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Indicators for sustainability assessment of small-scale wastewater treatment plants in low and lower-middle income countries

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ABSTRACT

Wastewater treatment in low and lower-middle income countries is often limited by lack of local technical expertise, institutional capacity, and financial resources, making it challenging to reach SDG6-target 6.3, i.e. halving the proportion of untreated wastewater. Several studies suggest sets of sustainability indicators for assessing the planning and/or operation of WWTPs. However, existing standard indicators are typically focused on the context of high and upper-middle income countries, whereas low and lower-middle income countries face other types of issues. The development of a contextualized set of relevant and effective sustainability indicators to support the planning and/or operation of small-scale WWTPs in low and lower-middle income countries is crucial. This study develops a contextualized set of sustainability indicators for small-scale wastewater treatment plants in Bolivia, which is classified as a lower-middle income country. Indicators were identified using a literature review combined with empirical studies using focus groups with managers and operators, as well as, workshops with experts. The aim of the focus groups and workshops was to acquire an understanding of the local context and identify relevant sustainability indicators. The practical investigation took place at five sites in Cochabamba, Bolivia. The results suggest that sustainability assessment of WWTPs in low and lower-middle income countries should emphasize the institutional dimension (e.g. Institutional capacity, Interactions, and Information) and the technical dimension (e.g. Sewage network functionality and Expertise) alongside indicators in the social, economic and environmental dimensions.

1. Introduction

Wastewater management remains a critical issue in low and lower-middle income countries. Efforts to improve sanitation, including the Millennium Development Goal (MDG) target of halving the percentage of people living without improved access to sanitation, have resulted in 2.1 billion people worldwide gaining access to sanitation between 1990 and 2015 (WHO & Unicef, 2015). Despite significant progress, the MDG sanitation target was missed by 9%, with the result that 2.4 billion people worldwide were still without access to improved sanitation in 2015 (WHO & Unicef, 2015). In addition, the earlier focus on sanitation access masked the lack of wastewater treatment. It is estimated that over 80% of the wastewater produced in the world, and over 95% of that produced in low and lower-middle income countries, is being discharged untreated into the environment (WWAP (United Nations World Water Assessment Programme), 2017). This issue is aggravated by rapid urbanization, resulting in severe local pollution and negative effects on ecosystems and human health (Sustainable Development Solutions Network, 2015). The recently introduced Sustainable Development Goals (SDGs) include wastewater treatment, and SDG target 6.3 specifies that the proportion of untreated wastewater should be halved by 2030 (United Nations Statistical Commission, 2017).

A large portion of future urban growth is predicted to occur in small towns, where wastewater management is currently poor. Wastewater management in small towns poses a challenge due to the fact that neither rural solutions of community-based management nor the public/private utility models developed in large cities for the provision of basic services (i.e. water and sanitation) are entirely suitable (Pilgrim et al., 2007). It is expected that in Latin America, Africa and Asia the number of small towns will double by 2022 and double again by 2037 (Pilgrim et al., 2007). Moreover, in low and lower-middle income countries, small towns usually have unplanned growth, often without a proper

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infrastructure for wastewater treatment (Ujang and Buckley, 2002; Caplan and Harvey, 2010). Where efforts have been made to treat wastewater in small towns, it is typically achieved through the establishment of small-scale wastewater treatment plants (WWTPs), which commonly lack the requisite financial mechanisms, technical expertise, and structured management organization (e.g. for their operation, maintenance and administration) (Cossio et al., 2017; Noyola et al., 2012; Massoud et al., 2009). In addition, if WWTPs are incorrectly designed and/or operated they risk failing to treat the wastewater sufficiently. Achieving SDG target 6.3 is thus a major challenge in many low and lower-middle income countries, requiring support for strategic planning and on-going assessment of wastewater management.

Wastewater management is a complex process, starting with wastewater generation, followed by the sewage network, wastewater treatment, and reintegration of by-products, such as water, nutrients and sludge, into the environment (Bakir, 2001). Nowadays, it is increasing recognized that the recovery and reuse of resources from wastewater, following the concept of circular economy, is critical for sustainability (Molina-Sánchez et al., 2018; Molina-Moreno et al., 2017). In low and lower middle-income countries waste management to transform it into resources e.g. water, nutrients, bio-fertilizer and energy is under development (Salguero-Puerta et al., 2019). Achieving a sustainable wastewater management process requires the identification of site-specific factors that impact on wastewater composition, available and efficient treatment technologies, the sensitivity of the receiving environment, the organizational structure, and the availability of expertise, as well as, a detailed understanding of how they are interlinked (Munier, 2005). Planners need to select appropriate treatment technologies to assure the long-term functionality and sustainability of these systems. Operating managers need to be able to assess and identify potential improvement needs (e.g. adequate operation and maintenance or upgrading), and then plan accordingly to achieve a sustainable wastewater management system. A sustainable small-scale WWTP in low and lower-middle income countries should therefore be appropriate in the local context in terms of acceptability and feasibility if it is to function with available local resources, e.g. available funding and technical and organisational capacity (Singhirunnusorn and Stenstrom, 2009).

