scoring tables, it is difficult to avoid arbitrarily set thresholds between scores. However, we argue that the method is transparent and, as long as it is shown how the scoring tables have been constructed, we can live with the arbitrary nature of the thresholds.

The same goes for the issue of subjectivity, which is clearly at play throughout the process. However, we argue that the method is transparent and therefore subjectivity can be managed. For example, Step 2, choice of criteria, is clearly where subjectivity is introduced into the assessment. Nevertheless, by making the choice in a representative stakeholder group, different aspects are at least guaranteed to be included. Moreover, the chosen criteria, and with them the subjectivity of the stakeholder group, are clearly spelled out, as well as the indicators later chosen to assess each criterion. In Step 4, weighting, subjectivity and preferences in the stakeholder group are explicitly at the core. Comparing results before and after weighting will give one view on subjectivity.

For the *Health and hygiene* criteria assessment we used a risk framework, developed by the WHO. The framework is logical and provides a good starting point for looking at risks along the service chain. However, it also has the criteria that took the most time to evaluate.

The results

The summary results for the Montero sustainability assessment, as the systems function today, are shown in Section 3.2 above. Each system has its strengths and weaknesses. System 4 has the most indicators with high scores, with scores of 4 or 5 related to one or more of the indicators in each sustainability pillar. System 1 has the highest number of indicators with the lowest score, mainly related to *Affordability* and *Economic sustainability* and dependence on water.

One criterion we really struggled to find an appropriate indicator for was *Integration into urban planning* (see Sections 3.2, Step 7, and 3.3, the process). It seemed like whether the sanitation system was included in governing documents on different levels would be a relevant indicator but the result was slightly surprising: System 4 scored the highest, being included in most types of governing documents. Dry, urine-diverting systems (System 4) are in practice not as integrated into urban planning as the other systems are, so the choice of indicator may be questionable.

However, what the chosen indicator shows is that there is institutional support for dry, urine-diversion systems in Bolivia in general and in Montero in particular.

Overall, it can be concluded that none of the systems are removing nutrients and organic matter to a satisfactory level – Systems 2, 3 and 4 scored 1 on TP and BOD_5 release and no system scored 4 or 5 for these indicators. Therefore, *Release of nutrients and* BOD_5 is a common area for development in all these systems. However, the results in Section 3 are related to how the systems are working today in Montero (Systems 1, 3 and 4) or could be expected to work today (System 2); each system could be tweaked for improved functionality, which is what we consider in Section 4.

4. Results – what if the systems in Montero were operated in an "optimized" way?

Today's systems in Montero are not operated or managed to their full potential. It is possible to substantially improve their sustainability by introducing relatively minor adjustments to the operation and management practices, and by introducing small technical improvements or additional system components. This section describes the results of the sustainability assessment of these "optimized" systems if they were operated and managed to their full potential. Section 4 can, in a sense, be seen as a sensitivity analysis, looking into a more optimized potential of each system type.

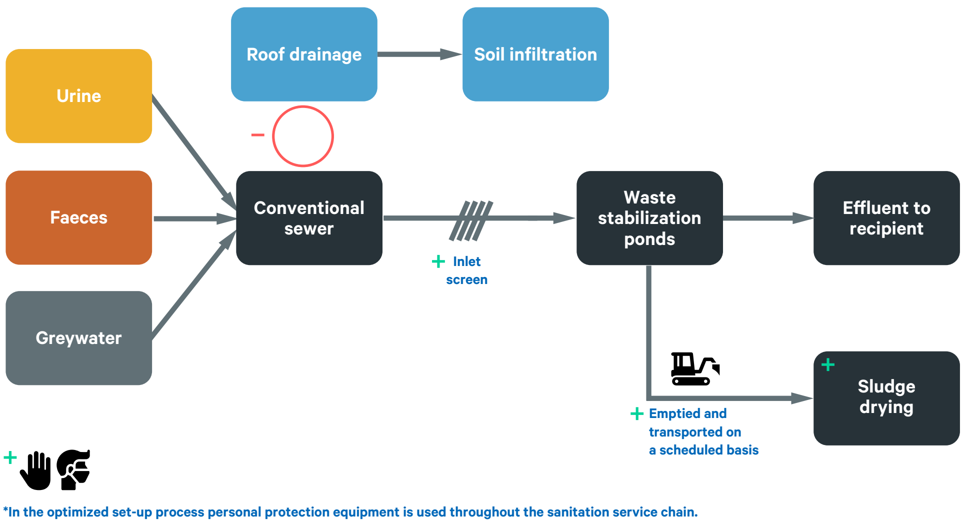
4.1 Description of the optimized systems

System 1: WC, conventional gravity-fed sewers and waste stabilization pond treatment

Optimization: disconnection of roof drainage from the sewer system, addition of inlet screen, use of PPE, proper management of lagoons and sludge, and sludge treatment (drying).

In today's system household roof drainages are frequently found to be directly connected to the conventional gravity-fed sewer system, a practice contributing to significant flooding issues during heavy rainfall. To improve the overall function of the system, roof drainages should be disconnected from the system to reduce the hydraulic load on the conveyance system and receiving treatment facility during high-flow events. Additionally, to reduce the BOD_5 load and sludge accumulation rate in the stabilization ponds, coarse grids and/or screens could be added at the inlet of the treatment facility. The accumulated sludge should be actively managed, removed and treated (dried) to reduce the internal TN and TP loadings, and to improve the overall treatment efficiency and function of the stabilization ponds. PPE should be used to reduce health risks for workers along the sanitation service chain.

Figure 4.1: Simplified schematic representation of the optimal implementation of System 1: household urine, faeces and greywater are collected in a conventional sewer system and conveyed to a series of WSP where the influent is passed through coarse grids and screens and treated effluent is led to a nearby recipient. Household roof drainage infiltrates into nearby soil, and drainage pipes have actively been disconnected from the conventional sewers. The WSP are routinely emptied of accumulated solids, which are removed and dried. PPE is used.

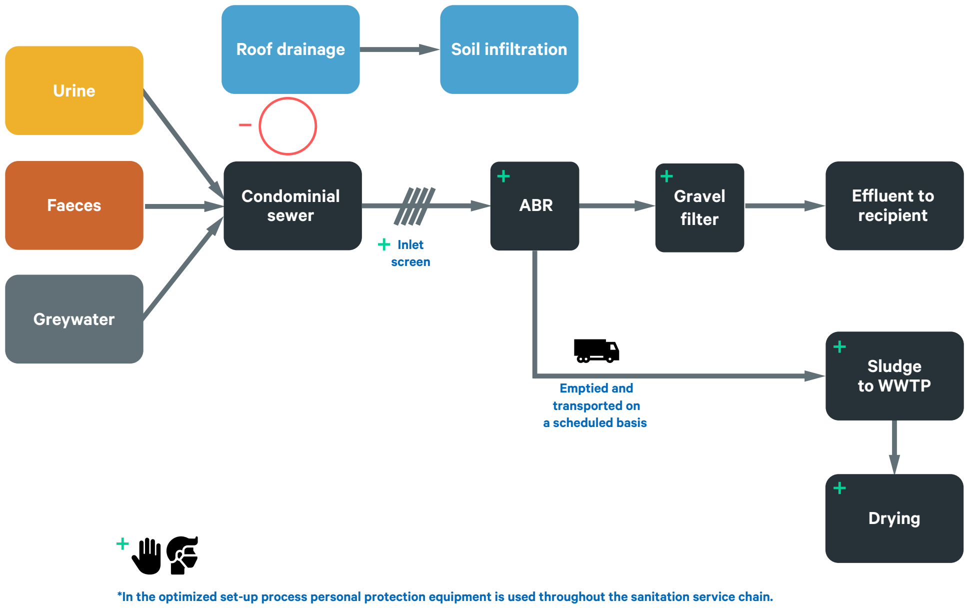


System 2: WC, condominial sewers and anaerobic primary treatment

Optimization: inlet screen and gravel filter, use of PPE, sludge treatment at central plant (drying)

Roof drainages are not commonly found to be connected to condominial sewer systems and this is not often reported as an issue when managing this type of system in a Bolivian context. If roof drainages are found to be connected to the sewer systems, they should be disconnected. The same improvements that have been suggested for System 1 (i.e. inlet screens and proper sludge management and drying) have been included as possible improvements to the distributed treatment facility in this system. The commonly used large septic or Imhoff tanks should be replaced with anaerobic baffled reactors (ABRs), a more efficient type of primary anaerobic treatment. To further improve the treatment efficiency, a properly designed gravel filter should be installed as a secondary treatment to improve the quality of the final effluent. Gravel filters provide additional TN, TP and BOD_5 removal. PPE should be used to reduce health risks for workers along the sanitation service chain.

Figure 4.2: Simplified schematic representation of the optimal implementation of System 2: household urine, faeces and greywater are collected in a condominial sewer system and conveyed to an ABR where the influent is led through inlet screens and the treated effluent is led through a gravel filter before going to a nearby recipient. The accumulated sludge in the primary anaerobic treatment is periodically emptied and trucked to a nearby WWTP. Household roof drainage infiltrates into nearby soil, and drainage pipes have actively been disconnected from the condominial sewers. PPE is used.

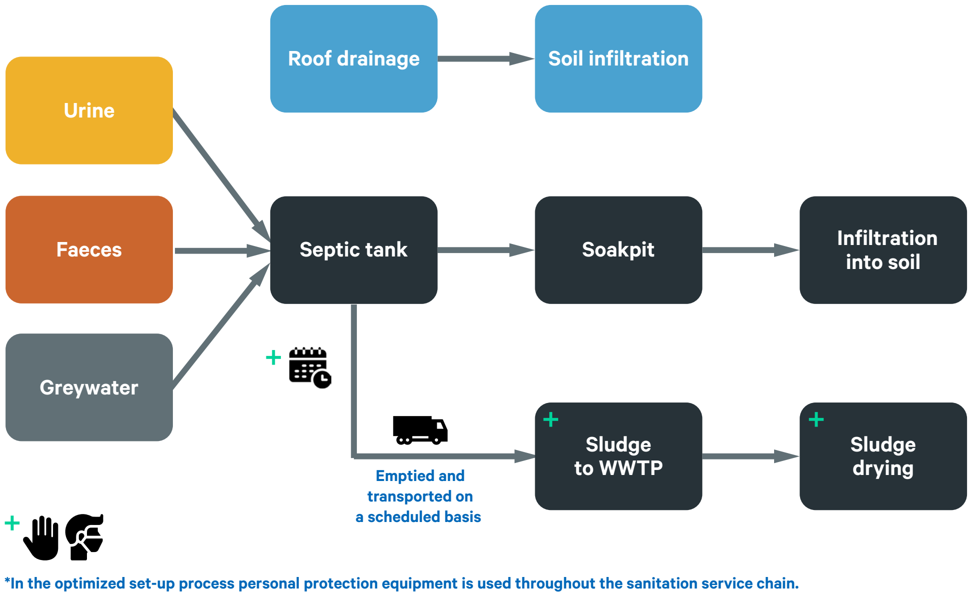


System 3: WC, household connection to an on-site septic tank with a soak pit

Optimization: formal collection service in place (e.g. scheduled), use of PPE, sludge treatment at the central treatment plant (drying)

On-site septic tanks are often only emptied once they are overflowing. Overloaded (and/or mostly full) tanks have significantly reduced treatment efficiency compared with well-maintained systems. This issue can be prevented by scheduled emptying. As an additional improvement, collected sludge should be transported to a treatment facility for further treatment (drying) to avoid negative environmental impact related to improper management (such as nutrients leaching into groundwater and/or nearby water bodies). PPE should be used to reduce health risks for workers along the sanitation service chain.

Figure 4.3: Simplified schematic representation of the optimized implementation of System 3: household urine, faeces and greywater are collected in a septic tank where the effluent is led to a soak pit for infiltration into the soil on-site. The accumulated sludge in the soak pit is emptied on a scheduled basis and the sludge is trucked to a nearby WWTP where it is dried. Household roof drainage infiltrates into nearby soil. PPE is used.

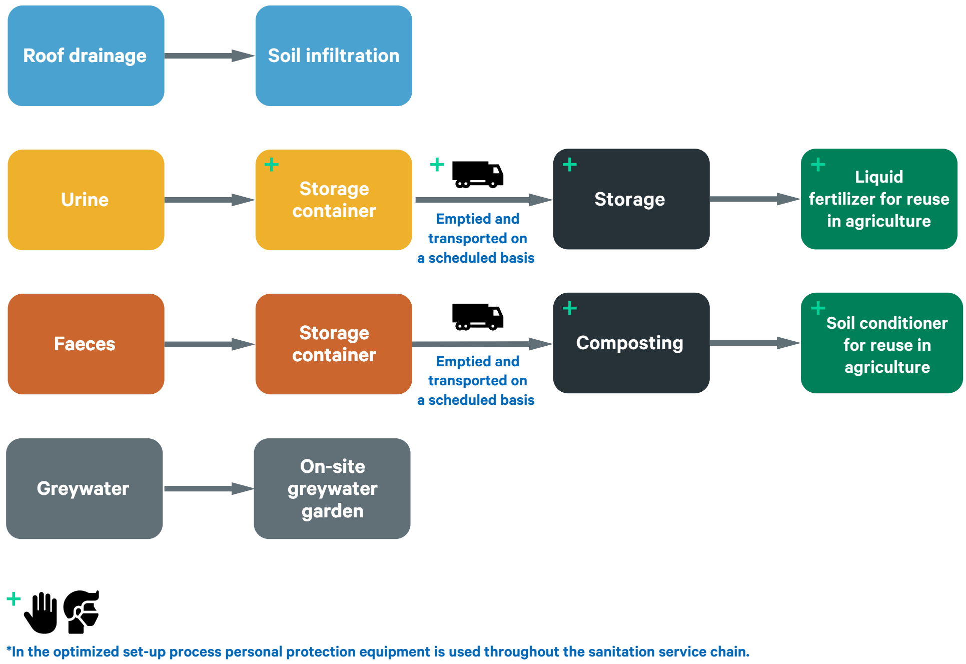


System 4: UDDTs and local greywater treatment

Optimization: collection and treatment of urine and faeces (Sumaj Huasi's model), use of PPE

The optimized way to manage source-separating sanitation systems is by collecting and reusing the nutrients and organic matter that are available in urine and faeces, ideally as fertilizers in local agriculture. Instead of infiltrating the urine on-site, as is the practice in today's system in Montero, the urine can be collected, sanitized and reused as a liquid nitrogen-rich and quick-acting fertilizer. Instead of burying the faeces they can be composted and reused as a P-rich soil conditioner. By separating urine and faeces from greywater and using the available nutrients in an efficient way (to avoid over-fertilization and/or at the wrong time) in agriculture, greywater is effectively the only potential influence on the local recipient and groundwater quality. Therefore, the annual load of TN, TP and BOD_5 to the environment is significantly reduced in the optimized System 4. PPE should be used to reduce health risks for workers along the sanitation service chain.

Figure 4.4: Simplified schematic representation of the optimal implementation of System 4: household urine and faeces are separated in single-vault UDDTs and collected separately. The urine and faeces are trucked to nearby treatment facilities where they are stored and sanitized before they are reused as fertilizer in agriculture. The household greywater is infiltrated in an on-site greywater garden. Household roof drainage infiltrates into nearby soil. PPE is used.



4.2 Results – optimized systems

The optimized systems were described in Section 4.1 above. Below are the results for the optimized systems presented for each sustainability aspect. To illustrate the optimization's effect on the sustainability assessment, the results for the existing systems are presented alongside those for the optimized ones.

Health and hygiene

The full results from the *Health and hygiene* assessment are available in Annex 5 and a summary of the results for all four systems is shown in Table 4.1. Once optimized, Systems 1, 2 and 3 improve their *Health and hygiene* sustainability, scoring 4. The use of PPE reduces the likelihood of risk events along the service chain for Systems 1, 2 and 3, as does the improvement of operation and maintenance routines.

Table 4.1 Health and hygiene assessment of existing and optimal systems.

	System 1		System 2		System 3		System 4	
	Existing	Optimized	Existing	Optimized	Existing	Optimized	Existing	Optimized
Health and hygiene	2	4	3	4	3	4	4	4

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

The optimized System 4 scored the same as for the existing System 4. The reason for this is that the optimized system includes more management steps than the existing system since urine is collected and treated in the optimized version. However, likelihood and severity of these management steps (or hazardous events) were considered low. Overall, System 4 stayed at score 4 for the optimized system.

Environment

Table 4.2 summarizes assumptions of treatment efficiencies and other environmental aspects of the four optimized systems.

Table 4.2: Assumptions made about the Environmental aspects of the function of optimized systems in Montero. For additional details see Annex 3.

	Optimized System 1	Optimized System 2	Optimized System 3	Optimized System 4
TN reduction	WSPs: 65%	ABR+gravel filter: 40%	Septic tank: 30% Soak pit: 0%*	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 30%
TP reduction	WSPs: 50%	ABR+gravel filter: 30%	Septic tank: 30% Soak pit: 0%*	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 30%
BOD reduction	WSPs: 85%	ABR+gravel filter: 95%	Septic tank: 75% Soak pit: 0%*	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 80%
Water use [l/cap,d]	120.7	120.7	120.7	90.7**
Separated sanitation flows* **	(i), (ii)	(i), (ii), (iii)	(ii), (iii), (v), (vi)	(ii), (iii), (vi), (vii), (viii)

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

The full results from the environmental assessment are available in Annex 5 and a summary of the results for all four systems is shown in Table 4.3.

Table 4.3: Environment assessment of existing and optimized systems.

	System 1		System 2		System 3		System 4	
	Existing	**Optimized**	**Existing**	**Optimized**	**Existing**	**Optimized**	**Existing**	**Optimized**
TN release	3	4	2	3	1	3	1	5
TP release	2	3	1	1	1	1	1	4
BOD5 release	3	4	1	5	1	3	1	4
Water use	3	3	3	3	3	3	5	5
Separation of sanitation flows	2	2	3	3	4	4	5	5

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

It can be seen from the results of the assessment that all optimized systems can increase their sustainability in terms of *Release of TN and* BOD_5. The largest potential for improvement is for System 4, where the collection and treatment of urine and faeces, instead of infiltration and burial, significantly reduces the release of TN, TP and BOD_5; System 4 can go from scoring the lowest to the highest for release of nutrients and organic matter if the system is optimized. For TP all systems also improve on their release, but the way the scoring scale is set makes the improvement invisible for Systems 2 and 3 in Table 4.3; the more modest improvement in TP reduction from 25% to 30% for System 2 and from 20% to 30% for System 3 improves the TP removal just to the threshold value between scores 1 and 2.