Studies dealing with the sustainability of WWTPs generally include the environmental, social and economic dimensions (Singhirunnusorn and Stenstrom, 2009; Hellström et al., 2000; Balkema et al., 2001, 2002; Bradley et al., 2002; Palme et al., 2005; Muga and Mihelcic, 2008; Popovic et al., 2013; Molinos-Senante et al., 2014; Mena-Ulecia and Hernández-Hernández, 2015; Plakas et al., 2016) as they correspond to the concept of sustainable development put forward by the World Commission on Environment and Development in 1987 (Molinos-Senante et al., 2014). Sustainability assessment studies of WWTPs have focused largely on selecting the most sustainable technology, optimizing use of natural resources (e.g. water and energy), and minimizing the environmental impact of the by-products that are derived (Balkema et al., 2002; Lundin et al., 1999; Lundin and Morrison, 2002; Chang et al., 2015). This environmental focus has been applied in many studies regarding the sustainability assessment of well-performing WWTPs with advanced technologies, mainly in high and upper-middle income countries (Hellström et al., 2000; Bradley et al., 2002; Palme et al., 2005; Molinos-Senante et al., 2014, 2015; Lundin et al., 1999; Sweetapple et al., 2015; Meneses-Jácome et al., 2016; Galvão et al., 2005; Duarte et al., 2010; Rodriguez-Garcia et al., 2011; Upadhyaya and Moore, 2012; Castillo et al., 2016; Lorenzo-Toja et al., 2016; Venkatesh et al., 2017; Moreno et al., 2017; Popovic and Kraslawski, 2018; Sawaf and Karaca, 2018; Dvarionienė et al., 2018; Akhoundi and Nazif, 2018; Alimahmoodi et al., 2012; Arroyo and Molinos-Senante, 2018; Hranova, 2010; Dong et al., 2018; Kellner et al., 2009; Langergraber, 2013; Mahjouri et al., 2017; Murray et al., 2009; Padilla-Rivera et al., 2016; Padrón-Páez et al., 2016; Russell, 2014),. In contrast, studies conducted in lower-middle income countries focus on more context-relevant aspects, such as affordability, institutional capacity, public health risk, and participation (Bao et al., 2013; Chaudhary and Pandey, 2016; Kalbar et al., 2012, 2016). If planners and operating managers in low and lower-middle income countries are to be able to make sustainability assessments of small-scale WWTPs, the standard indicators developed mainly by experts need to be contextualized to local requirements.

The aim of the present study is to define a set of contextualized sustainability indicators in the context of small-scale WWTPs in low and lower-middle income countries to support the selection of appropriate and sustainable technology in the planning phase or the assessment of current functionality and sustainability in the operating phase, thus supporting the identification of possible improvement measures. These indicators should be able to i) identify the factors that influence the functionality and sustainability of WWTPs and ii) support the selection of appropriate technology for implementation or identification of improvement measures during operation. In order to develop such a set of contextualized indicators, a set of standard indicators was identified through a systematic literature review, and local context indicators were identified or formulated to complement the standard set of indicators by empirical studies using focus group meetings with operating managers and workshops attended by local experts. Adaptation of theoretical indicators to the local context was based on relevance and capacity for action to ensure the functionality and sustainability of the small-scale WWTPs. The empirical studies were carried out at five case study sites in Cochabamba, Bolivia.

2. Methods

The development process for contextualized indicators included a combination of two methodological approaches: a reductionist approach led by experts, i.e. 'top down', and a participatory approach that is community based, i.e. 'bottom up' (Bell and Morse, 2003; Reed et al., 2006). The top-down method develops standard indicators that are generally quantitative and assess hard systems (Reed et al., 2005, 2006). The bottom-up method aims to develop more qualitative indicators that support enhancement of the soft systems by understanding the local context for their assessment. Understanding how human factors (e.g. behaviour, culture, knowledge) affect the performance of the system (e.g. wastewater treatment system) allows changes to be monitored over time (Reed et al., 2006; Bell and Morse, 2004). The process of contextualized indicator development ensures effective monitoring of issues that are key to the local context. Standard indicators are frequently difficult to use, due either to lack of data availability or relevance to the system assessed. It is thus important to validate the feasibility and relevance of standard indicators in a specific context and to develop local indicators that can assess critical aspects of the system in order to achieve sustainability (Freebairn and King, 2003).

2.1. Context: area of study

Bolivia, a lower-middle income country (World Bank, 2018) located in South America and with a population of 10 million, has one of the lowest sanitation coverage levels in Latin America. Between 1995 and 2015 it made limited progress in terms of sanitation coverage, increasing from 28% to 50% in urban areas and from 11% to 28% in rural areas (WHO & Unicef, 2015). However, 70% of the wastewater collected is not treated (MMAyA, 2013) and many small towns have wastewater management issues, including poor or lack of operation and maintenance, lack of expertise for the type of technology implemented, low social acceptance, and inappropriate design (Cossio et al., 2017). Three rural municipalities, Tiraque, Colomi and Tarata (Table 1) in the Bolivian Department of Cochabamba, were used as case study sites to develop a contextualized set of sustainability indicators. The small-scale WWTPs in these three municipalities included the most commonly used technologies in the country, e.g. Imhoff tanks and stabilization ponds. The capitals of these municipalities, which are considered small towns with more than

Table 1
Overview of the five small-scale WWTPs.

Location of WWTP	Code	Number of households connected	Treatment technologies
Tiraque, capital	WWTP1	690	Pre-treatment, 1 Imhoff tank, 2 biofilters (in parallel)
Virvini	WWTP2	104	1 Imhoff tank
Colomi, capital	WWTP3	1016	2 Imhoff tanks (in parallel)
Chamoco	WWTP4	153	Pre-treatment, 2 Imhoff tanks (in parallel)
Tarata, capital	WWTP5	1084	Pre-treatment, 2 anaerobic ponds, 2 facultative ponds, 4 maturation ponds (all ponds in parallel)

2000 inhabitants and with mixed characteristics typical of both rural communities and urban areas (Caplan and Harvey, 2010), are served by three of the WWTPs studied (i.e. WWTP1, WWTP3 and WWTP5). Two small communities (>500 inhabitants) in the municipalities of Tiraque and Colomi, i.e. Virvini (WWTP2) and Chamoco (WWTP4) respectively, were also included in the study.