The other indicators for environmental sustainability, *Water use* and *Separation of sanitation flows*, are not affected by the optimization. To improve *Water use,* additional interventions at the household level would need to be introduced. Increased *Separation of sanitation flows* cannot be achieved under an optimization of the existing system paradigm and therefore stays unchanged.

Social sustainability

The full results from the social sustainability assessment are available in Annex 5 and a summary of the results for all four systems is shown in Table 4.4.

Table 4.4: Social sustainability for existing and optimized systems.

	System 1		System 2		System 3		System 4	
	Existing	Optimized	Existing	Optimized	Existing	Optimized	Existing	Optimized
Social acceptability	5	5	5	5	3	4	4	4
Household affordability	1	1	2	2	3	3	3	2

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Social acceptability is not expected to change with the optimizations, except for System 3. By ensuring that there is a scheduled emptying service of the septic tanks in System 3, it is assessed that the *Social acceptability* will increase.

Household affordability is expected to change only for System 4. The introduction of urine collection in System 4 will reduce the *Household affordability* score from 3 for the existing system to 2 for the optimized system.

Technical function

The full results from the technical sustainability assessment are available in Annex 5 and a summary of the results for all four systems is shown in Table 4.5.

Table 4.5: Technical function for existing and optimized systems.

	System 1		System 2		System 3		System 4	
	Existing	Optimized	Existing	Optimized	Existing	Optimized	Existing	Optimized
Appropriate system design	1	1	2	2	3	3	4	4
Vulnerability to water scarcity	1	1	1	1	3	3	5	5
Vulnerability to flooding	2	2	3	3	3	3	4	4
Integration into urban planning	3	3	3	3	3	3	4	4
Technical complexity*	4	3	4	3	3	3	3	3
Integration with other sectors	4	4	4	3	3	2	4	3

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Introducing the proposed optimizations does not affect the assessment of the indicators *Level of applicability, Vulnerability to water scarcity* and *Integration into urban planning* for any of the included systems; these indicator scores reflect the fundamental design and technical components of the systems.

Vulnerability to flooding is reduced in different parts of the systems (at household, conveyance or treatment level) by introducing the proposed optimizations, although not at such a level that the average impact of flooding is reduced (e.g. shifting the average impact from high to medium, medium to low or low to very low).

Technical complexity is increased for Systems 1 and 2 with the addition of technical components such as inlet screens. Systems 3 and 4 have the same technical complexity in their optimized versions.

Applying the optimizations, the needed *Level of integration with other actors* increases for all systems except System 1. For Systems 2, 3 and 4 at least one additional type of actor (e.g. farmers who can apply the reuse product in their fields) is needed compared with the existing systems for reuse to take place. Therefore, all these systems score lower in their optimized versions compared with the existing ones on level of *Integration with other sectors*.

Economic sustainability

The full results from the *Economic sustainability* assessment are available in Annex 5 and a summary of the results for all four systems is shown in Table 4.6.

Table 4.6: Economic sustainability of existing and optimized systems.

	System 1		System 2		System 3		System 4	
	Existing	Optimized	Existing	Optimized	Existing	Optimized	Existing	Optimized
Economic sustainability	1	1	3	3	5	4	4	2

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)}. + {use of PPE}

There is no change in *Economic sustainability* for Systems 1 and 2 between the existing and optimized versions. The expected cost changes for the optimized systems in infrastructure and operation and maintenance (including the use of PPE) are relatively limited compared with the existing systems, showing decreases in coverage of costs of 2% for each system type. For System 3 the decrease in coverage of costs is also 2%, as for Systems 1 and 2. However, System 3 goes from 91% coverage to 89% and passes the threshold to a score of 4. System 4 drops from a score of 4 to a score of 2, because of additional costs related to the urine collection.

Discussion – optimized systems

Table 4.7 summarizes the results from the sustainability assessments of the existing and optimized systems in Montero, but without weighing. Once again, we have chosen not to calculate an overall summary score for the optimized systems. The more important information is the movement in score possible by the optimization, such as the move from score 2 to 4 for *Health and hygiene* for System 1, or the move from score 1 to 5 for TN release for System 4, enabled by the optimizations within each system type.

The optimization of the systems has a few overarching effects. *Environmental* and *Health and hygiene* sustainability are generally increased for the optimized systems, which are the primary functions desired from sanitation systems. This increased performance in environmental and health protection comes at a cost: increased technical complexity and *Integration with other sectors* as well as decreased economic sustainability. This fact is most clearly demonstrated with System 4 where the optimized system, with urine collection services in place, increased its scores on nutrient and organic matter release from 1 to 4 or 5 (the highest scores of all systems for *Environmental sustainability*), but with a drop in *Economic sustainability* from 4 to 2. It can also be noted, however, that the optimized System 4 costs less than System 1 and provides the highest levels of environmental protection of all systems. Therefore, it is reasonable that dry, urine-diverting systems with collection services should be included in service options and have access to the same financing mechanisms and levels of subsidies as centralized sewered systems.

Table 4.7: Summary of the sustainability analysis of existing and optimized systems in Montero.

		System 1		System 2		System 3		System 4	
		Existing	Optimized	Existing	Optimized	Existing	Optimized	Existing	Optimized
Health and hygiene	Health and hygiene	2	4	3	4	3	4	4	4
Environmental sustainability	TN release	3	4	2	3	1	3	1	5
	TP release	2	3	1	1	1	1	1	4
	BOD5 release	3	4	1	5	1	3	1	4
	Water use	3	3	3	3	3	3	5	5
	Separation of sanitation flows	2	2	3	3	4	4	5	5
Social sustainability	Social acceptability	5	5	5	5	3	4	4	4
	Household affordability	1	1	2	2	3	3	3	2
Technical and institutional sustainability	Appropriate system design	1	1	2	2	3	3	4	4
	Vulnerability to water scarcity	1	1	1	1	3	3	5	5
	Vulnerability to flooding	2	2	3	3	3	3	4	4
	Integration into urban planning	3	3	3	3	3	3	4	4
	Technical complexity*	4	3	4	3	3	3	3	3
	Integration with other sectors**	4	4	4	3	3	2	4	3
Economic sustainability	Financial sustainability	1	1	3	3	5	4	4	2

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

4.3 The importance of innovation

There are a number of different innovations, with differing technology readiness levels (TRLs), possible within each sanitation system. As has been shown above, each system type has its own challenges and weak points and therefore the need for innovation looks different for each system type and each context. For example, System 1 in the Montero context has high hydraulic loading, which reduces the possibility of removing nutrients in the system. Therefore, solutions that can improve the removal of nutrients are needed for System 1. On the other hand, for System 4, the main challenge to achieve agricultural reuse is the management of large volumes of urine. Hence, reduction of urine volumes while keeping nutrients in the product could be an interesting innovation for System 4.

Below we give some examples of innovations that could be appropriate for the Bolivian context. It is worth noting that some of the suggestions are not strictly innovations but are included as they are not widespread in Bolivia.

System 1: conventional gravity-fed sewers and waste stabilization pond treatment

Innovation: as optimized + UASB before the pond system + agricultural reuse if possible, otherwise in-pond chemical precipitation to remove microalgae and TP

A main challenge for System 1 is to improve the quality of effluent from WSPs regarding its nutrient content. Three possible ways to do that are to:

- use the WSP effluent for crop production
- add more volume/surface area of ponds
- add treatment steps with low areal footprint.

In the case of Montero, the city is limited by available space/land and the utility cannot increase the size of the WSPs to meet stricter effluent criteria, nor are there any farms situated within a feasible distance from the ponds so that the treated wastewater and nutrients can be efficiently diverted and utilized. As such, the addition of treatment steps with a low areal footprint could be a suitable way forward to meet stricter effluent criteria without increasing the size of the plant.

Two innovations (for the Bolivian context) for the optimized version of System 1 (see Section 4.1, System 1) are the addition of a UASB (to produce methane and reduce pond loading rate) and in-pond chemical precipitation to remove microalgae (source of BOD_5, TN and TP) and excess TP (see Box 4.1). These "innovations" have a high TRL and are applied worldwide already.

BOX 4.1: SYSTEM 1 (CONVENTIONAL GRAVITY-FED SEWERS AND WASTE STABILIZATION POND TREATMENT) – OPTIMIZED VERSION AND INNOVATIONS FOR THE MONTERO CONTEXT

Optimized version of System 1

- Disconnection of roof drainage from sewer system.
- Use of PPE.
- Improved pre-treatment using mechanized screens at the inlet.
- Proper management of lagoons and sludge.
- Sludge treatment (drying).

See Section 4.1 for more details of the optimized version of System 1.

Innovations

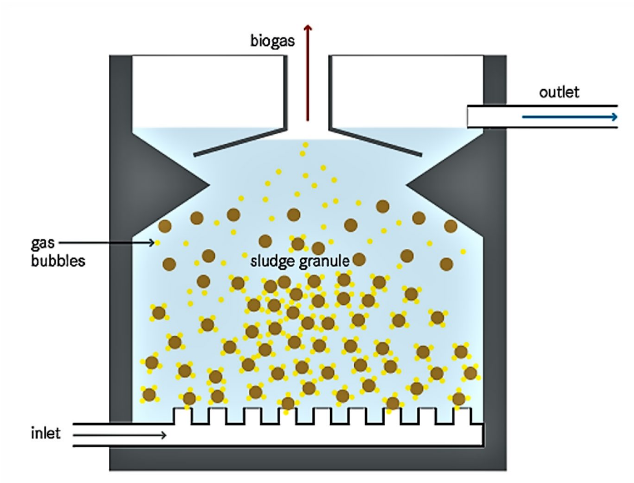
WSPs are very common in Bolivia because of the low construction costs and easy operation. A complete pond system, which usually includes anaerobic, facultative and aerobic (maturation) ponds, is able to efficiently treat wastewater by reaching high reduction levels of solids, organic loads and even nutrients when combined with aquaculture. Among the disadvantages of stabilization ponds, the following should be highlighted:

- they require a large land area
- anaerobic ponds usually generate odours due to the production of methane
- the cost of periodically desludging ponds is high.

One way of improving the performance of stabilization ponds is to modify the treatment train by including anaerobic reactors before the pond system. This improvement brings a series of benefits. First, most of the sludge from primary treatment will be removed from the anaerobic reactors before entering the pond system, resulting in savings in O&M costs since it is much easier to pump the stabilized sludge out of the reactor than remove it from the bottom of ponds.

In the picture, we can see an ABR implemented before the pond system, which resulted in capacity enhancement and an effluent with a higher quality in an existing plant in the municipality of Punata (Cochabamba, Bolivia).

Alternatively, a more efficient type of anaerobic reactor can be implemented, such as the UASB, which has an even smaller footprint and can reduce up to 70–80% of organic load present in raw wastewater. The ponds can act as secondary and tertiary treatment (including reduction of pathogens). According to preliminary calculations, this could result in a plant with about 25% larger capacity, in the same original land area and with an increase in total cost of approximately 12 %.



Cross-section of an Upflow Anaerobik Sludge Blanket (UASB) reactor.
Source: Tilley et al. 2014

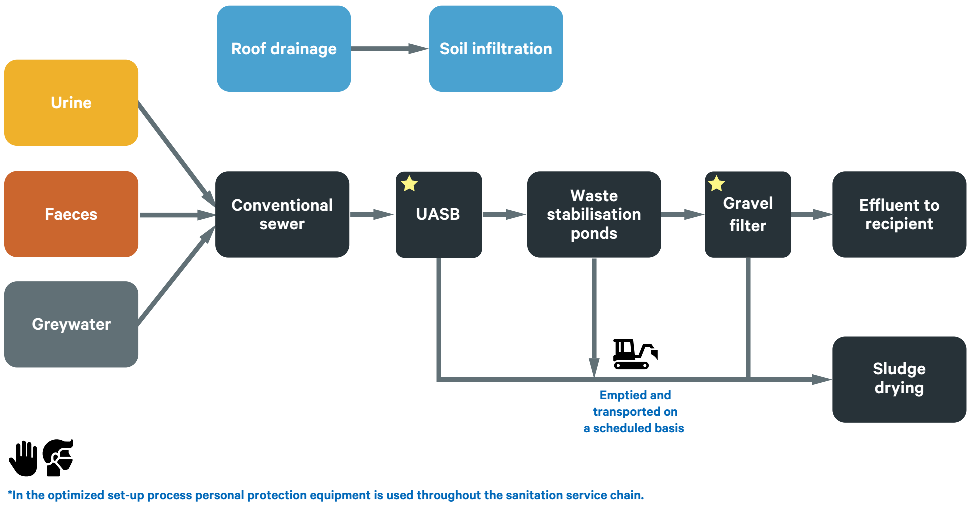
The UASB is a single-tank process in an anaerobic treatment system achieving high removal of organic matter. Wastewater enters the reactor from the bottom and flows upward. A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it. Bacteria living in the sludge break down organic matter by anaerobic digestion, transforming it into biogas. Solids are also retained by a filtration effect of the blanket. The up-flow regime and the motion of the gas bubbles allow mixing without mechanical assistance. Baffles at the top of the reactor allow gases to escape and prevent an outflow of the sludge blanket. As with all anaerobic treatments, UASBs require a post-treatment to remove pathogens, which in this case can take place in the subsequent aerobic ponds. The stabilized sludge extracted from a UASB can be used in agriculture, after sanitization. (More info: UASB Reactor | SSWM – Find tools for sustainable sanitation and water management!)

Chemical precipitation for phosphorus removal

Phosphorus removal by chemical precipitation involves the addition of metal salts to react with soluble phosphate to form solid precipitates that are removed by solids separation processes including clarification and filtration. The most common metal salts used are in the form of alum (aluminium sulfate), sodium aluminate, ferric chloride, ferric sulfate, ferrous sulfate and ferrous chloride.

The implementation of a chemical precipitation system involves the construction of a holding tank for the chemicals, a dosage pump and a settling tank. Alum is then dosed and mixed with the secondary treatment effluent. Additional sludge is generated and separated at a settling tank. Phosphorus is removed along with the sludge from the settling tank or secondary clarifier.

Figure 4.5: Simplified schematic representation of System 1 in an optimized version with the innovations added.



Health and hygiene: The added treatment steps of the UASB and the chemical precipitation imply additional tasks for the sanitation workers, hence also risks. However, with the right PPE and appropriate management routines the likelihood and severity of these risks can be kept low. The UASB process will reduce the load to the WSP and the ponds will work more efficiently for pathogen removal if the loading rate is not changed. It is therefore likely that there will be a positive health outcome from improved effluent quality from the suggested innovations. Overall, we assess that there will be a positive health outcome on the outgoing water, as long as the additional tasks at the WWTP are well managed.

Environment: The addition of a UASB reactor reduces the BOD_5 load to the WSP. The UASB will provide the anaerobic step and the pond system will thus have a larger aerobic volume. This should allow for additional TN removal through aerobic processes and more algal growth, which in turn should remove more TN and TP through sedimentation. The chemical precipitation step will ensure that the algae will be captured. The UASB will reduce odour problems at the treatment plant and add the possibility to collect and use methane. Failing that, there is at least a possibility to reduce methane discharge from the system if the gas is burned or flared. Overall, we assess that there will be a positive impact on the environmental aspects by introducing the innovations.

Social: Affordability will be negatively affected by the additional costs for introducing new technology. Otherwise, there will be no change to social indicators.

Technical: Additional unit processes are added to the treatment plant (UASB and chemical precipitation), which adds labour and supervision demand to the system. At the same time the capacity of the plant is increased by removing a higher solids and BOD_5 load from the pond system through the UASB process. Overall, we assess that there will be increased technical complexity from the introduced innovations.

Economic: The UASB and chemical precipitation will demand additional investments and significant O&M costs at the treatment plant level due to the use of chemicals and the increased generation of sludge. At the same time there may be a possibility for the utility to absorb some of these additional costs as the capacity of the treatment plant is somewhat improved. Overall, it is likely that the economic sustainability will be negatively impacted by introducing the innovations.

Table 4.8: Effect on sustainability dimensions by introducing UASBs and chemical precipitation into System 1. The optimizations of System 1 are marked in green.

Effect of introducing innovations (UASB and chemical precipitation) into optimized System 1 (WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE})				
Health and hygiene	**Environment**	**Social**	**Technical**	**Economic**
0/+	+	-	-	-

System 2: condominial sewers and anaerobic primary treatment

Innovation: as optimized + submerged aerated filter

The treatment efficiency of System 2's optimized version (Section 4.1) can be significantly improved by replacing the gravel filter of the secondary treatment with a submerged aerated filter (SAF). This "innovation" has a high TRL and is applied worldwide already.

BOX 4.2: SYSTEM 2 (CONDOMINIAL SEWERS AND ANAEROBIC PRIMARY TREATMENT) – OPTIMIZED VERSION AND INNOVATIONS

Optimized System 2

- Improved pre-treatment.
- ABR.
- Gravel filter.
- Sludge is dried locally.
- Use of PPE.

See Section 4.1 for more details of the optimized version of System 2.

Innovations

The SAF replaces the gravel filter to improve the quality of the final effluent and to reduce the footprint of the treatment plant. The principle of operation of the SAF is that pre-treated or settled wastewater passes through a filter bed where a bacterial culture (biofilm) degrades the dissolved organic load. Also, a fraction of suspended solids is adsorbed by the biofilm and thus removed from the wastewater. The SAF system presents a very stable/reliable operation and, unlike suspended biomass processes, it does not require sludge return or recirculation. This system can achieve 90% organic matter removal (BOD or COD) when the ratio of COD/BOD is less or equal to 2.5.

Sludge is periodically removed and then treated and dried at the centralized wastewater treatment plant.

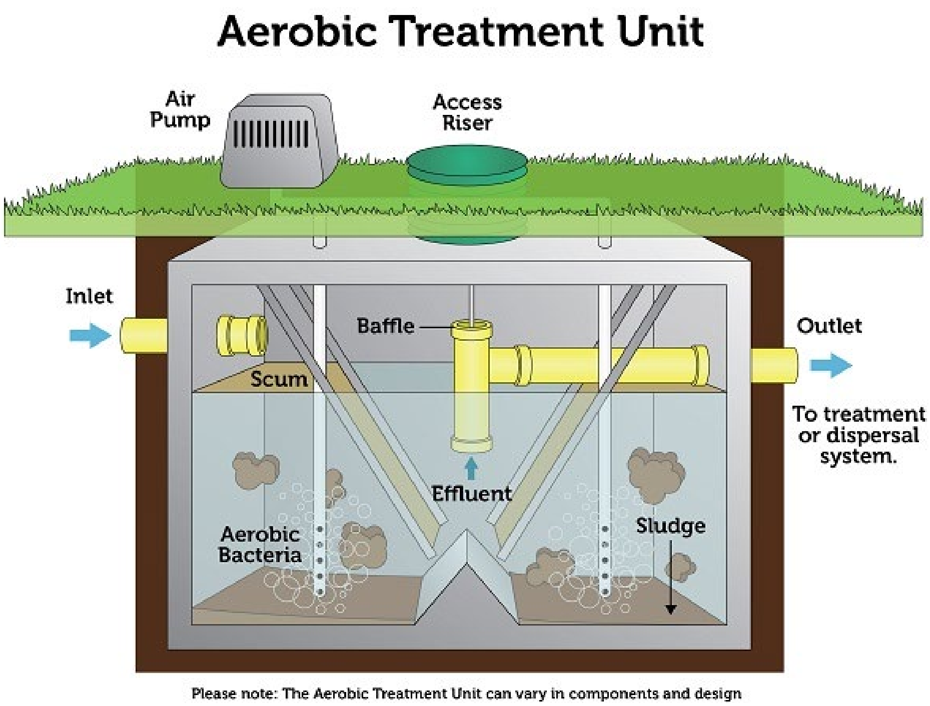
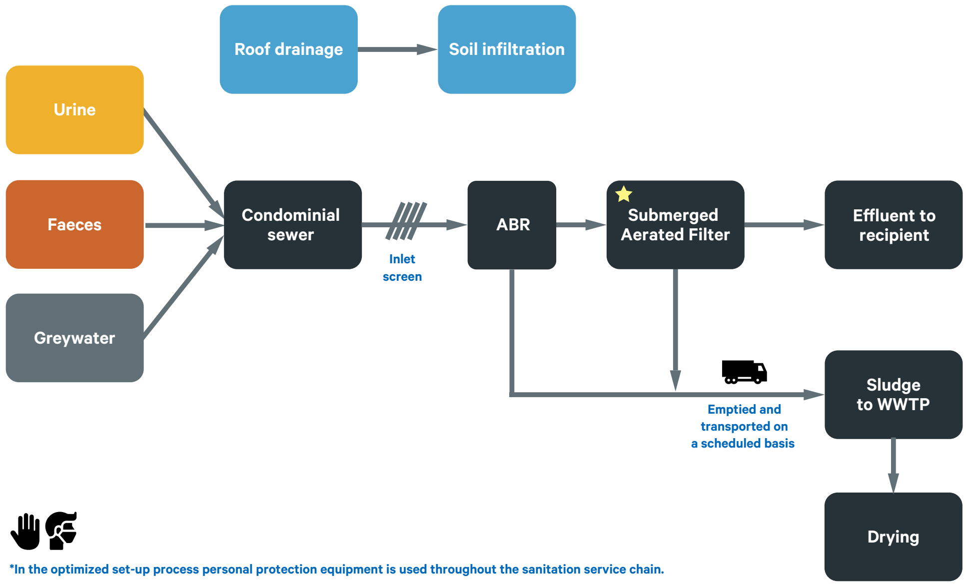


Figure 4.6: Simplified schematic representation of System 2 in an optimized version with innovations added (starred).



Health and hygiene: The extra treatment steps will add additional risks for workers. However, with appropriate PPE and management routines it is believed the likelihood and severity of these additional risks can be kept low. An aerated process will reduce the pathogen content in the outgoing wastewater, but not enough to provide disinfection. Overall, we assess that there will be a positive health outcome on the outgoing water, as long as the additional tasks at the WWTP are well managed.

Environment: Adding the SAF after the ABR will, in essence, add additional aerobic compartments to the ABR, remove additional BOD_5 and TN and improve the effluent quality. Overall, we assess that there will be a positive impact on the environmental aspects.

Social: Affordability will be negatively affected by the additional costs for introducing new technology. Otherwise, there will be no change to social indicators.

Technical: An additional unit process is added to the treatment plant, which increases the technical complexity, labour and supervision demand. The aerated step will require a constant electricity supply, and increased system supervision will be needed. Overall, we assess that the addition of the aeration step will increase the technical complexity of the system.

Economic: The extended aeration will demand significant additional investments at treatment plant level. At the same time there is a possibility for the utility to absorb this additional cost by a (possible) increased capacity in the treatment plant. The affordability will be negatively impacted by the investments.

Table 4.9: Effect on sustainability dimensions of introducing submerged aerobic filters into System 2. The optimizations of System 2 are marked in green.

Effect of introducing innovations (SAF) into System 2 (WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE})				
Health and hygiene	**Environment**	**Social**	**Technical**	**Economic**
0/+	+	-	-	-

System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge at treatment plant

Innovation: as optimized + proper infiltration system + addition of urea treatment step of the faecal sludge

The optimized version of System 3 (Section 4.1) is further improved with properly designed soil infiltration systems and innovative urea treatment at the wastewater treatment plant of the collected faecal sludge (Box 4.3). Soil infiltration has a high TRL since it is widely applied already. The faecal sludge urea treatment step can be estimated to have a fairly high TRL (7), but it is still an emerging technology.

BOX 4.3: SYSTEM 3 (HOUSEHOLD CONNECTION TO AN ON-SITE SEPTIC TANK WITH A SOAK PIT) – OPTIMIZED AND INNOVATIONS

Optimized version of System 3

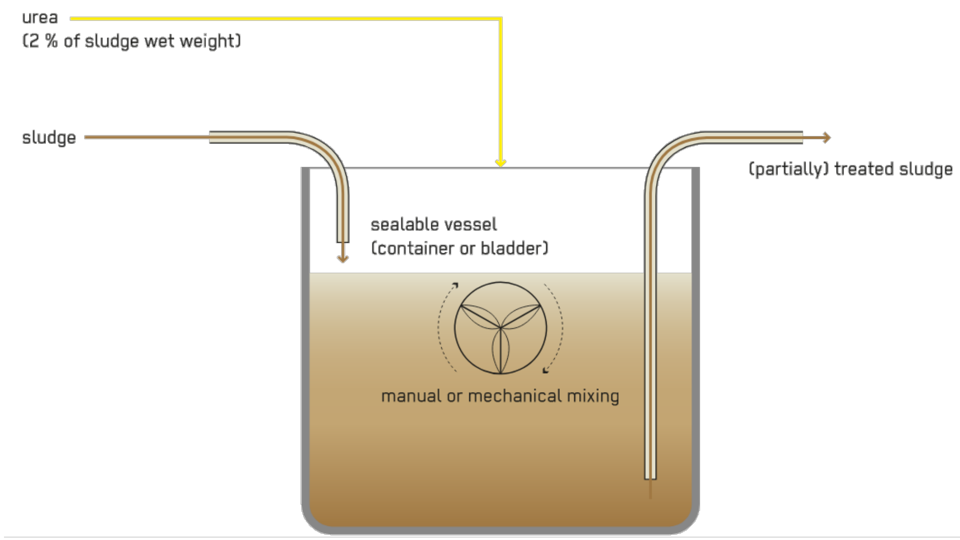
- Formal collection service in place.
- Use of PPE.
- Sludge treatment at central plant (drying).

See Section 4.1 for more details of the optimized version of System 3.

Innovations

One way of treating and sanitizing sludge is by the addition of urea $CO(NH_2)$. This process creates an alkaline environment that inactivates pathogens. Usually, urea is added at a ratio of 2% of the overall sludge wet weight. Urea is initially placed in a storage vessel (e.g. bladder/closed tank) and then faecal sludge is pumped into the vessel.

The process depends on temperature and partial pressures of ammonia gas above the liquid. Hence, ventilation and head space also influence the process conditions. It is recommended that treatment is undertaken in a sealed vessel to minimize the amount of ammonia gas that escapes and to force the equilibrium towards soluble ammonia. The treatment should be done in a reactor as a batch process to ensure consistent sanitization in the sludge. The efficiency of the process is usually measured by monitoring the concentration of indicator organisms such as *Enterococcus spp.* and



Escherichia coli.

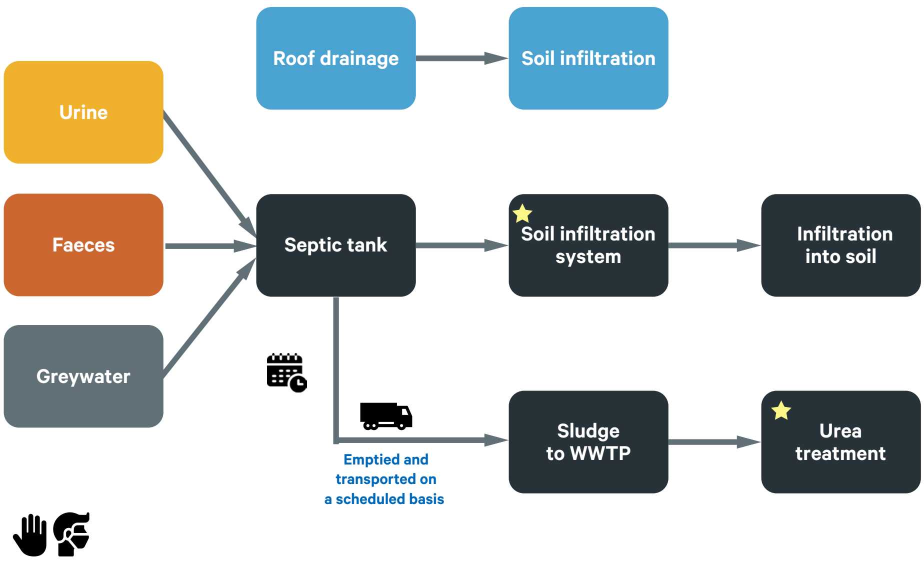
Standard sealable vessel for mixing of urea with sludge .

A pump can be used to circulate the sludge within the storage vessel to ensure adequate contact between the urea and sludge. Urea decomposition requires a minimum of four days, so a retention time in the closed vessel of approximately one week is recommended.

This treatment technology produces a sanitized sludge (safe for use in agriculture from a pathogen perspective) and occupies much less space than conventional drying beds. On the downside, the costs for transporting the final product (sanitized wet sludge) to a reuse site can be high when agricultural activity is distant from the treatment plant.

Source: Emergency WASH Knowledge Portal (https://www.emergency-wash.org/)

Figure 4. 7: Simplified schematic representation of the optimal implementation of System 3 with innovations (starred).



*In the optimized set-up process personal protection equipment is used throughout the sanitation service chain.

Health and hygiene: There should be a decreased risk of pathogen and nitrate infiltration to groundwater at the household level with a proper soil infiltration system. The additional treatment step (urea treatment) at the WWTP will add risks for workers at the WWTP. Urea treatment should, however, provide a safer sludge product for reuse than sludge drying only. Overall, we assess that there will be a positive health outcome on the outgoing water from the infiltration system and the treated sludge, and a positive outcome at the WWTP, as long as the additional tasks are well managed.

Environment: A properly constructed soil infiltration system will remove BOD_5, TN and TP from the septic tank effluent more efficiently than a soak pit. Removal rates will depend on local conditions and may vary over time. Overall, we assess that there will be a positive change to the environment by implementing the suggested innovations.

Social: Affordability will be negatively affected, with increased costs for system improvements. Otherwise, there will be no change to social indicators.

Technical: An additional unit process is added to the treatment plant, which increases the technical complexity, labour and supervision demand. The urea treatment step will require a constant electricity supply (for mixing), and increased system supervision will be needed. Overall, we assess that the addition of the urea treatment step will increase the technical complexity of the system.

Economic: The construction of proper infiltration systems at household level and the additional urea treatment step at the treatment plant level will demand significant additional investments. It is unclear if there is any possibility of recouping some of the investment costs through additional capacity.

Table 4.10: Effect on sustainability dimensions by introducing soil infiltration systems and urea treatment into System 3. The optimizations of System 3 are marked in green.

Effect of introducing innovations (infiltration bed/trenches and urea treatment of faecal sludge) into optimized System 3 (WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying) + {use of PPE})				
Health and hygiene	**Environment**	**Social**	**Technical**	**Costs**
0/+	+	-	-	-

System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant

Innovation: as optimized + addition of urine stabilization at household level and urine drying and urea treatment of compost at treatment plant

System 4's optimized version (Section 4.1) can be considerably improved at the reuse level by sanitization of the faecal compost and by drying of the urine to reduce the volume. The first step is stabilization of urine at household level. At the WWTP the urine is dried and urea is added to the faecal compost (Box 4.4). Urine stabilization and drying is under development and therefore has a low TRL at this point. However, since urine drying will be piloted in El Alto in 2022, the innovation is included here as a possible future urine management strategy. The addition of urea to compost can be considered to have a higher TRL, where the sanitizing effect of urea is known already for faecal sludge and blackwater.

BOX 4.4: SYSTEM 4 (UDDTS AND LOCAL GREYWATER TREATMENT) – OPTIMIZED AND INNOVATIONS

Optimized system

- Collection of urine and faeces at household level.
- Storage of urine at WWTP.
- Composting of faecal material at WWTP.

See Section 4.1 for more details of the optimized version of System 2.

Innovations

An alkaline stabilizing agent needs to be regularly added to the urine at the household level. This stabilizing agent will minimize the conversion of urea to ammonia. There is ongoing development of how this alkaline stabilizing agent can be dosed to the urine in a user-friendly way, such as by pre-addition in jerrycans by the service provider so that the user does not have to add it. Ongoing development suggests that about 2 g of stabilizing agent/L of urine will be needed.

A mobile urine drying treatment plant is currently under development, where it is expected that the drying of stabilized urine can be achieved with the use of 0.5 kWh/L of urine, using solar power. By drying the urine the mass can be reduced by 90% while keeping very high levels of the nutrients in the remaining product. The dried product resembles sand, contains 8.2% N, 0.7% P and 2.5% K, and 100 g of the dried product can fertilize 1 m^2. In the picture, dried urine has been used to the right, no fertilizer in the middle and commercial fertilizer to the left. Read more about urine drying at https://sanitation360.se/.

Addition of urea for inactivation of pathogens and parasites has been shown to be a successful sanitization method at doses of 1–2% (Nordin et al., 2009). The innovation for System 3 (see Section 4.3, System 3) is building on the sanitization effect of urea. Urea addition to compost is therefore a promising concept to further investigate and develop in the Bolivian context, to reduce health and hygiene risks at the compost reuse stage.

Health and hygiene: Conducting urine stabilization at the household level adds a potential risk of users coming into contact with the alkaline stabilization agent, although additional work is currently being done to design new lower-risk ways of dosing the stabilization agent. The additional treatment step (urine drying and urea treatment of the compost) will add additional tasks for workers at the WWTP, and therefore additional risks. With correct PPE and management routines it is believed that the likelihood and severity of these risks can be kept low. Urea treatment after composting provides a safer reuse product compared with composting only. Overall, we assess that there will be a positive health outcome on the compost, as long as the additional tasks at the WWTP are well managed.

Environment: Urine drying simplifies reuse of urine as a fertilizer by reducing the volume while maintaining most of the nutrients. Treating the compost with urea will sanitize it through increased pH, which will lead to the inactivation of pathogens and increase the N content in the compost. Nutrient reuse will be simplified compared with the optimized system, due to the dry fertilizer product. Given the indicators used for assessment in this study, however, these improvements are not going to influence the *Environment* criteria. Hence, we assess that there will be no significant change to the environmental parameters used in this study with this innovation.

Social: Affordability will be negatively affected, with increased costs for system improvements. Otherwise, there will be no change to social indicators.

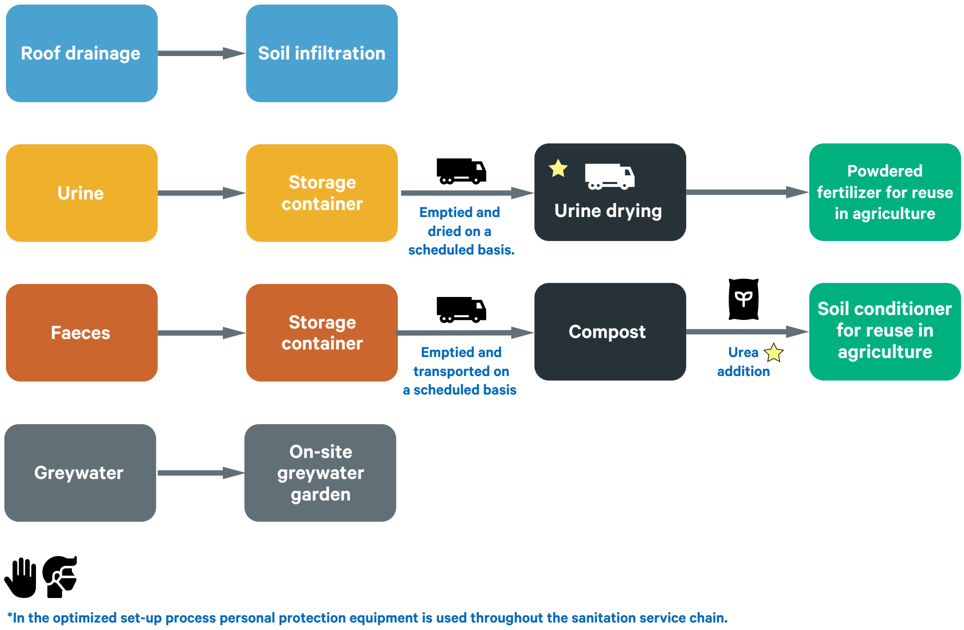
Technical: The pick-up frequency of urine should be the same as for the optimized option. The urine stabilization agent needs to be regularly added to the urine containers at household level, which can probably be organized when emptying by the utility. The urine-drying unit at WWTP level needs constant access to electricity, but it is believed that this need can be covered with solar power. Overall, we assess that the urine stabilization, urine drying and addition of urea to compost will increase the *Technical complexity* of the system.