A preliminary survey was carried out to identify local stakeholders and understand how the basic services, i.e. water and sanitation, were provided to the population. This process included contacting key informants who could provide information regarding wastewater collection and treatment in the context studied. Information was gathered through informal interviews and meetings with staff from the municipalities, water board members, operational managers at the WWTPs, local leaders, and others involved in basic sanitation projects. The WWTPs in the five case studies are managed by a water board association, which is a group of users, generally elected by all users linked to the organization that provides basic services in the town (e.g. water supply system and sewage network). The water board association is thus responsible for ensuring the management of the WWTPs (i.e. operation, maintenance and administration). A performance assessment made in the five case studies as part of a previous study showed that the WWTPs were not working to their full potential, mainly due to a lack of operation and maintenance and overloads (i.e. flow and organic matter) (Cossio et al., 2017).

2.2. Identification and categorisation of standard indicators

To compile a full list of sustainability indicators to assess the WWTPs, a systematic literature search was performed in the Scopus database. The search was restricted to studies from 2000 onwards. The search string used the key words 'sustainability', 'criteria', 'indicator' and 'wastewater treatment plants', as well as combinations of these words. Detailed search strings (i.e. combinations of the key words) and the number of hits are presented in Supplementary Material (Table S1). Identified documents were screened by reading the abstracts and selecting studies that suggested or implemented a sustainability assessment of WWTPs using a framework of sustainability indicators/criteria. Relevant studies were selected for the systematization and categorisation of indicators. The country in which each selected study was implemented was identified and categorized according to the World Bank Country Income Classification list, i.e. high, upper-middle, lower-middle and low income (World Bank, 2018). Each study was also categorized according to the phase for which the indicators were developed, i.e. planning or operation. Indicators and criteria identified in the studies were grouped according to similarities to create a full literature list of sustainability indicators for wastewater treatment plants. Each group was categorized under the sustainability dimension that most of the original studies had indicated. The final standard set of sustainability indicators was obtained by selecting those indicators that were mentioned in one third or more, i.e. $\geq$ 33%, of the relevant studies.

2.3. Understanding the local context

Focus groups were used to acquire a deeper understanding of the local context. The interaction between participants in focus groups can often produce data that is not easily accessible using individual interviews (Flick, 2014). Moreover, when data availability is a limitation on the formulation of strategies for improvement, the SWOT analysis method is a useful means of understanding the history of a management system, such as a sewage network and a WWTP, and identifying critical aspects that require greater attention in the assessment (Cuppens et al., 2013). Focus group meetings were held with members of the water association boards and WWTP managers/operators at each of the case study locations in order to identify key management issues according to the local context. Each focus group was presented with the results of a performance assessment of the WWTP based on a previous study (Cossio et al., 2017) and it was then instructed to carry out a SWOT analysis, i.e. identify the strengths, weaknesses, opportunities and threats of the WWTP. Brainstorming was used to reflect on the current situation at the WWTPs and the following questions were used as guidance: What is working well? What are the main issues in the sewage service? What are the main issues at the WWTPs? What is the cause of the problem? How can these problems be solved? What do we do first? How can these improvements be measured? The insights produced during each focus group meeting were written on a flipchart in front of the participants. Discussions continued until data collection was saturated. The information was transcribed and coded for content, and similar input data was gathered under strengths, weaknesses, opportunities and threats. All data was categorized to identify common SWOTs mentioned in all five groups.

2.4. Identification of local sustainability indicators

Two workshops, attended by local experts who had worked on implementing water and sanitation projects in Bolivia, were organized to formulate local sustainability indicators based on the SWOT analysis. To obtain different perspectives on the formulation of the indicators, local experts from the technical field (seven participants) and the social field (six participants) were invited to take part in two separate workshops. The results from the previous study on the performance assessment of the WWTPs (Cossio et al., 2017), and the results from the SWOT analysis from the focus group meetings, were presented to the experts. The workshop participants were requested (i) to identify any additional aspect not brought up in the SWOT analysis but which was considered critical to the functionality and sustainability of the WWTPs, (ii) to formulate local indicators to measure these aspects, and (iii) to rank the importance of the sustainability dimensions that were identified in the literature review and which were presented to the experts for the purpose of the exercise. The workshop participants were asked to write down on post-it notes as many aspects that came to mind. The notes were collected and put on a board, each sorted under one of the five sustainability dimensions identified from the literature. The experts were then asked to formulate indicators. It was stated that the indicators should be measurable and be applicable by local stakeholders to assess the current situation of the WWTPs and to support decisions regarding potential improvements in the way they were managed. To rank the sustainability dimensions, each participant was asked to rank the dimensions individually. The results were then summarized to obtain a final ranking of the dimensions by each expert group.

2.5. Development of a contextualized set of sustainability indicators

The process for contextualizing the standard set of sustainability indicators identified from the literature involved an analysis of what has been found theoretically in relation to the sustainability assessment, i.e. a standard set of sustainability indicators, and what was highlighted by the stakeholders as relevant in relation to the context, i.e. local indicators. The development process was implemented in two stages: (i) aspects and indicators identified in the focus group meetings and expert workshops were matched with the full literature list of sustainability indicators, (ii) new local indicators were formulated when relevant aspects were not covered by the full literature list. As a result, the final set of contextualized indicators includes the standard set of sustainability indicators identified from the literature, local sustainability indicators that were matched to the full literature list of sustainability indicators, and new local sustainability indicators not matched in the reviewed literature.