Economic: There will be a need for capital investments in the urine-drying technology and increased O&M costs in relation to the drying and the adding of an alkaline agent at household level. It is likely that there will be a higher demand for the safe compost and the dry fertilizer product than for the products from the optimized system. It is very unlikely that the increased costs from investments will be fully covered by the increase in demand for the products, but some costs can potentially be offset by having a more attractive end product.

Table 4.11: Effect on sustainability dimensions by introducing urine drying and urea addition to compost into System 4. The optimizations of System 4 are marked in green.

Effect of introducing innovations (urine stabilization, urine drying and urea addition to compost) into optimized System 4 (dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}).				
Health and hygiene	**Environment**	**Social**	**Technical**	**Economic**
0/+	0	-	-	-

Figure 4.8: Simplified schematic representation of the optimal implementation of System 4 with innovations (starred).



5. Conclusions

5.1 A sustainability assessment method

In this report we present a sustainability assessment method based on a multi-criteria approach and stakeholder engagement. The method has seven steps, which are carried out with the cooperation of sanitation professionals and relevant stakeholders. It can be used at different stages in the sanitation planning process, from understanding the overall merits of different systems early in the process to later decision-making for implementation.

An important step in the process is the choice of indicators to assess the sustainability of different criteria. The choice of criteria and indicators will influence what is assessed and how. To ensure acceptance of the outcome of the evaluation, stakeholder engagement is key in the choice of criteria at the beginning of the process and at the end for validation of the results. The stakeholder engagement for validation of the results was hampered in this project due to the Covid-19 pandemic; it was held digitally, which in the case of Montero was not an ideal solution.

It is important to base sustainability assessment on actual and on-site data whenever possible. If not available, data from similar contexts or from literature and expert judgements can be used.

5.2 Understanding sustainability of sanitation system types

We believe that cities that are taking their mandate of sanitation service extension seriously could learn a lot from the sanitation experiences in Montero. The city is a forerunner and a good example when it comes to using a mix of sanitation approaches to meet its citizens' sanitation service needs: three of the four system types investigated in this report are already in use in Montero, and several system types are being considered in the planning of sanitation services extensions in Montero.

The sustainability assessment of the *systems as they function today* in Montero showed that all systems have their strengths and weaknesses. System 4 has the most indicators with high scores, having scores of 4 or 5 for one or more of the indicators in each sustainability pillar. System 1 has the highest number of indicators with the lowest score, mainly related to *Affordability* and *Economic sustainability* and dependence on water.

Given the merits of the sanitation systems demonstrated in this study, even as they function today, it is reasonable that a mixture of sanitation solutions should be included for a city-wide inclusive sanitation approach in contexts similar to those in Montero.

For the environmental assessment there is a particular lack of local/national data, which introduced uncertainty into the assessment.

The *optimization of the systems* gave a few overarching results. *Environmental* and *Health and hygiene* sustainability were generally increased for the optimized systems, which are the primary functions desired from sanitation systems.

Improvements to *Health and hygiene* within the optimized systems were achieved with little additional operating costs. The use of PPE by sanitation workers reduced the likelihood of risk events along the service chain for Systems 1, 2 and 3, as did the improvement of operation and maintenance routines, all of which can be considered low-cost interventions.

However, this increased *Environmental* performance comes at a cost: increased *Technical complexity* and more difficult *Integration with other sector*s as well as decreased *Economic sustainability.* This was most clearly demonstrated with System 4 where the optimized system, with a urine collection service in place, increased its scores on nutrient and organic matter release from 1 to 4 or 5 (the highest scores of all systems on *Environmental sustainability*), but with a drop in *Economic sustainability* from 4 to 2. Nevertheless, the optimized System 4 still costs less than the optimized System 1 and provides higher levels of environmental protection.

It is worth noting that safe resource reuse (water, nutrients, energy), which is desired from the perspectives of a circular economy and long-term sustainability, will require an increased *Integration with other sectors*. Therefore, the water sector will have to adapt and cooperate with other sectors to achieve long-term resource sustainability. A low score on *Integration with other sector*s therefore does not mean that the system itself is unsustainable; it only means that additional effort is necessary to cooperate outside the water sector.

Some of the lower scores for the sewered systems (Systems 1 and 2) are difficult to improve with optimization efforts (*Vulnerability to flooding*, *Vulnerability to water scarcity*, *Appropriate system design*, *Household affordability* and *Economic sustainability*) because of the inherent inflexibility in the technical design of sewered systems.

Sustainable sanitation protects public health and the environment. To provide sustainable sanitation services is costly for all system types. To achieve long-term financial sustainability for a utility, it is necessary to cover all costs (CAPEX and OPEX) of the system. Costs can be covered via different financial mechanisms, notably the four Ts: tariffs, taxes, transfers (i.e. development aid) and trade, where trade sometimes can offset some costs if the system produces products that can be sold. An example of such products for "trade" is fertilizers from optimized System 4 (urine and safe compost).[7] In our analysis we looked only at how much of the costs are covered by the tariff applied. It is clear that System 1 needs to rely heavily on taxes and transfers to make it financially sustainable, which is also what happens for centralized sewered systems across the world today. System 1 is subsidized to a level that none of the other systems are. We would like to underline that all sanitation system types should have access to the same financing mechanisms and subsidy levels as centralized sewered systems. Individual households should not be expected to carry the full costs for on-site systems along the full service chain, especially when more prosperous parts of cities are served by highly subsidized centralized sewered systems.

To address the issue of affordability, cross-subsidies between different customers are needed to guarantee access to sanitation services for families with lower incomes.

Integration into municipal and urban planning can be improved. For example, municipal regulation is needed for all alternatives.

For municipalities that want to engage in a sustainability analysis, we recommend using this report as an inspiration for guiding the process as well as for choice of criteria, indicators and systems. However, it is important that the actual choice of criteria and systems is made in a participatory fashion with relevant stakeholders. It is also advisable that the sanitation experts identify the indicators and carry out the assessment during a concentrated and limited time, to keep the stakeholder engagement and process more alive and efficient.

7 Access to a reliable supply of local fertilizers can also play a role to reduce societal vulnerability to price hikes in chemical fertilizers or supply chain disruptions, such as we have seen in the wake of Covid-19.

5.3 The importance of innovation

The innovations presented in this report differ in their TRLs. Some, especially in Systems 1 and 2, are innovative in the Bolivian setting, but not generally in the world. Others, like in System 4, are truly innovative and therefore have lower TRLs. Innovations are, however, needed to improve the sector's protection of public health and the environment.

Innovations will generally increase sustainability of *Health and hygiene* and/or *Environment* at decreased *Economic* sustainability and increased *Technical complexity* across the different system types. It is worth reiterating that sustainable protection of health and the environment from poor sanitation is going to demand more resources from the sector than we are investing today.

6. Available resources

In this section we list resources that may be useful for the assessment process.

Knowledge platforms

- World Bank Citywide Inclusive Sanitation Platform: https://www.worldbank.org/en/topic/sanitation/brief/citywide-inclusive-sanitation#3
- Sustainable Sanitation Alliance: www.susana.org
- Sustainable sanitation and water management toolbox: https://sswm.info/

Planning guidelines

- Community-Led Urban Environmental Sanitation (CLUES): https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/1300
- Sanitation 21 – a planning framework for improving city-wide sanitation services: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/2712
- Open planning of sanitation systems: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/193
- A Sanitation Journey – Principles, Approaches and Tools for Urban Sanitation: https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/Sandec_Home/sanitation_journey.pdf

Health and hygiene

- WHO tool for sanitation safety planning: https://www.who.int/publications/i/item/9789241549240

Environment and technical function

- Compendium of Sanitation Systems and Technologies: https://www.eawag.ch/en/department/sandec/publications/compendium/
- Compendium of Sanitation Technologies in Emergencies: https://www.eawag.ch/en/department/sandec/projects/sesp/water-sanitation-and-hygiene-in-emergencies/
- Guide to Sanitation Resource-Recovery Products & Technologies: https://pub.epsilon.slu.se/21284/
- Greywater management in low- and middle-income countries: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/947
- Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries – A practical guide: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/1153
- IWA Biological Wastewater Treatment Series Volume 1–7: https://www.iwapublishing.com/books/book-series/biological-wastewater-treatment-series
- Source Separation and Decentralization for Wastewater Management: https://iwaponline.com/ebooks/book/616/Source-Separation-and-Decentralization-for
- Fecal Sludge Management – Systems Approach for Implementation and Operation: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/3591
- Faecal Sludge and Septage Treatment – A guide for low- and middle-income countries: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/3439
- Domestic Wastewater Treatment In Developing Countries: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/3064
- Assessment of treatment plant performance and water quality data: A guide for students, researchers and practitioners: https://www.iwapublishing.com/books/9781780409313/assessment-treatment-plant-performance-and-water-quality-data-guide-students
- Preparing scheduled desludging: https://iwaponline.com/ebooks/book/828/Preparing-Scheduled-Desludging
- Indicadores de Desempeño para Servicios de Saneamiento: https://iwaponline.com/ebooks/book/820/Indicadores-de-Desempeno-para-Servicios-de
- Methods for faecal sludge analysis: https://iwaponline.com/ebooks/book/823/Methods-for-Faecal-Sludge-Analysis
- Nature-based solutions for wastewater treatment: https://iwaponline.com/ebooks/book/834/Nature-Based-Solutions-for-Wastewater-TreatmentA
- An introduction to greywater management: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/942
- Nutrient stocks, flows and balances for the Bolivian agri-food system: Can recycling human excreta close the nutrient circularity gap?: https://www.frontiersin.org/articles/10.3389/fenvs.2022.956325/full

Economic

World Bank Costing tool: http://200.58.79.50/fmi/webd/CWIS%20Planning%20Tool%201_4

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Annex 1. Material from the workshop in Montero

A.1.1: Invitation to the workshop in Montero

MONTERO, 19 SEPTIEMBRE DE 2019

Taller "Codesarrollo de criterios para la reflexión sobre el saneamiento sostenible a partir de la experiencia en el Municipio de Montero"

GOBIERNO AUTÓNOMO MUNICIPAL DE MONTERO

Para vivir Bien

El Gobierno Autónomo Municipal de Montero, el Instituto de Medio Ambiente de Estocolmo (SEI) y UNICEF tienen el agrado de invitarle a participar en el Taller "Codesarrollo de criterios para la reflexión sobre el saneamiento sostenible a partir de la experiencia en Montero" que se desarrollará el día jueves 19 de septiembre en jornada continua en el marco de la Agenda Global de los Objetivos de Desarrollo Sostenible.

Se reflexionará y dialogará sobre la importancia de valorar los aspectos técnicos, sociales, institucionales, los referidos a salud, a lo financiero, al contexto nacional y al cuidado del medio ambiente para la implementación de los sistemas de saneamiento para que sean sostenibles.

Se pretende que a partir de este diálogo se contribuya al análisis del saneamiento respecto a la identificación de criterios que sean útiles para:

- Desarrollar lineamientos para inversiones futuras de saneamiento más sostenible en Bolivia;
- Destacar las ventajas competitivas de diferentes modelos de saneamiento;
- Lograr potenciales mejoras en la perspectiva de sostenibilidad de diferentes sistemas de saneamiento, tomando en cuenta el contexto local.

SEI Stockholm Environment Institute — Suecia Sverige — unicef

Taller para la sostenibilidad del saneamiento en Bolivia

Casa Municipal de Cultura

Montero, Santa Cruz

Hora: de 9.00 am a 4.30 pm –

Jueves 19 de septiembre de 2019

Programa del taller

09:00 – 09:30	Café e inscripción
09:30 – 10:00	Breve bienvenida
10:00 – 10:50	Introducción conceptual al taller
10.50 - 12.20	Desarrollo de criterios – *trabajo en grupos*
12:30 – 13:30	Almuerzo
13:30 – 14:30	Desarrollo de criterios – *socialización de resultado*
14:30 – 15:15	Breve descripción de diferentes sistemas de saneamiento
15.15 - 15. 30	Refrigerio
15.30 – 16.15	Potencial y aceptabilidad de sistemas innovadores de saneamiento
16:15 – 16:30	Siguientes pasos y conclusiones

Mayor información:
melina.balderrama@helvetas.org

OBJETIVOS DE DESARROLLO SOSTENIBLE

*Esta actividad hace parte del **proyecto Bolivia WATCH** desarrollada por el SEI, ejecutado en alianza estratégica con Helvetas Swiss Intercooperation y con el auspicio de la Embajada de Suecia / Asdi, en el marco de las acciones de integración de cuencas hidrográficas, agua y saneamiento en la planificación y gestión por encargo del Ministerio de Medio Ambiente y Agua*

A.1.2: Criteria identified during the workshop

The criteria were identified in groups. The groups then ranked their identified criteria, using green stickers (dots).

Table A.1.1 A summary of criteria and prioritization between criteria by group 1.

Group 1					
Category	**Criteria**	**Dots**	**% dots in category**	**% of dots**	**Rank**
Health	Health risk for the family when operating and maintaining the system	4	6.3	2.0	
	Avoid illnesses, diarrhoea, and skin infections	7		3.4	
	Adequate sanitation for health and educational centres	2		1.0	
Environment	Contamination of the water sources	14	22.0	6.8	1
	*Municipal regulations to not contaminate the environment**	8		3.9	
	Able to recycle nutrients	12		5.9	3
	Use of water and energy	4		2.0	
	*Level of environmental knowledge of the beneficial population**	7		3.4	
Socio-cultural	Feasibility and comfort for the family to operate and maintain the system	2	19.5	1.0	
	*Promotion of practices for health and hygiene**	7		3.4	
	Gender	4		2.0	
	*Well-considered educative promotion**	4		2.0	
	*Clear communication of the available techniques, advantages and disadvantages**	8		3.9	
	Use and customs, applicable interculturally	8		3.9	
	Universal access (for everyone)	7		3.4	
Technical/ Institutional	Resilient infrastructure	6	30.2	2.9	
	Understand the context: the place, number of inhabitants, types of activities	9		4.4	
	Efficiency of system (minimizing leaks)	5		2.4	
	According to municipal plan for water and sanitation	7		3.4	
	Consider the local technical competence of the operators of the service	17		8.3	
	Takes future population into account	6		2.9	
	Availability of local material	1		0.5	
	Capacity of the actual WWTP	11		5.4	5
Economical	Arrange a fair tariff	13	20.0	6.3	2
	Financing is available	7		3.4	
	Cost–benefit analysis in the long term (30 years)	7		3.4	
	Commitment from beneficiaries to pay for the services	2		1.0	
	Costs of operation and maintenance and of investment	12		5.9	4
Others	Take national norms into account	4	2.0	2.0	
	Sum:	205	100	100	

* Important aspects but not possible to use as criteria in the assessment of sanitation systems

Table A.1.2 A summary of criteria and prioritization between criteria by group 2.

Group 2					
Category	**Criteria**	**Dots**	**% dots in category**	**% of dots**	**Rank**
Health	Reduce points of risk	7	12.8	4.7	
	Reduce spreading of disease	12		8.1	4
Environment	Protection of hydraulic resources	14	14.9	9.5	3
	Minimize environmental impacts	5		3.4	
	Energy effectiveness	3		2.0	
Socio-cultural	Social acceptance of services	10	25.7	6.8	
	Change of habit	11		7.4	5
	Cleanliness	8		5.4	
	Easiness of use	9		6.1	
Technical/ Institutional	Urban municipal planning	15	19.6	10.1	2
	Adequate system design	7		4.7	
	Resilience to climate change	7		4.7	
Economical	Economical sustainability of the services	18	27.0	12.2	1
	Operating costs	11		7.4	5
	Implementation costs	11		7.4	5
	Sum:	148	100	100	

* Important aspects but not possible to use as criteria in the assessment of sanitation systems

Table A.1.3 A summary of criteria and prioritization between criteria by group 3.

Group 3					
Category	**Criteria**	**Dots**	**% dot ins category**	**% of dots**	**Rank**
Health	Reduce disease and mortality for children and infants	16	13.3	11.2	1
	Health risk of fertilizers with recycled nutrients	3		2.1	
Environment	Minimize contamination	4	25.9	2.8	
	*Environmental education**	7		4.9	
	Minimize use of water	7		4.9	
	Protect the surface water and groundwater	11		7.7	4
	Recirculate nutrients to agriculture	5		3.5	
	Comply with law 1 333 (environment)	3		2.1	
Socio-cultural	Social acceptance of systems	12	16.8	8.4	3
	Generate employment	0		0	
	*Beneficiary participation in choice of tech, payment via the tariff, and control of EPSA**	3		2.1	
	Fair tariff for service	4		2.8	
	Improve life quality for the family	4		2.8	
	Easy to understand and use	1		0.7	
Technical/ Institutional	Simplicity in collection and transportation	2	25.9	1.4	
	*National commitment of applying new technologies and recycling nutrients**	7		4.9	
	Technically appropriate	8		5.6	
	Evaluating technical capacity of regulations and operation of services	9		6.3	5
	Environmentally friendly technology	3		2.1	
	Robustness against climate change	8		5.6	
Economical	Cheaper and safer	0	14.7	0	
	Create income	0		0	
	Availability of resources and other inputs	2		1.4	
	Cost of the construction and operation	6		4.2	
	Financially sustainable	13		9.1	2
Others	*Involve public and private bodies**	5	3.5	3.5	
	Sum:	143	100	100	

* Important aspects but not possible to use as criteria in the assessment of sanitation systems

Table A.1.4 A summary of criteria and prioritization between criteria by group 4.

Group 4					
Category	**Criteria**	**Dots**	**% dots in category**	**% of dots**	**Rank**
Health	Reduction of cases of acute respiratory infections and acute diarrhoeal disease	4	5.1	5.1	
Environment	Ease of collection and recycling nutrients	**8**	20.3	**10.1**	**4**
	Consumption of water	6		7.6	5
	Consumption of energy	2		2.5	
Socio-cultural	Fast and flexible implementation	3	26.6	3.8	
	Need to change habits	10		12.7	1
	Easiness of use for the households	4		5.1	
	Level of desire and aspiration of the population	4		5.1	
Technical/ Institutional	Complexity in operation	2	21.5	2.5	
	Complexity in organization (EPSA and society)	9		11.4	3
	Resilience level against flooding	3		3.8	
	*Level and management of information for the service**	3		3.8	
Economical	Operation and maintenance cost	**9**	25.3	11.4	2
	Availability of resources	3		3.8	
	Environmental costs	0		0	
	Total investment	6		7.6	5
	Economic capacity	2		2.5	
Others	*Population density**	1	1.3	1.3	
	Sum:	79	100	100	

* Important aspects but not possible to use as criteria in the assessment of sanitation systems

Annex 2. Method for assessment of Health and hygiene

The health and hygiene assessment was conducted using a risk framework developed by the WHO (World Health Organization, 2015). The health risks related to exposure to pathogens, gases and elevated levels of nitrates in groundwater for the different sanitation systems were evaluated by determining potentially hazardous events in each step of the sanitation service chain. The potential risks in each step were identified and assessed by a group of sanitation experts, using the likelihood and severity descriptions that are presented in Table A.2.1 and calculating a risk score for each hazard according to this equation:

Risk Score (R) = Likelihood (L) × Severity (S)

Table A.2.1: Likelihood and severity definitions that have been used as a basis to determine the risk scores of different health risks.

Descriptor		Description
Likelihood (L)		
Very unlikely	1	Has not happened in the past and is **highly improbable** that it will happen in the next 12 months.
Unlikely	2	Has not happened in the past but **may occur in exceptional circumstances** in the next 12 months.
Possible	3	May have happened in the past and/or **may occur under regular circumstances** in the next 12 months.
Likely	4	Has been observed in the past and/or is **likely** to occur in the next 12 months.
Almost certain	5	Has often been observed in the past and/or **will almost certainly occur** in most circumstances in the next 12 months.
Severity (S)		
Insignificant	1	Hazard or hazardous event resulting in **no or negligible health effects** compared with background levels.
Minor	2	Hazard or hazardous event potentially resulting in **minor health effects** (e.g. temporary symptoms like irritation, nausea, headache).
Moderate	4	Hazard or hazardous event potentially resulting in **self-limiting health effects or minor illness** (e.g. acute diarrhoea, vomiting, upper respiratory tract infection, minor trauma).
Major	8	Hazard or hazardous event potentially resulting in **illness or injury** (e.g. malaria, schistosomiasis, food-borne trematodiasis, chronic diarrhoea, chronic respiratory problems, neurological disorders, bone fracture).
Catastrophic	16	Hazard or hazardous event potentially resulting in **serious illness or injury, or even loss of life** (e.g. severe poisoning, loss of extremities, severe burns, drowning).

The combination of severity and likelihood for each hazardous event was used to determine risk levels (Table A.2.2) as “low risk”, “medium risk”, “high risk” or “very high risk”. The overall risk assessment per system type is shown in Table A.2.3. Both the total risk score (the sum of risk for all hazardous events for the system) and the number of “high” and “very high” risks were used to give a *Health and hygiene* score.

Table A.2.2: Risk level determination matrix that has been applied in the report. The risk score is determined by multiplying the likelihood of an event by the severity of the outcome of that event happening.

			Severity (S)				
			Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
			1	2	4	8	16
Likelihood	**Very unlikely**	1	1	2	4	8	16
	Unlikely	2	2	4	8	16	32
	Possible	3	3	6	12	24	48
	Likely	4	4	8	16	32	64
	Almost certain	5	5	10	20	40	80
		Risk score R = (L) × (S)	≤ 6	7–12		13–32	> 32
		Risk level	**Low risk**	**Medium risk**		**High risk**	**Very high risk**

Table A.2.3: Scoring system used to determine the health score for each sanitation system. Two parameters are evaluated: total sum of risks and the number of "high" or "very high" risks. The number of hazardous events differs between systems. We have used an average of 11 hazardous events to calculate the threshold values for total risk scores in the scoring table. The total risk score requirement is calculated as the average number of indicators (n=11) and a risk score threshold for each risk level. Very low total risk (<11*6), low total risk (<11*10), medium total risk (<11*13), high total risk (≥11*13). If there are any very high risk hazards present in any of the sanitation systems, they are automatically given a score of 1, irrespective of the total risk score.

Description	Risk requirement	Total risk score	Score
Very high total risk	> 0 risks rated very high	-	1
High total risk	> 4 risks rated high, no risks rated very high	Total risk score ≥ 143	2
Medium total risk	≤ 4 risks rated high, no risks rated very high	Total risk score < 143	3
Low total risk	≤ 3 risks rated high, no risks rated very high	Total risk score < 110	4
Very low total risk	0 risks rated high or very high	Total risk score < 66	5

Annex 3. Method for assessment of Environment

Release of N, P and BOD_5 to the environment

The calculations for release of N, P and organic matter were made in two steps. First, we looked at effluent concentrations, after which we interpreted these concentrations in actual loads in kg/pe/yr, so that the different system types could be compared.

Step 1 – effluent concentrations

There is currently no national legislation in Bolivia that regulates effluent water quality from wastewater treatment plants and facilities. Old guidelines for effluent quality for *"mining wastewater"* are currently used as the *de facto* informal national standard for the treatment of municipal wastewater. There is no legal supervision from any regulatory authority. There are currently ongoing conversations in the Bolivian government/parliament about enacting similar legislative limits to those used in the EU based on the EU Water Framework Directive. The EU has strict limits on effluent water quality parameters, which will be difficult for Bolivian wastewater treatment plants to reach without significant technological improvements to their current wastewater treatment infrastructure, or a significant shift in the ways in which wastewater and/or excreta are treated or reused.

For BOD_5 release we used the *de facto* regulation of 80 mg/L in effluent value as the starting point to get 3 points in this effluent concentration step. We then assumed that a system following EU regulation for BOD_5 release + 20% is a reasonable expectation to get 5 points on BOD_5 on permissible effluent concentrations, which equals 30 mg/L (25 mg/L+0.2*25). The difference between 3 points (80 mg/L) and 5 points (30 mg/L) is 50 mg/L. With linear extrapolation the value for 4 points falls between these two at 55 mg/L (30 mg/L + 50/2 mg/L). For the values for 1 and 2 points we used the same approach: the difference between 3 and 1 points was 50 mg/L, making it 130 mg/L, and the value for 2 points fell between 1 and 3 points (Table A.3.1).

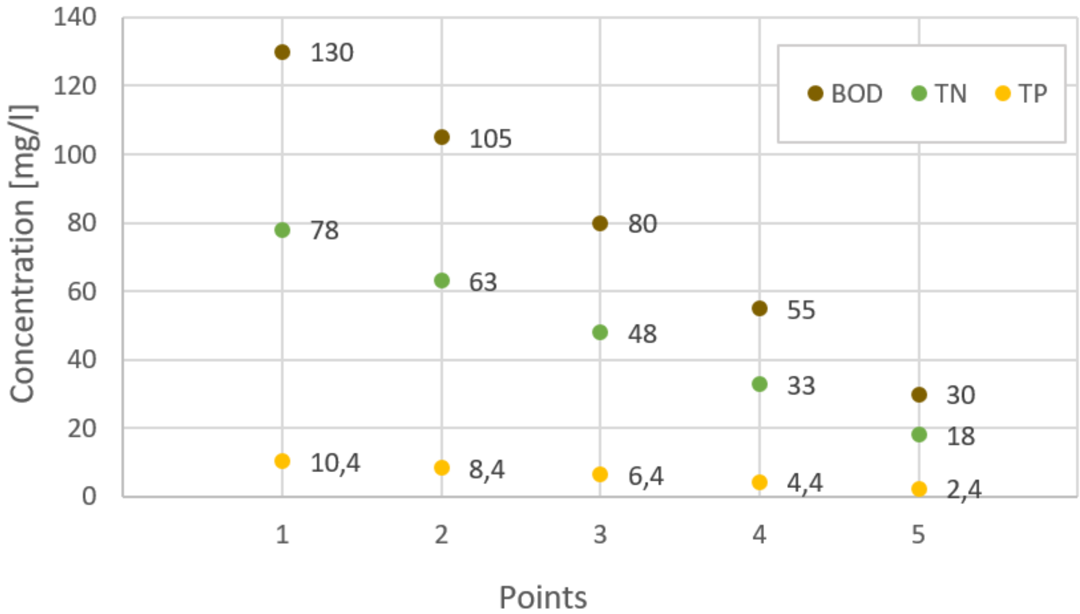
For TN and TP we have no existing Bolivian regulation to use as a starting point. However, for 5 points we used the same approach as for BOD_5: the EU regulation + 20% as *permissible effluent concentrations* (e.g. for TN = 15 + 0.2*15= 18 mg/L to arrive at 5 points). We then looked at the relative change for BOD_5 between 5 and 3 points (an increase of (80–30)/30=167%). To calculate the effluent concentration of N and P for 3 points we added 167% to the value for 5 points (e.g. 18+1.67*18 = 48 mg/L for TN). To get the value for 1 point we added the difference between 3 and 5 points to the value for 3 points (e.g. 48 + 1.67*18 = 78 mg/L for TN). Values for 2 and 4 points were obtained using midpoints between 3 points and point 1 or point 5, respectively (Table A.3.1 and Figure A.3.1).

Table A.3.1: Calculated permissible effluent concentrations.

Parameter	1 point	2 points	3 points	4 points	5 points
BOD_5*	130	105	80	55	30
TN*	78	63	48	33	18
TP*	10.4	8.4	6.4	4.4	2.4

* Unit: mg/L

Figure A.3.1: Permissible effluent concentrations for BOD5, TN and TP in relation to points in Table A.3.1.



Step 2 – conversion of effluent concentrations to loads in kg/cap,yr

Effluent concentrations are useful to compare sanitation systems that are waterborne and from which the wastewater sanitation flows from the household are mixed and conveyed to a wastewater treatment plant. This corresponds to Systems 1 and 2 in this study. To be able to compare how well these systems perform against Systems 3 and 4, which are not waterborne, there is a need to look at an *annual per capita load to the environment* instead. To make the annual per capita load to the environment in kg we have used the effluent concentrations from Table A.3.1, the average per capita water use in Montero (120 L/cap,day) and have assumed that all water use is converted to wastewater. The results from these calculations are shown in Table A.3.2. The load, L, is shown as intervals. For example, to score 4 on TN removal the annual load must be between 1.45 kg and 0.79 kg. 0.79 kg/cap,yr relates to the effluent concentration for 5 points (Table A.3.1) and 1.45 kg/cap,yr to the corresponding effluent concentration for 4 points in the same table.

Table A.3.2: L = effluent load in kg/cap,yr.

Criteria	1	2	3	4	5
Release of TN*	L > 3.42	3.42 > L > 2.76	2.76 > L > 1.45	1.45 > L > 0.79	L < 0.79
Release of TP*	L > 0.46	0.46 > L > 0.37	0.37 > L > 0.19	0.19 > L > 0.11	L < 0.11
Release of BOD_5*	L > 5.69	5.60 > L > 4.60	4.60 > L > 2.41	2.41 > L > 1.31	L < 1.31

* Unit: kg/cap,yr

A.3.1 Sanitation system inputs

A.3.1.1 Use of water

Table A.3.3: Per capita consumption of drinking water in Montero.

Per capita consumption of drinking water in Montero – COSMOL		
Management year 2019		
Month	**Factor [cap/household]**	**Per capita consumption [L/day]**
January	5	125.61
February	5	111.49
March	5	126.24
April	5	117.39
May	5	119.89
June	5	109.83
July	5	111.50
August	5	129.57
September	5	120.06
October	5	128.45
November	5	125.70
Average		120.70
Number of total connections		26 979
Number of active connections		25 666

Based on personal communication with Gustavo Heredia , it is estimated that the daily per capita water use for flushing toilets is 30 L/cap,d in Bolivian toilets, based on the assumption that the average person flushes a toilet five times a day and that every flush uses 6 L of water. It is assumed that the daily per capita greywater production is the difference between the average daily per capita water consumption minus the water used for flushing toilets, which gives 90.7 L/cap,d.

A.3.1.2 Calculation of urine and faeces inputs to the sanitation systems

Estimated amounts of annual per capita excreted urine and faeces in a Bolivian setting are presented in Table A.3.4.

Table A.3.4 Estimated annual per capita "production" of urine and faeces in Bolivia.

Produced urine	450	L/cap,yr	(Ministerio de Medio Ambiente y Agua (MMAyA) Bolivia 2010)
Produced faeces	46.85	kg/cap,yr	Calculated[8]

Nitrogen and phosphorus content in urine and faeces

Jönsson et al. (2004) presented two simple equations to calculate the TN and TP content in human excreta:

$$N = 0.13 * Total\ food\ protein$$

$$P = 0.011 * (Total\ food\ protein + Total\ vegetal\ protein)$$

8 Calculated from Ministerio de Medio Ambiente y Agua (MMAyA) Bolivia, 2010; Silveti, Condori, and Mamani, 2011; Vinnerås et al., 2006)

Data on total food protein and total vegetal protein consumption in different countries can be found in FAO statistics (FAOSTAT).

Table A.3.5: FAOSTAT protein intake statistics for Bolivia for 2018.[9]

Country	Vegetal protein [g/cap,d]	Non-vegetal protein [g/cap,d]	Total food protein [g/cap,d]	N content in excreta [g/cap,d]	P content in excreta [g/cap,d]
Bolivia	37.59	35.87	73.46	9.55	1.22

To further divide the N and P content in excreta into urine and faeces we used the method reported in Jönsson and Vinnerås (2004). They investigated the proportion of excreted nutrients in urine and faeces and found, for a Swedish context, 88% of excreted nitrogen in urine and 12% in faeces. For phosphorus they reported 67% in urine and 33% in faeces. In this report we assumed the same proportional content split of N and P in urine and faeces as reported by Jönsson and Vinnerås to calculate the figures for Bolivia (Table A.3.6).

Table A.3.6: Estimated N and P in urine and faeces in Bolivia.

Nutrient content	Urine [g/cap,d]	Faeces [g/cap,d]
N	8.40	1.15
P	0.82	0.40

For estimations of BOD_5, N and P in greywater we looked at Morel and Diener (2006) complemented with Jönsson et al. (2005) for P content. Morel and Diener suggest that typical concentrations of BOD, TN and TP in greywater from households using around 100 L/cap,day can be 250 mg/L, 10 mg/L and 15 mg/L, respectively. The TP concentration can vary considerably depending on the use of phosphate-based detergents. In the case of Montero, we believe that 15 mg/L of TP in the greywater would be an overestimation, since lab results on PO_4-P in the influent to the wastewater treatment plant have shown around 15 mg/L. We therefore chose to use Jönsson et al. (2005) for the P estimation in greywater instead, which estimates the TP in greywater to be 76% of the TP in urine. In Table A.3.7 we have used the greywater "production" (90.7 L/cap,day) and the average N content in greywater to calculate the TN content. For the TP content we have taken 76% of the P content in urine in Table A.3.6.

Table A.3.7. Estimated N and P content in greywater.

	Greywater
TN [g/cap,d]	0.91
TP [g/cap,d]	0.62

Biological oxygen demand (BOD_5)

The daily per capita BOD_5 load varies from country to country, and the differences are largely due to variations in greywater quality and to a lesser extent variation in diet. According to Mara (2003), for domestic wastewater in a developing country, a good assumption of BOD_5 load is 40 g per person a day. This load is assumed to be valid in Bolivia and Montero. Additionally, according to data presented by Jönsson et al. (2005), 37% of the BOD_5 load originates from faeces, 8% from urine and the remaining 55% from greywater. Combining the information from Mara (2003) and the proportions from Jönsson et al. (2005) it can be estimated that out of the produced 40 g BOD_5/cap,d, 14.8 g BOD_5/cap,d can be found in faeces, 3.2 g BOD_5/cap,d can be found in urine and the remaining 22 g BOD_5/cap,d can be found in the greywater, which is in line with the BOD_5 load that can be estimated using the BOD_5 concentrations in Morel and Diener (2006) (Table A.3.8).

9 https://www.fao.org/faostat/en/#data/FBS

Table A.3.8: Estimated BOD loads per sanitation flow .

	Urine	Faeces	Greywater
BOD [g/cap,d]	3.2	14.8	22

A.3.2 Treatment efficiencies

Treatment efficiencies were assumed or estimated due to a lack of appropriate local measurement data. The estimated treatment efficiencies for the different systems included in this study were based on a range of treatment efficiencies reported in the literature. Where efficiencies have been assigned, they have been rounded to the nearest 5%. It is assumed that today's systems in Montero, based on local knowledge of the systems, do not treat the wastewater efficiently, and it is assumed or expected that the systems fall in the lower range of treatment efficiencies that have been reported in the literature. Conversely, it is assumed that the optimized systems described in this study have treatment efficiencies in the higher range of what has been reported in literature.

System 1: treatment with WSP

The removal of TN, TP and BOD_5 from a series of WSPs is highly variable and depends on, among several other factors, the pond configuration and size, surface loading and various environmental factors (e.g. sunshine and ambient temperature). In this study the treatment efficiency of a three-step series consisting of an anaerobic pond, a facultative pond and a maturation pond has been estimated. The treatment efficiencies found in literature and the values used for assessment of today's and the optimized systems are shown in Table A.3.9.

Table A.3.9: Treatment efficiencies reported in literature and assumed treatment efficiencies for today's System 1 and the optimized System 1.

	Treatment efficiencies in literature	Today	Optimized
TN reduction	50–65% (Von Sperling, 2007)	WSPs: 40%	WSPs: 65%
	26–60% (Oliveira and von Sperling, 2011)		
TP reduction	>50% (Von Sperling, 2007)	WSPs: 35%	WSPs: 50%
	~50% (Mara, 2003)		
	20–50% (Oliveira and von Sperling, 2011)		
BOD5 reduction	80–85% (Von Sperling, 2007)	WSPs: 80%	WSPs: 85%
	>60% (Mara, 2003)		
	73–85% (Oliveira and von Sperling, 2011)		

System 2: primary anaerobic treatment (large septic tanks, ABRs, UASB reactors)

There are several types of technologies that are available/operational for distributed primary anaerobic treatment in Montero, including large septic tanks, ABRs, Imhoff tanks and UASBs. Today, large septic tanks and Imhoff tanks are the most common primary anaerobic treatment technologies in Bolivia. The purpose of primary anaerobic treatment is to remove solids and settleable BOD_5 and not to provide significant nutrient removal. To provide nutrient removal, the primary anaerobic treatment needs to be combined with additional unit processes.