3. Results

3.1. Set of standard indicators

The literature search in Scopus initially identified 1104 studies in total, which were reduced to 278 after the search was narrowed, see Supplementary Material for details (Table S1). After screening, 43 studies were selected for the systematization of sustainability indicators, see Supplementary Material (Table S2). Of the 43 selected studies, only four were carried out in lower-middle income countries and no study was carried out in a low-income country. The vast majority of the studies were thus carried out in high and upper-middle income countries. A detailed description of the full list of sustainability indicators and their references can be found in Supplementary Material (Table S3).

The literature review resulted in a list of 40 unique sustainability indicators, systematized into five dimensions: environmental, social, economic, technical, and institutional. This list of 40 sustainability indicators from the literature review, together with the number and percentage of studies in which they were mentioned and the phase to which they were applied (i.e. the planning and/or operational phase) is presented in the Appendix, Table A.

A total of 12 sustainability indicators were mentioned in 33% or more of the studies and they were consequently identified as standard sustainability indicators for the assessment of WWTPs (Table 2). It should be noted that the standard set of sustainability indicators resulting from the literature search does not include the institutional dimension. Suggested units for the indicators are presented in Table 2.

Table 2
The standard indicators from the literature used to assess the sustainability of WWTPs, organized according to the sustainability dimensions identified in the literature review, i.e. environmental, social, economic, and technical.

Dimension	Indicator	Description	Suggested units
Environmental	Energy use	Energy used per volume unit of treated wastewater or inhabitant.	kW/p.e. kWh/m^3
	Global warming potential	Emissions of greenhouse gases (GHG) into the atmosphere.	kg CO_2eq./p.e.-year kg CO_2eq./m^3
	Removal of BOD, TSS, TN, TP and FC	Contaminant removal efficiency to mitigate health and environmental risks.	%
	Land area	Land area required for the wastewater treatment facility.	m^2/p.e.
	Quality of effluent and sludge	Pollutants discharged into water and toxic compounds discharged into soil.	mg/L kg/p.e.-year
	Potential recycling	Reuse of treated wastewater: nutrients (N, P) and energy.	g/p.e.-year %
Social	Public acceptance	Opinion of the local population affected by the plant.	Qualitative
	Aesthetics	Measured level of nuisance deriving from e.g. odour, noise, visual impact, insects and other pests.	Qualitative
Economic	Investment costs	Cost of construction and installation of the WWTP.	$/$m^3$ $/p.e.-year
	Operating and maintenance costs	Operating costs per volume unit of wastewater treated.	$/$m^3$
Technical	Reliability	Infrastructure or mechanical reliability; resilience; security; ability to endure shock loads and/or seasonal effects; potential for overflow.	Qualitative
	Complexity of construction and O&M	Ease of construction, complexity of plant construction and system installation; complexity of operation and maintenance; professional skills required for operation and maintenance.	Qualitative

p.e. = population equivalent which expresses the ratio between the sum of the pollution load produced during a 24-h period by institutions (i.e. schools or health centres) and the individual load produced by one person in a household.

3.2. The local context

In Bolivia, WWTPs are funded and built by municipalities, regional Departments (e.g. Department of Cochabamba), or national entities (e.g. Ministry of Water and Environment). Once the infrastructure is in place, it is generally handed over to the local water association, which oversees its management by hiring managers/operators or assigning responsibilities to the board members. The local conditions regarding functionality and sustainability of the WWTP were analysed in greater depth by means of SWOT exercises in the five focus group meetings run at each water association. The number of participants in the five focus groups varied from 7 to 10.

3.2.1. Strengths

A common strength mentioned in all five focus group meetings was a good level of participation among the users, and the fact that members of the water association board, who are also users, work *ad honorem,* i.e. they work voluntarily and without payment, to oversee the management of the WWTPs. Good leadership and commitment to their role as water association board members was regarded as being key to assuring the standard of service provision and management. In the cases of WWTP1, WWTP3 and WWTP5, the board members hire staff to perform the administrative and operational tasks, while at WWTP2 and WWTP4 the board members designate one operator from among the members to take charge of the WWTP. In these cases, they usually work with and maintain the WWTPs as necessary. However, operators, either hired or board members appointed as operators, do not always complete all the required tasks to maintain the WWTPs. This strength is related to the Participation indicator, which is included in the full list of sustainability indicators (see Appendix).

A further strength identified by the participants was the fact that each water association has regulations and statutes in place to help it function as an organization to which users belong after they are connected to the sewage system. This can be matched with the Institutional capacity indicator, which is included in the full list of sustainability indicators, but not in the standard set (see Appendix). Payment of tariffs was identified as a further strength by all five groups, even though the fees collected typically do not cover the operating and maintenance costs (which was in turn mentioned as a weakness). The payment of tariffs was identified in the literature review (Tariff) and is included in the full list of sustainability indicators (see Appendix).

Other strengths cited by some of the water associations were: users participate in monthly meetings and leaders can train the users in specific topics (related to Participation, see Appendix); the percentage of user debt is low and users can contribute 5–10% of the investment cost of the WWTP (related to Tariff and Affordability, see Appendix); the staff participate in training; the water association holds a licence from the national government to operate; the water association has a three-year plan (all related to Institutional capacity, see Appendix).

It can be noted that none of the local strengths raised in the focus group meetings are included in the standard set of 12 sustainability indicators.

3.2.2. Weaknesses

Inappropriate use of the sewage network was mentioned as a weakness in all five groups. Inappropriate use will lead to problems in the network pipes, causing them to collapse due to accumulated solids and grease in the pre-treatment process at the WWTPs (NB: many users lack installations with grease traps in their households and/or restaurants). Furthermore, rainwater entering the sewage network can cause clogging due to accumulated sediments. Sewage network functionality depends on its adequate design and awareness among users of how to use it correctly. Proper use of the sewage network is related both to the Awareness (of users) indicator and the Information (from managers to users) indicator with regard to how to implement and use an adequate household installation to the sewage network. Awareness and Information are indicators included in the full list of sustainability indicators (see Appendix). On the other hand, sewage functionality is not included in the 12 standard indicators or in the full list of sustainability indicators.

Tariffs were also mentioned as a weakness by all groups when the fees collected are insufficient to cover the cost of operation and maintenance or hiring a skilled technician to manage the WWTP. This weakness is linked to indicators such as Tariff, Affordability and Cost effectiveness, which are taken from the full list of sustainability indicators (see Appendix). Lack of technical capacity and expertise to operate and maintain the WWTP was also highlighted by all five water associations. This is related to the Complexity of O&M (in the standard set of sustainability indicators, Table 2) and Staff requirements and Expertise (in the full list of sustainability indicators, see Appendix).

Other weaknesses were mentioned in one or more of the focus groups. One example is poor management of the WWTP, for which a possible indicator could be Complexity of O&M, as included in the standard set of sustainability indicators. Lack of monitoring of wastewater quality was also cited as a weakness, which could be reflected in the standard sustainability Quality of effluent (Table 2). Weaknesses such as lack of staff to operate the WWTP and lack of preventive and routine maintenance at the WWTP are linked to the Staff requirements indicator in the full list of sustainability indicators (see Appendix). The absence of regulations for the use of the sewage network was mentioned as a weakness, which is linked to the Institutional capacity of the municipality that is in charge of the introduction of regulations for the use of basic services. On the other hand, lack of information to users as a weakness could be linked to the institutional capacity of the water association. Institutional capacity could thus be relevant at different levels in the hierarchy. Political differences among the members of the board were cited as a weakness as it may affect good performance (e.g. due to delays in the decision-making process), which could be reflected in the institutional capacity of the water board association in solving internal conflicts.

3.2.3. Opportunities

All five water associations saw the existence of support from the local university for carrying out water analysis and providing technical assistance as a significant opportunity. The municipality is also seen as an asset as it provided support with equipment used to clean the WWTPs, establishes municipal regulations (e.g. proper use of the sewage network), and applies for funding, either at national level or from external sources, to upgrade or implement new WWTPs. Specific opportunities related to some of the water associations were: social media available in the municipality for communication purposes; support from international NGOs; support from the users. All the common and specific opportunities identified during the focus group meetings were related to the Interactions indicator in the full list of sustainability indicators (see Appendix).

3.2.4. Threats

The biggest threat expressed in all five focus groups took the form of conflicts with the population due to health issues. Health issues could be caused by contamination of rivers with poorly treated wastewater discharge, especially in the areas close to the discharge point where families reuse the water for washing clothes, bathing, irrigation, and watering animals. Indicators such as Public health risk, Acceptance and Information in the full list of sustainability indicators (see Appendix) would be the indicators used to assess this threat in combination with the standard indicator, i.e. Quality of effluent and sludge (Table 2). Environmental risks were also mentioned but were not considered to be as critical as the health risks.

Other threats mentioned in one or more groups were: rainwater entering the sewage network, which often affects sewage network functionality and can cause overflows in the WWTPs, especially during the rainy season. Irrational use of water due to an absence of water meters, along with wastewater discharged from health centres without any treatment, are aspects related to Institutional capacity at the municipal level to establish regulations for the use of basic services and discharge of different types of wastewater into the sewage network, i.e. wastewater from health centres. Lack of communication between the municipality, local leaders and users can be assessed by means of Interaction and Information, which are included in the full list of sustainability indicators (see Appendix).

3.3. Formulation of local indicators

The resulting local sustainability indicators from the workshops with local experts are presented in Table 3. The most relevant local sustainability indicators, based on the number of times they were mentioned in the groups, were: Institutional capacity of the water association and Institutional capacity at a higher level (i.e. municipal, departmental and national level). Awareness among the inhabitants of the need for wastewater treatment was also identified as important. Aesthetics, Participation and Expertise were mentioned by more than 50% of the participants.

Sewage network functionality was not listed by the local experts and as the participants in the focus group meetings stressed its relevance to the functionality and sustainability of the WWTPs it has been proposed as a new indicator for inclusion in a contextualized set of sustainability indicators. Sewage network functionality as a sustainability indicator can be applied in both the planning and operational phases as it supports decisions regarding the correct design of new, small-scale WWTPs and improving the operation of existing small-scale WWTPs.

The order of importance arrived at by local experts after ranking the sustainability assessment dimensions is presented in Table 4. Both groups of experts (i.e. technical and social experts) assigned the highest value to the institutional dimension and the lowest value to the environmental dimension. This can be compared to what was found in the literature review, where the citation percentage for environmental indicators was significantly higher than for institutional indicators. This prioritization of dimensions by local experts supported the addition of the institutional dimension to the four dimensions most frequently mentioned in the literature review (i.e. environmental, social, economic, technical).