Imhoff tanks are commonly used as a type of settler for primary anaerobic treatment to remove suspended solids and reduce particulate BOD_5 from the influent. Nutrient removal efficiencies for Imhoff tanks are not widely reported in literature. However, the suspended solids removal can be assumed to be the same for Imhoff tanks as for septic tanks (Metcalf & Eddy, 1991). We assume in this study that Imhoff tanks therefore remove nutrients and BOD_5 in approximately the same way as a general septic tank. For references and removal efficiencies of septic tanks see Table A.3.11 .

ABRs are improved septic tanks that have been upgraded with a series of baffles; in essence an ABR is a septic tank with several chambers. ABRs are more hydraulically robust and provide improved anaerobic treatment compared with both septic and Imhoff tanks.

Combined with a gravel filter ABRs provide a notable performance increase compared with Imhoff tanks. The replacement of the Imhoff with an ABR is our suggestion to optimize the anaerobic step of the system. This ABR + gravel filter combination has been evaluated in Bolivia by Echeverría et al. (2019), whose results suggest that approximately 40% TN removal, 30% TP removal and 95% BOD_5 removal is achievable. The same treatment efficiencies are assumed to also be achievable in Montero (Table A.3.10).

Table A.3.10: Assumed treatment efficiencies for today's System 2 and the optimized System 2.

	Today	Optimized
TN reduction	Imhoff tank: 20%	ABR+gravel filter: 40%
TP reduction	Imhoff tank: 25%	ABR+gravel filter: 30%
BOD5 reduction	Imhoff tank: 35%	ABR+gravel filter: 95%

System 3: septic tanks and soak pits

The treatment efficiencies of septic tanks are largely affected by how they are designed (i.e. if and how they are compartmentalized), the hydraulic load they are subjected to and how frequently they are emptied. Due to high groundwater tables and recurring flooding in Montero it is assumed that the soak pits provide no significant additional treatment or removal of nutrients or BOD_5. The treatment efficiencies found in literature and the values used for assessment of today's and the optimized systems are shown in Table A.3.11.

Table A.3.11: Assumed treatment efficiencies for today's System 3 and the optimized System 3.

	Treatment efficiencies in literature	Today	Optimized
TN reduction	5–14% (Montangero and Belevi, 2007) 18–31% (Nasr and Mikhaeil, 2013)	Septic tank:10% Soak pit: 0%	Septic tank: 30% Soak pit: 0%
TP reduction	11–27% (Montangero and Belevi, 2007) 26–33% (Nasr and Mikhaeil, 2013) 20–30% (Lusk, Toor, and Obreza, 2011)	Septic tank: 20% Soak pit: 0%	Septic tank: 30% Soak pit: 0%
BOD5 reduction	30–40% (Tilley et al., 2014) 54–77% (Nasr and Mikhaeil, 2013)	Septic tank: 30% Soak pit: 0%	Septic tank: 75% Soak pit: 0%

System 4: Double-vault UDDTs

In today's system with double-vault UDDTs, the separated urine is directly infiltrated into the soil on-site and the separated faeces are collected and transported by truck to a centralized facility where they are buried. As the separated fractions are not subjected to any treatment before infiltration and burial, it is estimated/assumed that the removal of TN, TP and BOD_5 is 0%. Due to high groundwater tables and recurring flooding in Montero it is assumed that on-site infiltration provides insignificant treatment for removal of nutrients and BOD_5, and that off-site faecal burial is subjected to the same issues. The household greywater is piped separately and is infiltrated in an on-site greywater garden.

Greywater infiltration can be done in multiple ways. The greywater infiltration systems in Montero are assumed to be comparable with *vertical flow planted filters*, reported by Morel and Diener (2006) to have expected removal rates of <60% of TN, 35–95% of TP and 75–95% of BOD_5. The treatment efficiencies that are used in this assessment are shown in Table A.3.12.

Table A.3.12 Assumed treatment efficiencies for today's System 4 and the optimized System 4.

	Treatment efficiencies in literature	Today	Optimized
TN reduction	< 60% of TN	Urine infil.: 0%* Faecal burial: 0%* Greywater infil.: 30%	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 30%
TP reduction	35–95% of TP	Urine infil.: 0%* Faecal burial: 0%* Greywater infil.: 30%	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 30%
BOD5 reduction	75–95% BOD5	Urine infil.: 0%* Faecal burial: 0%* Greywater infil.: 80%	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 80%

Summary of existing systems

Table A.3.13. Assumed reduction rates for the systems today in Montero.

	System 1	System 2	System 3	System 4
TN reduction	WSPs: 40%	Imhoff: 20%	Septic tank:10% Soak pit: 0%*	Urine infil.: 0%* Faecal burial: 0%* Greywater infil.: 30%
TP reduction	WSPs: 35%	Imhoff: 25%	Septic tank: 20% Soak pit: 0%*	Urine infil.: 0%* Faecal burial: 0%* Greywater infil.: 30%
BOD5 reduction	WSPs: 80%	Imhoff: 35%	Septic tank: 30% Soak pit: 0%*	Urine infil.: 0%* Faecal burial: 0%* Greywater infil.: 80%

TN, TP and BOD reduction: * As the systems function today there is effectively no treatment by applying these practices as the groundwater table is highly situated and TN, TP and BOD can be expected to leach into the groundwater.

Summary of optimized systems

Table A.3.14. Assumed reduction rates for the optimized systems.

	System 1	System 2	System 3	System 4
TN reduction	WSPs: 65%	ABR+gravel filter: 40%	Septic tank: 30% Soak pit: 0%**	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 30%
TP reduction	WSPs: 50%	ABR+gravel filter: 30%	Septic tank: 30% Soak pit: 0%**	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 30%
BOD5 reduction	WSPs: 85%	ABR+gravel filter: 95%	Septic tank: 75% Soak pit: 0%**	Urine coll.: 100% Faecal coll.: 100% Greywater infil.: 80%

TN, TP and BOD reduction: ** As the systems function today it is assumed that there is effectively no treatment by applying soak pit infiltration as the groundwater table is highly situated and TN, TP and BOD can be expected to leach into the groundwater.

Annex 4. Method for assessment of Economic sustainability and Affordability

For cost analysis, the equivalent annual cost (EAC) methodology was used. The EAC is the annual cost of owning, operating and maintaining an asset over its entire life. EAC is often used to analyse two or more possible projects or technological alternatives with different lifespans, where cost is a relevant variable.

The EAC analysis includes all the initial investment costs (CAPEX) as well as the recurring costs for operation and management (OPEX). In this study, CAPEX and OPEX costs were determined for each component of all the sanitation alternatives. The CWIS costing and planning tool (beta) developed by the World Bank Group was used to systematize the cost analysis. The tool is available via the World Bank website[10] and is shown in Figure A.3.2.

All investments in infrastructure, sanitation components and operation activities generate costs that must be covered for services to be sustainable over time. These costs can be covered by financial flows coming from one or more of the following sources:

- tariffs and household investments
- taxes
- transfers
- trade (of recovered resources).

In this study we looked only at the tariffs and household investments to assess the *Economic sustainability*. Each system type was assessed at the level to which the EAC is covered by the tariff and household investments (Table A.3.16).

Table A.3.16. Scoring of *Economic sustainability*.

Description	Score
< 60% of system costs are covered by current tariff and household investments	1
60–70% of system costs are covered by current tariff and household investments	2
70–80% of system costs are covered by current tariff and household investments	3
80–90% of system costs are covered by current tariff and household investments	4
> 90% of system costs are covered by current tariff and household investments	5

Tariffs should be affordable to users. Affordability implies that payment for services should not present a barrier to access or prevent people from meeting other basic human needs. This concern is reflected in SDG target 6.1, which calls for universal and equitable access to safe and affordable drinking water for all. While affordability is an important consideration for all households, regardless of service level, there is no commonly agreed way to measure it.

The UN offers some guidance on how water affordability should be measured. In 2002, the UN stated that to be affordable, water costs should not exceed 3% of household income, with the combined cost of water and sanitation not exceeding 5% (Table A.3.17). The affordability scoring is shown in Table A.3.18.

10 https://www.worldbank.org/en/topic/sanitation/brief/citywide-inclusive-sanitation#3 http://200.58.79.50/fmi/webd/CWIS%20Planning%20Tool%201_4

Figure A.3.2: The World Bank tool for city-wide inclusive sanitation planning.

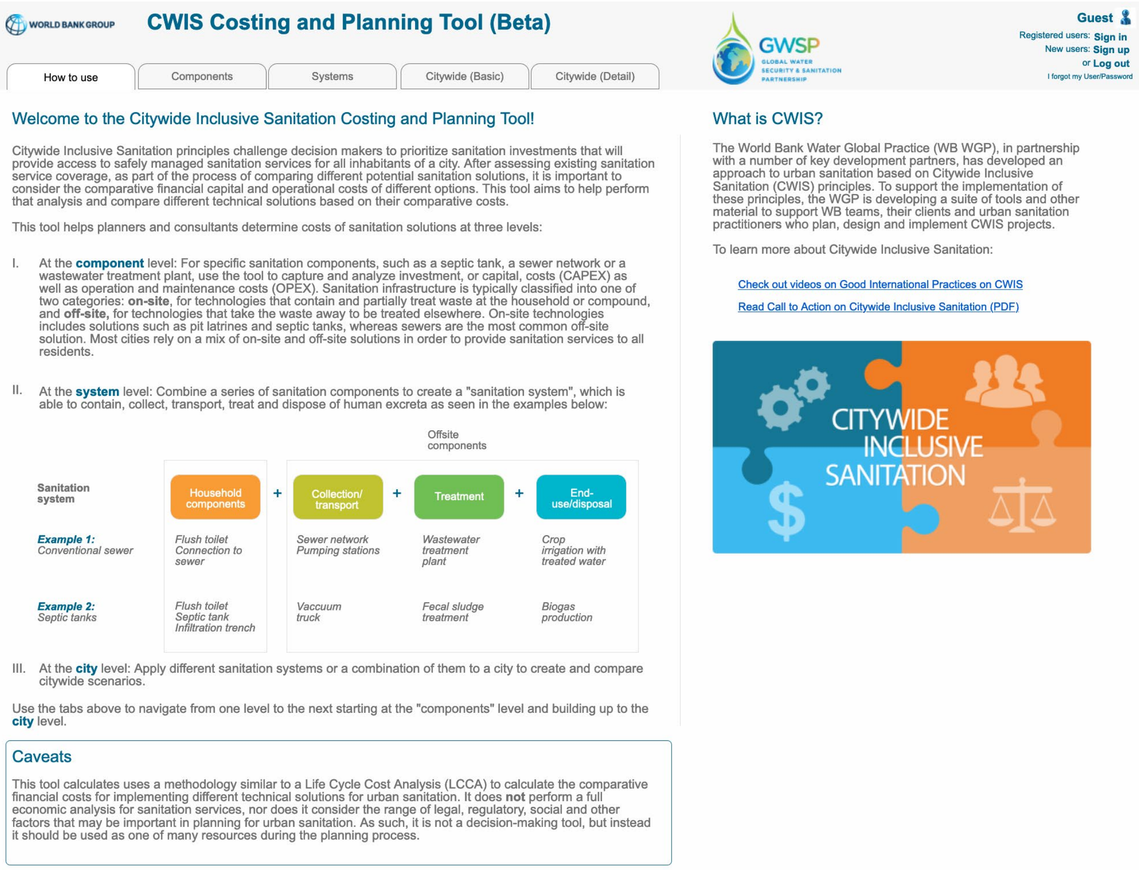


Table A.3.17. Summary of listing assumptions made in order to calculate Household affordability of the different sanitation systems.

Assumptions:	
Cost of constructing a bathroom enclosure with shower [USD]	2 000
Number of people per household	5
National minimum wage [USD/household,month]	305
Maximum portion of income that should go towards water and sanitation [%]	5%
Portion of water and sanitation costs used towards sanitation only [%]	60%
Maximum income that should go towards sanitation [%]	3
Maximum income that should go towards sanitation [USD/cap,yr] (3% of the minimum wage)	21.96

Table A.3.18: Scoring of Affordability.

Description	Score
CAPEX and OPEX of the system are covered by more than 12% of a minimum wage	1
CAPEX and OPEX of the system are covered by 12% of a minimum wage	2
CAPEX and OPEX of the system are covered by 9% of a minimum wage	3
CAPEX and OPEX of the system are covered by 6% of a minimum wage	4
CAPEX and OPEX of the system are covered by 3% of a minimum wage	5

Annex 5. Detailed results

A.5.1 Health and hygiene assessment

A.5.1.1 Assessment for existing systems

Table A.5.1: Detailed results of the Health and hygiene assessment for the existing System 1.

System 1 – WC, conventional sewers and WSP								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Risk of diarrhoea	3	12	2
Conveyance	Pathogens: Exposure to untreated sewage during sewage overflows	Community	Seasonal flooding	3	Risk of diarrhoea	4	12	
	Pathogens: Exposure to sewage at manual maintenance of pumping stations	Sanitation worker	Maintenance occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
	Gases: Exposure to dangerous levels of H_2S in pumping stations	Sanitation worker	Without assisted breathing risk of exposure to H_2S	2	If protective gear is not used, the severity can be really high	16	32	
	Pathogens: Exposure to untreated wastewater at sewage line maintenance	Sanitation worker	Maintenance occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
Treatment	Pathogens: Exposure to untreated wastewater at cleaning of screens and other O&M tasks	Sanitation worker	Maintenance occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
	Pathogens: Exposure to wastewater at sampling events	Sanitation worker	Sampling occurs often but exposure can be controlled	2.5	Risk of diarrhoea	4	10	
	Pathogens: Exposure to sludge at sludge emptying of ponds and storage	Sanitation worker	Emptying of ponds happens every 10–20 years	1	Risk of diarrhoea	4	4	
	Pathogens: Exposure to wastewater at plant malfunctioning (overflows)	Sanitation worker	Occasional technical malfunction	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to wastewater at plant malfunctioning (overflows)	Community	Exposure to nearby communities will happen less often than at WWTP	1	Risk of diarrhoea	4	4	
Microbial quality of discharged wastewater sanitation flow	Pathogens: Exposure to wastewater when released	Community	Possible exposure downstream of outlet and/or at reuse	4	Likely food-borne disease at water reuse, major non-regulatory compliance in terms of water quality	8	32	
Quality of stored sludge from the ponds	Pathogens: Exposure to sludge after storage	Community	Emptying of ponds happens every 10–20 years	1	Risk of diarrhoea, but lower risk than from wastewater	4	4	

Table A.5.2: Detailed results of the Health and hygiene assessment for the existing System 2.

System 2 – WC, condominial sewer system and primary anaerobic treatment (Imhoff tank) with discharge to open channel								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper hand washing	4	Risk of diarrhoea	3	12	3
Conveyance water	Pathogens: Exposure to untreated sewage during sewage overflows	Community	Stronger social control and shorter networks – less infiltration and less connections	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to sewage at manual maintenance of pumping stations	Sanitation worker	Maintenance occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
	Pathogens: Exposure to untreated wastewater at sewage line maintenance	Sanitation worker	Maintenance occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
Conveyance sludge	Pathogens: Risk of exposure from spills at community level	Community	Possibility of spills and exposure	3	Risk of diarrhoea	4	12	
	Pathogens: Risk of exposure from spills on street	Community	Not very likely	1	Risk of diarrhoea	4	4	
Treatment community	Pathogens: Exposure to faecal sludge at overflowing of septic tank	Community	Less frequent than seasonal	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure during emptying of large septic tank	Sanitation worker	Emptying occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
Treatment sludge	Pathogens: Manipulation of sludge at emptying at treatment plant	Vacuum truck sanitation worker and sanitation worker at WWTP	Emptying occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
Microbial quality of discharged wastewater sanitation flow	Pathogens: Exposure to wastewater when released	Community	Possible exposure downstream of outlet and/or at reuse	4	Likely food-borne disease at water reuse, likely major non-regulatory compliance in terms of water quality	8	32	
Quality of stored sludge from the ponds	Pathogens: Exposure to sludge after storage	Community	Emptying of ponds happens only every 10–20 years	1	Risk of diarrhoea, but lower risk than from wastewater	4	4	

Table A.5.3: Detailed results of the Health and hygiene assessment for the existing System 3.

System 3 – WC, septic tanks, soak pits, vacuum emptying and sludge discharge in WWTP								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Risk of diarrhoea	3	12	3
	Pathogens: Infiltration of septic tank effluent to groundwater	Household	High groundwater table and sandy soil present high likelihood	5	Many people impacted of pollution of groundwater	4	20	
	Nitrates: Infiltration of septic tank effluent to groundwater	Community	Depends on the type of soil – high groundwater table and sandy soil present high likelihood	5	Many people impacted of pollution of groundwater	4	20	
	Pathogens: Exposure to faecal sludge at overflowing of septic tank	Household	Less frequent than seasonal but high probability that there are systems failing	5	Risk of diarrhoea	3	15	
Conveyance	Pathogens: Manipulation of sludge at emptying	Vacuum truck sanitation workers	Exposure is likely during emptying – higher likelihood than for the dry system	3	Risk of diarrhoea	4	12	
	Pathogens: Manual cleaning of septic tank when there is a caking up problem or similar	Informal sanitation workers	Similar risks as maintenance of pumping stations and handling of faeces in the dry system – protective gear is important but may not be used	3	Risk of diarrhoea	4	12	
	Gases: Exposure to dangerous levels of H_2S	Sanitation worker	Without assisted breathing risk of exposure to H_2S	1	If protective gear is not used, then the severity can be really high	16	16	
	Pathogens: Risk of exposure from spills at household	Household	Possibility of spills and exposure	3	Diarrhoea, but lower severity of exposure within household compared with exposure at wastewater treatment	3	9	
	Pathogens: Risk of exposure from spills on street	Community	Not very likely	1	Risk of diarrhoea	4	4	
Treatment	Pathogens: Manipulation of sludge at emptying at treatment plant	Vacuum truck sanitation worker and sanitation worker at WWTP	Emptying occurs often but exposure can be controlled	3	Risk of diarrhoea	4	12	
Quality of stored sludge from the ponds	Pathogens: Exposure to sludge after storage	Community	Emptying of ponds happens every 10–20 years	1	Risk of diarrhoea, but lower risk than from wastewater	4	4	

Table A.5.4: Detailed results of the Health and hygiene assessment for the existing System 4.

System 4 – Dry urine-diversion toilet, with local greywater treatment, infiltration of urine and collection and burial of faeces								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Risk of diarrhoea	3	12	4
	Pathogens: Exposure to faeces and/or urine during maintenance of collection chamber and urine piping	Household member	Risk of improper handwashing after maintenance and splashing during maintenance	4	Diarrhoea, but lower severity of exposure within household compared with exposure at wastewater treatment	3	12	
	Pathogens: Infiltration of urine	Household	Not very likely	1	Few pathogens in urine	1	1	
	Nitrates: Infiltration of urine	Household	Moderate likelihood	3	Blue baby syndrome risk	4	12	
	Pathogens: Infiltration of greywater	Household	Direct infiltration, low exposure risk	2	Less pathogens than faeces but more than urine	2	4	
Conveyance	Pathogens: Exposure to untreated faeces during collection	Sanitation worker	Exposure is likely during change of containers/ emptying of containers, depending on use of protective gear; but it is also less likely than exposure at a wastewater spill	2.5	Risk of diarrhoea	4	10	
	Pathogens: Risk of exposure from spills at household	Household	Possibility of spills and exposure but less likely than for Systems 2 and 3	2	Diarrhoea, but lower severity of exposure within household compared with exposure at wastewater treatment	3	6	
	Pathogens: Risk of exposure from spills on street	Community	Not very likely	1	Risk of diarrhoea	4	4	
Treatment	Pathogens: Exposure to untreated faeces during handling at burial	Sanitation worker	Opening of containers, pouring down, risk of dust and skin exposure; dependent on use of protective gear	3	Risk of diarrhoea	4	12	
	Pathogens: Pathogen transport to groundwater from faeces burial	Community	Very likely, due to proximity to the groundwater table	3	Risk of diarrhoea	4	12	

A.5.1.2 Assessment of optimized systems

Table A.5.5: Detailed results of the *Health and hygiene* assessment for the optimized System 1.

System 1 – WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Risk of diarrhoea	3	12	4
Conveyance	Pathogens: Exposure to untreated sewage during sewage overflows	Community	Less than seasonal flooding with no roof drainages	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to sewage at manual maintenance of pumping stations	Sanitation worker	Exposure during maintenance is controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Gases: Exposure to dangerous levels of H_2S in pumping stations	Sanitation worker	Use of PPE for assisted breathing is established	1	If protective gear is not used, loss of life is possible	16	16	
	Pathogens: Exposure to untreated wastewater at sewage line maintenance	Sanitation worker	Exposure during maintenance is controlled through use of PPE	2	Risk of diarrhoea	4	8	
Treatment	Pathogens: Exposure to untreated wastewater at cleaning of screens and other O&M tasks	Sanitation worker	Exposure during maintenance is controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to wastewater at sampling events	Sanitation worker	Exposure during sampling is controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to sludge at sludge emptying of ponds and storage	Sanitation worker	Emptying of ponds every 5+ years, exposure is controlled through use of PPE	1	Risk of diarrhoea	4	4	
	Pathogens: Exposure to wastewater at plant malfunctioning (overflows)	Sanitation worker	Proper design, operation and maintenance of WWTP are established	1	Risk of diarrhoea	4	4	
	Pathogens: Exposure to wastewater at plant malfunctioning (overflows)	Community	Exposure to nearby communities will happen less often than at WWTP	1	Risk of diarrhoea	4	4	
Microbial quality of discharged wastewater sanitation flow	Pathogens: Exposure to wastewater when released	Community	Possible exposure downstream of outlet and/ or at reuse, environmental controls are enforced	3	Food-borne disease risk at water reuse reduced by compliance to regulation	8	24	
Quality of stored sludge from the ponds	Pathogens: Exposure to sludge after storage	Community	Emptying of ponds every 5+ years, environmental controls are enforced	1	Risk of diarrhoea, but lower risk than from wastewater	4	4	

Table A.5.6: Detailed results of the Health and hygiene assessment for the optimized System 2.

System 2 – WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Risk of diarrhoea	3	12	4
Conveyance water	Pathogens: Exposure to untreated sewage during sewage overflows	Community	Less than seasonal flooding with no roof drainages	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to sewage at manual maintenance of pumping stations	Sanitation worker	Exposure during maintenance is controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Pathogens: Exposure to untreated wastewater at sewage line maintenance	Sanitation worker	Exposure during maintenance is controlled through use of PPE	2	Risk of diarrhoea	4	8	
Conveyance sludge	Pathogens: Risk of exposure from spills at community level	Community	Risk of spillage reduced when cleaning routines are implemented	2	Risk of diarrhoea	4	8	
	Pathogens: Risk of exposure from spills on street	Community	Not very likely	1	Risk of diarrhoea	4	4	
Treatment community	Pathogens: Exposure to sludge at overflowing of ABR	Community	Very low risk for overflow when scheduled emptying is implemented	1	Risk of diarrhoea	4	4	
	Pathogens: Exposure during emptying of ABR	Sanitation worker	Exposure during emptying is controlled through use of PPE	1	Risk of diarrhoea	4	4	
Treatment sludge	Pathogens: Manipulation of sludge at emptying at treatment plant	Vacuum truck sanitation worker and sanitation worker at WWTP	Exposure during emptying is controlled through use of PPE	2	Risk of diarrhoea	4	8	
Microbial quality of discharged wastewater sanitation flow	Pathogens: Exposure to wastewater when released	Community	Possible exposure downstream of outlet and/or at reuse	3	Food-borne disease risk at water reuse reduced by compliance to water reuse regulation	8	24	
Quality of stored sludge from drying beds	Pathogens: Exposure to sludge after storage	Community	Environmental controls are enforced effectively, barriers are implemented; reuse of dried sludge, applying barriers depending on use	1	Risk of diarrhoea, but lower risk than from wastewater	4	4	

Table A.5.7: Detailed results of the Health and hygiene assessment for the optimized System 3.

System 3 – WC, septic tanks + soak pit, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Risk of diarrhoea	3	12	4
	Pathogens: Infiltration of septic tank effluent to groundwater	Household	High groundwater table and sandy soil present high likelihood	5	Many people impacted by pollution of groundwater	4	20	
	Nitrates: Infiltration of septic tank effluent to groundwater	Community	Depends on type of soil	5	Many people impacted by pollution of groundwater	4	20	
	Pathogens: Exposure to faecal sludge at overflowing of septic tank	Household	Regular emptying or scheduled emptying to avoid overflows is implemented	1	Risk of diarrhoea	3	3	
Conveyance	Pathogens: Manipulation of sludge at emptying	Vacuum truck sanitation worker	Exposure during emptying is controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Pathogens: Manual cleaning of septic tank when there is a caking up problem or similar	Sanitation worker	Similar risks as maintenance of pumping stations and handling of faeces in the dry system; exposure is controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Gases: Exposure to dangerous levels of H_2S	Sanitation worker	Exposure during emptying is controlled through use of PPE	1	If protective gear is not used, the severity can be really high	16	16	
	Pathogens: Risk of exposure from spills at household	Household	Risk of spillage reduced when cleaning routines are implemented	2	Diarrhoea, but lower severity of exposure within household compared with exposure at wastewater treatment	3	6	
	Pathogens: Risk of exposure from spills on street	Community	Not very likely	1	Risk of diarrhoea	4	4	
Treatment	Pathogens: Manipulation of sludge at emptying at treatment plant	Vacuum truck sanitation worker and sanitation worker at WWTP	Exposure during emptying is controlled through use of PPE	2	Risk of diarrhoea	4	8	
Quality of stored sludge from drying beds	Pathogens: Exposure to sludge after storage	Community	Environmental controls are enforced effectively, barriers are implemented; reuse of dried sludge, applying barriers depending on use	1	Risk of diarrhoea, but lower risk than from wastewater	4	4	

Table A.5.8: Detailed results of the Health and hygiene assessment for the optimized System 4.

System 4 – Dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}								
Sanitation step	**Hazardous event**	**Risk group**	**Likelihood**		**Severity**		**Risk score**	**Score**
			Explanation	**Score**	**Explanation**	**Score**		
Use at household	Pathogens: Exposure to faeces during use of toilet at home	Household member	Risk of improper handwashing	4	Diarrhoea, but lower severity within household	3	12	4
	Pathogens: Exposure to faeces and/or urine during maintenance of collection chamber and urine piping	Household member	Risk of improper hand washing after maintenance and splashing during maintenance	4	Diarrhoea, but lower severity of exposure within household compared with exposure at wastewater treatment	3	12	
	Pathogens: Infiltration of greywater	Household	Direct infiltration, low exposure risk	2	Less pathogens than faeces but more than urine	2	4	
Conveyance	Pathogens: Exposure to untreated urine during collection	Sanitation worker	Exposure during emptying is controlled through use of PPE	1	Almost no pathogens in urine, potential faecal contamination	1	1	
	Pathogens: Exposure to untreated faeces during collection	Sanitation worker	Exposure is likely during collection of containers but controlled through use of PPE	2	Risk of diarrhoea	4	8	
	Pathogens: Risk of exposure from urine spills at household	Household	Likely that the sanitation workers will clean up spills	1	Few pathogens in urine.	1	1	
	Pathogens: Risk of exposure from faecal spills at household	Household	Likely that the sanitation workers will clean up spills	2	Diarrhoea, but lower severity within household	3	6	
	Pathogens: Risk of exposure from urine spills on street	Community	Not very likely	1	Few pathogens in urine	1	1	
	Pathogens: Risk of exposure from faecal spills on street	Community	Not very likely	1	Risk of diarrhoea	4	4	
Treatment	Pathogens: Manipulation of urine at emptying into storage tank	Sanitation worker	Exposure is controlled through use of PPE	1	Few pathogens in urine	1	1	
	Pathogens: Risk of urine leakage from storage tank	Sanitation worker	Exposure is controlled through use of PPE	1	Few pathogens in urine	1	1	
	Nitrates: Risk of urine infiltration to groundwater from leakage from storage tank	Community	Not very likely	1	Risk of blue baby syndrome	4	4	
	Pathogens: Exposure to untreated faeces at composting	Sanitation worker	Exposure during composting is controlled through use of PPE	2	Risk of diarrhoea	4	8	
Quality of stored urine for reuse	Pathogens: Exposure to sanitized urine when reused	Household / Community	Not very likely	1	Very few pathogens in sanitized urine	1	1	
Quality of compost for reuse	Pathogens: Exposure to compost when reused	Household / Community	Possible exposure at reuse, but reduced with barriers	2		4	8	

A.5.2 Environmental sustainability assessment

A.5.2.1 Release of nitrogen, phosphorus and BOD_5

Assessment for existing systems

Table A.5.9: Summary of the assessment of release of TN for the existing systems.

Existing systems: TN removal				
	INPUT [kg/cap,yr]	OUTPUT [kg/cap,yr]	Effective removal %	Score
System 1	3.82	2.29	40	3
System 2	3.82	3.05	20	2
System 3	3.82	3.44	10	1
System 4	3.82	3.72	3	1

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Table A.5.10: Summary of the assessment of release of TP for the existing systems.

Existing systems: TP removal				
	INPUT [kg/cap,yr]	OUTPUT [kg/cap,yr]	Effective removal %	Score
System 1	0.62	0.44	34	2
System 2	0.62	0.50	25	1
System 3	0.62	0.54	19	1
System 4	0.62	0.60	10	1

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Table A.5.11: Summary of the assessment of release of BOD_5 for the existing systems.

Existing systems: BOD5 removal				
	INPUT [kg/cap,yr]	OUTPUT [kg/cap,yr]	Effective removal %	Score
System 1	14.60	2.92	80	3
System 2	14.60	9.49	35	1
System 3	14.60	10.22	30	1
System 4	14.60	8.18	44	1

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Assessment for optimized systems

Table A.5.12: Summary of the assessment of release of TN for the optimized systems.

Optimized systems: TN removal				
	INPUT [kg/cap,yr]	OUTPUT [kg/cap,yr]	Effective removal %	Score
System 1	3.82	1.34	65	4
System 2	3.82	2.29	40	3
System 3	3.82	2.67	30	3
System 4	3.82	0.23	94	5

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Table A.5.13: Summary of the assessment of release of TP for the optimized systems.

Optimized systems: TP removal				
	INPUT [kg/cap,yr]	OUTPUT [kg/cap,yr]	Effective removal %	Score
System 1	0.67	0.34	49	3
System 2	0.67	0.471	30	1
System 3	0.67	0.471	30	1
System 4	0.67	0.16	76	4

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Table A.5.14: Summary of the assessment of release of BOD_5 for the optimized systems.

Optimized systems: BOD5 removal				
	INPUT [kg/cap,yr]	OUTPUT [kg/cap,yr]	Effective removal %	Score
System 1	14.60	2.19	85	4
System 2	14.60	0.72	95	5
System 3	14.60	3.65	75	3
System 4	14.60	1.61	89	4

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

A.5.3 Economic and social sustainability assessment

A.5.3.1 Assessment for existing systems

Table A.5.15: Scoring for *Social acceptability* for the existing systems.

	Description	Score
System 1	Minor household management of the user interface, no household management after the user interface.	5
System 2	Minor household management of the user interface, no household management after the user interface.	5
System 3	There is a collection service available for management of the septic tank contents after the household level. The household needs to engage in calling in the service.	3
System 4	There is a collection and management service available, e.g. scheduled emptying of collected urine and faeces and maintenance.	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Table A.5.16: Investment costs for each system type, existing and optimized, at household level, collection and treatment.

	Household level (USD/cap)	Collection (USD/cap)	Treatment (USD/cap)	Total (USD/cap)
System 1 existing	449.2	360.6	128.3	938.1
System 1 optimized	449.2	360.6	142.2	952.0
System 2 existing	449.2	103.8	47.6	600.6
System 2 optimized	449.2	103.8	64.2	617.2
System 3 existing	582.3	12.0	20.9	615.2
System 3 optimized	582.3	12.0	28.4	622.7
System 4 existing	439.0	6.0	4.4	449.4
System 4 optimized	439.0	11.5	35.9	486.4

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Table A.5.17: Summary of total costs (CAPEX+OPEX) for the existing systems.

Existing systems: Cost (CAPEX+OPEX) [USD/cap,yr]			
	CAPEX	OPEX	TOTAL
System 1	81.80	21.70	103.50
System 2	50.60	19.10	69.70
System 3	49.19	14.60	63.79
System 4	37.10	18.10	55.20

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Table A.5.18: Summary of the assessment of *Economic sustainability* for the existing systems.

Existing systems: Economic sustainability of the existing systems [USD/cap,yr]									
	Annual costs of system [USD/cap,yr]	Annual payments by households [USD/cap,yr]							
		Household installations*	Household maintenance	One-time connection fee	Avg. recurring fee	Direct or indirect subsidies [USD/cap,yr]	Level of subsidy [%]	Level of costs covered [%]	Score
System 1	103.5	32.99	5.00	4.59	10.80**	50.12	48	52	1
System 2	69.7	32.99	5.00	4.59	10.80**	16.22	23	77	3
System 3	63.79	43.08	7.00	-	8.00***	5.71	9	91	5
System 4	55.20	35.22	5.00	-	4.48****	10.50	19	81	4

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

* One-time investment in bathroom of 200 USD/household annualized over 20 years with a 5% discount rate (+ additional household installations for Systems 3 and 4).

** Household pays 4.5 USD every month for sewer service (on average).

*** Household pays 40 USD/m^3 for tanks of 4 m^3 volume average once every four years.

**** Household pays 39 Bs four times a year for collection of 60 litre containers of faeces. Urine is being infiltrated on-site.

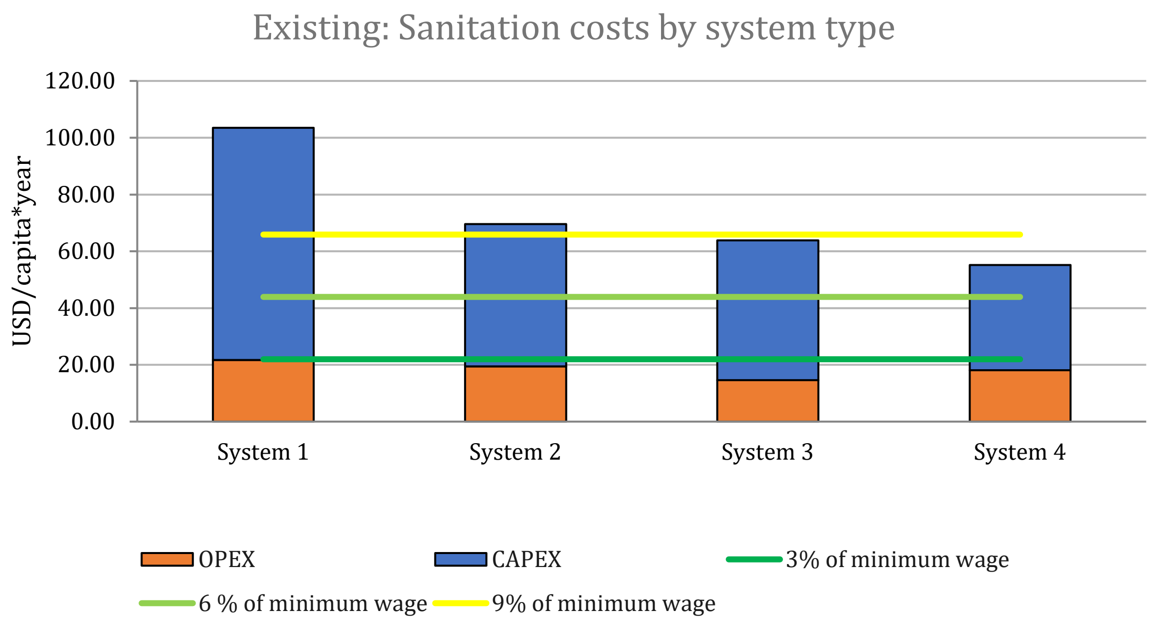
As shown in Table A.5.19 and Figure A.5.1, the minimum income/household/month used is USD 305 and the number of people/household is five for the affordability calculations (Table A.3.17).

Table A.5.19: Summary of the assessment of household affordability for the existing systems.