3.4. A contextualized set of sustainability indicators

The final suggested set of contextualized sustainability indicators is presented in Table 5. The set includes the 12 standard sustainability indicators, expanded with the addition of 14 indicators related to the local context and matched to the full list of sustainability indicators (see Appendix) and one new local indicator – Sewage network functionality. Most of the contextualized sustainability indicators can be applied in both the planning and operational phases. However, there are indicators

Table 3
Local sustainability indicators organized according to sustainability dimensions identified in the literature review: environmental, social, economic, technical, and institutional. The number of times the indicator was mentioned by local experts is noted (there were 13 experts in total). All local sustainability indicators in this list are included in the full literature list of sustainability indicators.

Dimension	Indicator	#	Description
Environmental	Removal of BOD, TSS, TN, TP and FC	3	Efficiency of the WWTP according to monitoring parameters.
	Quality of effluent and sludge	3	Effluent quality according to monitoring parameters (e.g. organic matter and pathogens).
	Potential recycling	6	Acceptable quality of effluent and sludge for reuse.
	Eutrophication potential	3	Environmental impact on the recipient water body due to release of nutrients.
Social	Public acceptance	6	Acceptance of the WWTP before implementation following consent by the population.
	Aesthetics	7	Acceptance of the nuisance level of odours from the WWTP, influenced by its location and distance to the nearest households.
	Participation	7	Level of user participation before the project is implemented (i.e. communication), validation of demand for the project, water board members coordinating with local leaders, users carrying out operational tasks if necessary.
	Staff requirements	3	Staff available to operate the WWTP (technical expert, operator, administrator, social communicator).
	Employee satisfaction	4	Staff at the WWTP with a proper salary.
	Awareness	9	Level of responsibility of inhabitants and a sense of the need for a WWTP to reduce contamination.
	Expertise	7	Technical and social expertise exists, and there is a transfer of knowledge to new members of staff or water board members (if necessary).
Economic	Operation and maintenance costs	4	Operation and maintenance costs per inhabitant-year.
	Tariff	5	Appropriate tariff calculated to cover the technical requirements (e.g. technical expert, operator, materials) and which are socially accepted by the users.
	Cost effectiveness	3	Percentage of income from tariffs allocated to a WWTP, operating costs, and monthly balance after expenditure.
	Affordability	4	Service cost affordable to users linked to the willingness to pay and reflected in the percentage of the users' debt.
Technical	Complexity of construction and O&M	5	Appropriate technology designed in line with the local context and available resources (e.g. technical and economical to operate, maintain, replace or upgrade).
Institutional	Interactions	3	Collaboration between the water association and the municipality, local universities and health institutions.
	Institutional capacity (water association)	13	Water association strengthened and with the capacity to fulfill its functions to manage the WWTP (e.g. institutional organigram, monitoring capacity, regulations and functions, O&M plan, awareness of environmental limits, fulfillment of agreements, capacity to transfer knowledge)
	Institutional capacity (higher level)	9	Experts available at municipal, departmental and national level to carry out their respective tasks in the management of the WWTPs (e.g. norms, laws, regulations).
	Information	2	Information/training to users during the pre-investment and construction of the project. General information distributed to users connected on how to use the sewage network. Technical information for operators to manage the wastewater treatment plant.

that may have greater impact if applied during the planning phase (e.g. Energy use, Removal of BOD, TSS, TN, TP and FC, Public acceptance, Investment cost, etc.) as they can provide decision-making support to select the most sustainable technology in a phase where the choice of technology is still to be made. On the other hand, indicators that are more useful during the operational phase to support monitoring as a means of identifying weaknesses in the functionality and sustainability of the current WWTP may support decisions regarding corrective measures (e.g. Quality of effluent and sludge, Employee satisfaction, Sewage network functionality, Institutional capacity) (see Appendix). The contextualized set of sustainability indicators should thus be seen as a gross list.

4. Discussion

Identification of local characteristics and requirements in low and lower-middle income countries for achieving water and sanitation system sustainability is critical (Jones and Silva, 2009). A vital issue identified in the local context that affected the performance of the WWTPs was sewage network functionality. This issue is linked to the lack of regulations in place for adequate connection to the sewage network, to the lack of information to users regarding connection requirements and proper usage, and to awareness among users of the importance of complying with good practice. Although the focus of this study is the treatment system, i.e. the WWTP itself, it would be relevant to include external components, such as the sewage network, which has a significant influence on the system, in an assessment. Consequently, Public health risk was a relevant indicator that was also identified in the local context since one of the main aims behind having a functional and sustainable WWTP is to mitigate this risk. In low and lower-middle income countries the safeguarding of public health, especially against microbial infections, is a common issue that should be addressed (Bao et al., 2013). Reuse of wastewater (raw as well as treated) is common practice where water resources are scarce, which may introduce health risks if not safely implemented (Cossio et al., 2019). However, as part of a circular economy, recovery of resources (e.g. water, nutrients, bio-fertilizers, energy) is crucial for reaching sustainability (Molina-Sánchez et al., 2018; Molina-Moreno et al., 2017). The indicators Energy use and Potential of recycling explicitly address such circularity, but it also needs to be carried out in a safe way (Cossio et al., 2019).

Appropriate Institutional capacity at the manager level (i.e. water associations) and at higher levels (e.g. municipality) was identified as being one of the most important aspects to achieve a functional and sustainable wastewater management system in the context of this study. If, for instance, governmental institutions do not have clear laws to protect the environment and mitigate health and environmental risks related to wastewater discharge, efforts made to achieve functional and sustainable WWTPs will be ignored at the local level. Furthermore, better

Table 4
Ranking of the dimensions by local experts according to their relevance to the sustainability of the WWTPs. The number in brackets indicates the prioritization level expressed by the group during the exercise. 1 = most important 5 = least important.

Field of expertise	Dimensions and ranking				
Technical field	Institutional (1)	Social (2)	Technical (3)	Economic (4)	Environmental (5)
Social field	Institutional (1)	Economic (2)	Social (3)	Technical (4)	Environmental (5)

organizational structures and adequate institutional capacity for wastewater management can mobilize financial resources and ensure that technical capacity is available to operate and maintain the plants in the long term. Interaction and dissemination of information between stakeholders (i.e. municipalities, water associations and users) were also considered important by local stakeholders to ensure the functionality and sustainability of the WWTPs. Consequently, strengthening institutional capacities at all levels and having clear roles and responsibilities for each stakeholder involved in wastewater management (Padilla-Rivera et al., 2016) were identified as important aspects in the local context. This, and the ranking by stakeholders of the institutional dimension as the most important factor, support the addition of a fifth sustainability dimension (institutional) in the context of low and lower-middle income countries.

The suggested contextualized set of indicators should be seen as a gross list and thus requires adaptation before it can be applied in practice. Practitioners should select only those indicators that are relevant to the specific phase (e.g. planning or operation) for which a particular assessment is to be applied. Based on the literature review, Table A in the Appendix shows which indicators are suggested to be used for assessments made in the planning phase and which indicators to be used for assessments made for already existing WWTPs. In the studies reviewed, almost all the indicators in the full literature list presented in the Appendix are proposed for both the planning phase and the operational phase, with only a few exceptions. However, among the standard set of indicators it is applications during the planning phase that dominate, except for Removal of BOD, TSS, TN, TP and FC, Quality of effluent and sludge, and Aesthetics. On the other hand, locally relevant indicators identified in the institutional dimension, such as Institutional capacity, Interactions, and Information, were mostly suggested for the operational phase. As this study highlights the importance of Institutional capacity at different levels in the hierarchy, it is recommended that they are also included in the planning phase to ensure that new WWTPs are sustainable in the local context.

The indicators suggested in this study are not independent, rather many are interrelated. Removal efficiency and Quality of the effluent and sludge are linked to Complexity of operation and maintenance, Expertise available, and Staff requirements, which are in turn linked to Tariff, Affordability, and Cost effectiveness. Future applications of the contextualized set of sustainability indicators suggested in this study would require a process for narrowing down the list, not only with regard to assessment of a specific phase, but possibly also with regard to interdependencies. This is especially important if the list of indicators is to be applied using a Multi-Criteria Decision Analysis (MCDA) framework, which typically requires criteria to be mutually preference independent (Belton and Stewart, 2002). Further refinement of the suggested gross list of contextualized indicators into a criteria hierarchy, potentially including weights, could be done e.g. by using the Fuzzy Delphi Method (Mahjouri et al., 2017; Kamble et al., 2017; Kamali et al., 2019), preferably then by involving local experts to keep the relevance of the developed indicator set. The Fuzzy Delphi method does not solve the issue of mutual independence however, thus this must also be tested before implementation in an MCDA framework.

Future use of these contextualized indicators in a sustainability assessment aiming to support a decision-making process will likely require weighting of the indicators as to which are of most importance in the given context. For MCDA applications, the relation between the scoring scales and the types of weights used is crucial. For example, local scales may introduce large errors in the analysis if importance weighting is applied, and it is often better to apply global scales to avoid such errors (Monat, 2009). The Analytical Hierarchy Process (AHP) approach avoids this problem by using the pair-wise comparison for weighting and has been extensively applied in sustainability assessments (with or without fuzzy numbers) (Molinos-Senante et al., 2014; Starkl et al., 2013; Bottero et al., 2011; Kalbar et al., 2013; Ren and Liang, 2017). Finally, any application of these indicators in a sustainability assessment should include a sensitivity analysis of the results, especially for decision-support models which considers comparison and ranking of different alternatives (Padilla-Rivera and Güereca, 2019). Sensitivity analyses can investigate both the effects of the weighting applied as well as the effect of uncertainties in the qualitative or quantitative inputs on the included indicators.

In high income countries, sustainability assessments of WWTPs place a lot of emphasis on sustainable use of water resources and the impact on the environment, supposedly due to the implied adequate performance of the technologies. Low and lower-middle income countries, on the other hand, are still facing major challenges regarding adequate performance of implemented technologies (Ujang and Buckley, 2002; Noyola et al., 2012; Massoud et al., 2009). The local managers and experts did not highlight the standard indicators, i.e. Energy use, Global warming potential, Land area or Investment costs. The Energy use indicator was not supported, possibly due to the fact that commonly implemented technologies in low and lower-middle income countries are in general low-energy technologies, e.g. stabilization ponds. As regards greenhouse gas production, total BOD emissions from water pollution are identified as a source of concern (Trading economics, 2019), to which untreated wastewater could be a contributing factor. There are few studies that address greenhouse gas emissions from wastewater treatment technologies established in low and lower-middle income countries. Hernández-Padilla et al. studied common technologies in Latin America and concluded that in the case of stabilization ponds the global warming impact was not as great compared to the other criteria included in the study (Hernández-Padilla et al., 2017). Nevertheless, Global warming potential should be included in a sustainability assessment of small-scale WWTPs: even if the impact may not be as great today, it is likely to increase along with other technologies. Land area is commonly available in small town locations although population growth projections should be taken into account, e.g. to avoid the WWTPs being surrounded by households that are affected by the smell. The Investment costs indicator was not mentioned in the empirical study involving local managers or experts, most probably because WWTP construction is generally subsidized by national government or external aid organizations. However, the failure of small WWTPs in some low and lower-middle income countries typically correlates with a lack of financial resources (Cossio et al., 2017; Massoud et al., 2009). Consequently, including Investment costs in the sustainability assessment would support the analysis if the cost of replacement or upgrading of planned or current technologies could be covered by users in the future (saving money from currents tariffs or paying an extra fee). By doing so, the financial and technical sustainability of the WWTPs can be better achieved if the local government or external organizations were unable to cover this demand.