Existing systems: Household affordability, expressed as cost of sanitation system in % of minimum income				
	CAPEX+OPEX per capita [USD/cap,yr]	CAPEX and OPEX per household [USD/household,yr]	Cost of sanitation as fraction of minimum household income [%]	Score
System 1	103.5	517.5	14.14	1
System 2	69.7	348.5	9.51	2
System 3	63.79	318.95	8.71	3
System 4	55.2	276	7.54	3

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment, local and collection and burial of faecal matter at treatment plant.

Figure A.5.1: Illustration of household affordability broken down into CAPEX and OPEX for existing systems. From left to right: System 1, System 2, System 3 and System 4.



A.5.3.2 Assessment for optimized systems

Table A.5.20: Scoring for Social acceptability for the optimized systems.

	Description	Score
System 1	Minor household management of the user interface, no household management after the user interface.	5
System 2	Minor household management of the user interface, no household management after the user interface.	5
System 3	There is a collection and management service available, e.g. scheduled emptying of septic tanks and maintenance.	4
System 4	There is a collection and management service available, e.g. scheduled emptying of collected urine and faeces and maintenance.	4

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Table A.5.21: Summary of total costs (CAPEX+OPEX) for the optimized systems and a cost comparison with the existing systems.

Optimized systems: Cost (CAPEX+OPEX) [USD/cap,yr]				
	CAPEX	**OPEX**	**TOTAL**	**Increase compared with existing system***
System 1	83.70	22.20	105.90	2.3%
System 2	51.50	19.50	71.00	2.0%
System 3	50.20	15.00	65.20	2.2%
System 4	42.30	26.50	68.80	24.6%

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

* Increase in total costs compared with the existing system

Table A.5.22: Summary of the assessment of Economic sustainability for the optimized systems.

Optimized systems: Economic sustainability of the optimized systems [USD/cap,yr]									
	Annual costs of system [USD/cap,yr]	**Annual payments by households [USD/cap,yr]**							
		Household installations*	**Household maintenance**	**One-time connection fee**	**Avg. recurring fee**	**Direct or indirect subsidies [USD/cap,yr]**	**Level of subsidy [%]**	**Level of costs covered [%]**	**Score**
System 1	105.9	32.99	5.00	4.59	10.80**	52.52	50	50	1
System 2	71.00	32.99	5.00	4.59	10.80**	16.22	25	75	3
System 3	65.20	43.08	7.00	-	8.00***	5.71	11	89	4
System 4	68.80	35.22	5.00	-	4.48****	10.50	35	65	2

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}

[1] One-time fee of 200 USD/household annualized over 20 years with a 5% discount rate.

[2] Household pays 4.5 USD every month for sewer service (on average).

[3] Household pays 40 USD/m^3 for tanks of 4 m^3 volume average once every four years.

[4] Household pays 39 Bs four times a year for collection of 60 litre containers of faeces.

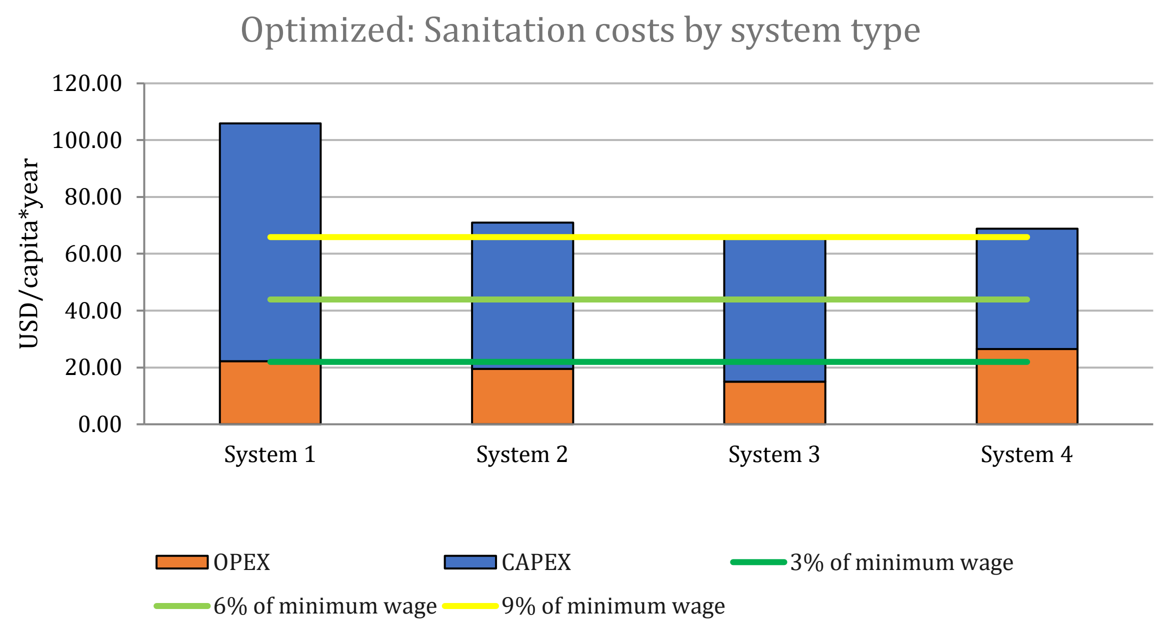
The minimum income/household/month used is USD 305 and the number of people/household is five for affordability calculations (Table A.5.23 and Figure A.5.2).

Table A.5.23: Summary of the assessment of *Household affordability* for the optimized systems.

Optimized systems: Household affordability, expressed as cost of sanitation system in % of minimum income				
	CAPEX+OPEX per capita [USD/cap,yr]	CAPEX and OPEX per household [USD/household,yr]	Cost of sanitation as a fraction of minimum household income [%]	Score
System 1	105.9	529.5	14.47	1
System 2	71	355	9.70	2
System 3	65.2	326	8.91	3
System 4	68.8	344	9.40	2

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}

Figure A.5.2: Illustration of household affordability broken down into CAPEX and OPEX of optimized systems. From left to right: System 1, System 2, System 3 and System 4.



A.5.4 Technical function assessment

A.5.4.1 Assessment of Appropriate system design

The systems (optimized additions in green).

- System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}.
- System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}.
- System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}.
- System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Assessment of existing and optimized systems

We assume there is no difference in *Appropriate system design* for the existing and the optimized systems. Therefore, the results are presented together.

Table A.5.24: Assessment matrix for *Appropriate system design* for existing and optimized System 1.

Density	**System 1**		
Very high			
High			
Intermediate			
Low			
Very low			
	Low	**Intermediate**	**High**
Level of planning needed			

Table A.5.25: Assessment matrix for *Appropriate system design* for existing and optimized System 2.

Density	**System 2**		
Very high			
High			
Intermediate			
Low			
Very low			
	Low	**Intermediate**	**High**
Level of planning needed			

Table A.5.26: Assessment matrix for Appropriate system design for existing and optimized System 3.

Density	System 3		
Very high			
High			
Intermediate			
Low			
Very low			
	Low	Intermediate	High
Level of planning needed			

Table A.5.27: Assessment matrix for Appropriate system design for existing and optimized System 4.

Density	System 4		
Very high			
High			
Intermediate			
Low			
Very low			
	Low	Intermediate	High
Level of planning needed			

A.5.4.2 Assessment of Vulnerability to flooding

The systems (optimized additions in green).

- System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}.
- System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}.
- System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}.
- System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Assessment of existing systems

Table A.5.28: Summary of the assessment of *Vulnerability to flooding* for existing System 1.

Existing System 1: WC, conventional sewers and WSP						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household		2				Based on information from Montero there are frequent flooding issues at the household level during flooding events.
Conveyance	1					Based on information from Montero there are frequent flooding issues in the streets during flooding events as the conveyance system is overloaded.
Treatment		2				Based on information from Montero there are considerable reductions in treatment efficiencies at flooding events although some minor treatment will still occur.

Table A.5.29: Summary of the assessment of Vulnerability to flooding for existing System 2.

Existing System 2: WC, conventional sewers and WSP						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household			3			Same as for System 1 but lower severity as the systems are smaller and collect smaller amounts of wastewater and stormwater.
Conveyance		2				Same as for System 1 but lower severity as the systems are smaller and collect smaller amounts of wastewater and stormwater.
Treatment			3			Same as for System 1 but lower severity as the systems are smaller and collect smaller amounts of wastewater and stormwater. The reason the treatment is assessed as 3 here is that we assume that fewer people connect their roof drainage to a condominial system.

Table A.5.30: Summary of the assessment of *Vulnerability to flooding* for existing System 3.

Existing System 3: WC, septic tanks, soak pits, vacuum emptying and sludge discharge in WWTP						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household			3			Based on information from Montero the septic tanks can overflow into the gardens, which in turn can overflow into the sidewalks and driveways.
Conveyance		5				Transport of faecal sludge to WWTP is considered to be unaffected by floods.
Treatment					2	Larger risk of flooding of septic tanks if not regularly emptied (less capacity in the tanks to manage some excess water from flooding). Treatment at household level is considered non-functional due to high groundwater level, and treatment at the treatment plant is considered as functional as System 1.

Table A.5.31: Summary of the assessment of *Vulnerability to flooding* for existing System 4.

Existing System 4: dry urine-diversion toilet, with local greywater treatment, infiltration of urine and collection and burial of faeces						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household					5	The collection of urine and faeces is done above ground and is therefore largely unaffected by floods and no spread of excreta should occur.
Conveyance					5	Transport of faeces to WWTP is considered to be unaffected by floods.
Treatment			3			Treatment at household level is estimated at 2 (infiltration of urine and greywater does not work) but at the treatment site it is estimated at 4 (storage on-site until groundwater level is lower.)

Assessment for optimized systems

Table A.5.32: Summary of the assessment of *Vulnerability to flooding* for optimized System 1.

Optimized System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household			3			Based on information from Montero there are frequent flooding issues at the household level during flooding events. Disconnecting roof drainage improves the situation compared with today's system.
Conveyance		2				Based on information from Montero there are frequent flooding issues in the streets during flooding events as the conveyance system is overloaded. Disconnecting roof drainage improves the situation compared with today's system.
Treatment		2				Based on information from Montero there are considerable reductions in treatment efficiencies at flooding events although some minor treatment through sedimentation will still occur. Disconnecting roof drainage only has a small impact on the treatment plant level as the WWTP is located at a low point and will flood anyway.

Table A.5.33: Summary of the assessment of *Vulnerability to flooding* for optimized System 2.

Optimized System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household			3			Same as for System 1 but lower severity as the systems are smaller and collect smaller amounts of wastewater and stormwater.
Conveyance			3			Same as for System 1 but lower severity as the systems are smaller and collect smaller amounts of wastewater and stormwater.
Treatment			3			Same as for System 1 but lower severity as the systems are smaller and collect smaller amounts of wastewater and stormwater.

Table A.5.34: Summary of the assessment of Vulnerability to flooding for optimized System 3.

Optimized System 3: WC, septic tanks + soak pit, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household			3			Based on information from Montero the septic tanks can overflow into the gardens, which in turn can overflow into the sidewalks and driveways.
Conveyance		5				Transport of faecal sludge to WWTP is considered unaffected by floods.
Treatment					2	Less risk of flooding of septic tank if it is regularly emptied (more capacity in the tanks to manage some excess water from flooding) (score 2), and treatment at treatment plant is considered as functional as System 1 (score 2)

Table A.5.35: Summary of the assessment of *Vulnerability to flooding* for optimized System 4.

Optimized System 4: Dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}						
	Impact					Explanation
	Very high	High	Medium	Low	Very low	
Household					5	The collection of urine and faeces is done above ground and is therefore largely unaffected by floods and no spread of excreta should occur.
Conveyance					5	Transport of faeces to WWTP is considered unaffected by floods.
Treatment			3			Treatment of greywater at household level is estimated at 2 (infiltration will not work) but at the treatment site it is estimated at 4.

A.5.4.3 Assessment of Integration into urban planning

The systems (optimized additions in green).

- System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}.
- System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}.
- System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}.
- System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

Assessment for existing and optimized systems

We assume there is no difference in *Integration into urban planning* for the existing and the optimized systems. Therefore, the results are presented together.

Table A.5.36: Summary of the assessment of *Integration into urban planning* for System 1.

System 1			
Planning document or policy	**Available for the system [yes/no]**	**Applicable document [with link]**	**Score**
National policies/plans/strategies are in place	yes	Plan Nacional de Saneamiento Básico Plan Estratégico institucional Ministerio de Medio Ambiente y Agua	3
Municipal policies and plans are in place	yes	Plan municipal de agua y saneamiento de Montero	
Municipal regulation on construction and operations	no	-	
Design and construction guidelines/standards are available	yes	Norma Boliviana NB 688: instalaciones sanitarias – alcantarillado pluvial, sanitario y tratamiento de aguas residuales	
Operational guidelines/standards are available	no	-	

Table A.5.37: Summary of the assessment of Integration into urban planning for System 2.

System 2			
Planning document or policy	**Available for the system [yes/no]**	**Applicable document [with link]**	**Score**
National policies/plans/strategies are in place	yes	RESOLUCIÓN ADMINISTRATIVA REGULATORIA AAPS No. 227/2010	3
Municipal policies and plans are in place	yes	Plan municipal de agua y saneamiento de Montero	
Municipal regulation on construction and operations	no	-	
Design and construction guidelines/standards are available	yes	Guía de Procedimientos Alcantarillado Condominial	
Operational guidelines/standards are available	no	-	

Table A.5.38: Summary of the assessment of Integration into urban planning for System 3.

System 3			
Planning document or policy	**Available for the system [yes/no]**	**Applicable document [with link]**	**Score**
National policies/plans/strategies are in place	No	-	3
Municipal policies and plans are in place	yes	Plan Municipal de Agua y Saneamiento Montero	
Municipal regulation on construction and operations	No	-	
Design and construction guidelines/standards are available	yes	Guía para la construcción de cámaras sépticas y sistemas de infiltración a nivel domiciliario	
Operational guidelines/standards are available	yes	Guía para la elaboración de procedimientos técnicos y administrativos para descargas de efluentes industriales especiales y lodos al alcantarillado sanitario	

Table A.5.39: Summary of the assessment of Integration into urban planning for System 4.

System 4

Planning document or policy	Available for the system [yes/no]	Applicable document [with link]	Score
National policies/plans/strategies are in place	yes	Programa Plurinacional de Baños Secos	4
Municipal policies and plans are in place	yes	Plan municipal de agua y saneamiento de Montero	
Municipal regulation on construction and operations	no	-	
Design and construction guidelines/standards are available	yes	Manual de construcción baños secos	
Operational guidelines/standards are available	yes	Manual de Operación y Mantenimiento de Baños Secos	

A.5.4.4 Assessment of Technical complexity

Assessment for existing systems

Table A.5.40: Summary of the assessment of Technical complexity for the existing systems.

	Description	Score
System 1	Passive system, low mechanization but more labour-intensive than for a score 5	4
System 2	Passive system, low mechanization but more labour-intensive than for a score 5	4
System 3	Some mechanization needed in system, some labour needed	3
System 4	Some mechanization needed in system, some labour needed	3

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Assessment for optimized systems

Table A.5.41: Summary of the assessment of *Technical complexity* for the optimized systems.

	Description	Score
System 1	Some mechanization needed in system, some labour needed	3
System 2	Some mechanization needed in system, some labour needed	3
System 3	Some mechanization needed in system, some labour needed	3
System 4	Some mechanization needed in system, some labour needed	3

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

A.5.4.5 Assessment of Integration with other sectors

Assessment for existing systems

Actors involved in the existing systems

- **System 1:** (1) builder, (2) treatment provider (COSMOL).
- **System 2:** (1) builder, (2) treatment provider (COSMOL).
- **System 3:** (1) builder, (2) emptier (private or COSMOL), (3) treatment provider (COSMOL).
- **System 4:** (1) builder (UNICEF), (2) emptier and disposal provider (COSMOL).

Table A.5.42: Summary of *Integration with other sectors* for the existing systems.

Existing systems					
	More than four actors are involved in making the system function	Not more than four actors are involved in making the system function	Not more than three actors are involved in making the system function	Not more than two actors are involved in making the system function	Not more than one actor is involved in making the system function
	1 point	2 points	3 points	4 points	5 points
System 1				4	
System 2				4	
System 3			3		
System 4				4	

System 1: conventional gravity-fed sewers and waste stabilization pond treatment; System 2: condominial sewers and anaerobic primary treatment; System 3: household connection to an on-site septic tank with a soak pit, treatment of faecal sludge in treatment plant; System 4: UDDTs, local urine infiltration, local greywater treatment and treatment of faecal matter at treatment plant.

Assessment for optimized systems

Actors involved in the optimized systems

- **System 1:** (1) builder, (2) treatment provider (COSMOL, not likely that the suggested optimization will change how reuse is made – possible indirect wastewater reuse downstream of the effluent point in both cases).
- **System 2:** (1) builder, (2) treatment provider (COSMOL), (3) farmers or other actors for reuse of sludge and treated wastewater.
- **System 3:** (1) builder, (2) emptier (private or COSMOL), (3) treatment provider (COSMOL), (4) farmers or other actors for reuse of sludge.
- **System 4:** (1) builder (UNICEF), (2) emptier and treatment provider (COSMOL), (3) farmers or other actors for reuse of treated urine, faeces/compost.

Table A.5.43: Summary of Integration with other sectors for the optimized systems.

Optimized systems

	More than four actors are involved in making the system function	Not more than four actors are involved in making the system function	Not more than three actors are involved in making the system function	Not more than two actors are involved in making the system function	TNot more than one actor is involved in making the system function
	1 point	2 points	3 points	4 points	5 points
System 1				4	
System 2			3		
System 3		2			
System 4			3		

System 1: WC, conventional sewers and WSP + {addition of inlet screen, proper management of lagoons and sludge, and sludge treatment (drying) + disconnection of roof drainage from sewer pipes} + {use of PPE}; System 2: WC, condominial sewer system and primary anaerobic treatment (ABR) with discharge to open channel + {addition of inlet screen and gravel filter, sludge management at central plant (drying) + disconnection of roof drainage to condominial sewers} + {use of PPE}; System 3: WC, septic tanks + soak pits, vacuum emptying + {formal collection service in place (e.g. scheduled), sludge treatment (drying)} + {use of PPE}; System 4: dry urine-diversion toilet, local greywater treatment + {collection and treatment of urine and faeces (Sumaj Huasi's model)} + {use of PPE}.

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