In the early studies reviewed, the main focus is in general on environmental and economic aspects related to the sustainability of WWTPs and the implication is that the technical indicators are part of the environmental dimension, e.g. the Removal of BOD, TSS, TN, TP and FC and Reliability (Molinos-Senante et al., 2014). Indicators relating to the social

Table 5
The suggested set of contextualized indicators for assessing the sustainability of small-scale WWTPs in Bolivia, organized according to the sustainability dimensions, i.e. environmental, social, economic, technical, and institutional, with suggested units for measurement and for application in the planning phase or the operational phase. Local relevance is indicated as being supported by local managers and/or local experts. The standard literature indicators are shown in bold type, the local extension, supported in the full literature list, is shown in normal type, and the new added local indicator is shown in italics.

Dimension	Indicator	Suggested units	Local relevance	
			Managers	Experts
Environmental	**Energy use**	kW/p.e. kWh/m^3		
	Global warming potential	kg CO_2 eq./p.e.-year kg CO_2 eq./m^3		
	Removal of BOD, TSS, TN, TP and FC	%	✓	✓
	Land area	m^2/p.e.		
	Quality of effluent and sludge	mg/L kg/p.e.-year	✓	✓
	Potential recycling	g/p.e.-year %		✓
	Eutrophication potential	kg of N, P/p.e.-year kg PO_4 eq./m^3		✓
Social	**Public acceptance**	Scoring system*		✓
	Aesthetics	Scoring system*		✓
	Public health risk	No. of outbreaks/unit population	✓	
	Participation	Scoring system*	✓	✓
	Staff requirements	No./flow rate	✓	✓
	Employee satisfaction	Scoring system*		✓
	Awareness	Scoring system*	✓	✓
	Expertise	No. of experts/ skilled staff	✓	✓
Economic	**Investment costs**	\$/p.e.-year \$/m^3		
	Operating and maintenance costs	\$/m^3		✓
	Tariff	\$/month	✓	✓
	Cost effectiveness	Scoring system*	✓	✓
	Affordability	\$/m^3 % of income/ m^3	✓	✓
Technical	**Reliability**	Scoring system*		
	Complexity of construction and O&M	Scoring system*	✓	✓
	Sewage network functionality	*No. of failures/ month*	✓	
Institutional	Interactions	No. of events/ year	✓	✓
	Institutional capacity (water association)	Scoring system*	✓	✓
	Institutional capacity (higher level)	Scoring system*	✓	✓
	Information	Scoring system*	✓	

The scoring system refers to the establishment of an assessment scale, preferably defined by local stakeholders.

dimension are included in studies dating from around 2008 (Muga and Mihelcic, 2008; Duarte et al., 2010; Popovic and Kraslawski, 2018; Mahjouri et al., 2017; Padilla-Rivera et al., 2016). Although the studies that include the social sustainability dimension are few in number, they have a broader perspective and therefore imply a large variety of indicators (Popovic and Kraslawski, 2018). In general, social indicators are qualitative and difficult to measure objectively, and often their meaning and relevance are suggested by local stakeholders (Padilla-Rivera et al., 2016). The social dimension and associated indicators are considered to be key to the success of the sustainability assessment of WWTPs although standard indicators are still in the process of being developed (Palme et al., 2005; Popovic and Kraslawski, 2018).

Indicators relating to the institutional dimension are included in studies from around 2010 and later (Upadhyaya and Moore, 2012; Venkatesh et al., 2017; Kellner et al., 2009; Padilla-Rivera et al., 2016; Iribarnegaray et al., 2015). In the studies reviewed as part of this research, institutional indicators were used in 7 out of 43 studies. Only four studies were found that dealt with lower-middle income countries (none dealt with low income countries) and none of them included the institutional dimension. Although this study suggests four institutional indicators, further research is needed, e.g. dealing with the measurability of institutional indicators applicable to the context of low and lower-middle income countries. Data availability for the assessment could be a limitation on the use of the contextualized set of indicators suggested. Indeed, lack of data is a weakness already identified at the global level in low and lower-middle income countries (WHO, 2018) when measuring the progress of Indicator 6.3.1 – proportion of wastewater safely treated, for the fulfilment of Target 6.3. It is therefore important to apply the indicators in practice in order to develop units or methods for assessing them, especially for those indicators requiring semi-quantitative or qualitative assessments. However, quantitative indicators for which data are readily available in a high-income country may not be as readily available in the context of small-scale WWTPs in low and lower-middle income countries.

The methods applied for arriving at a final set of contextualized indicators in this study are subject to some uncertainties. The literature review is based on certain search strings including relevant search terms, but important studies could have been missed. The grouping of indicators from literature may have been done differently by other analysts, i.e. there are some elements of interpretation included in the grouping procedure. A quantitative criterion is used to determine which indicators to include in the standardised set (i.e. 33%) – a different limit would give a slightly different result. The procedure for identifying contextualized indicators used local workshops and focus group meetings with experts and stakeholders, and the interpretation of the result may thus be subject to linguistic uncertainties, as well as, communication issues (Kamble et al., 2017). On the other hand, most of the contextualized indicators are matched against literature, so for all other indicators than "Sewage network" there is also support from literature that they are relevant. However, no formal sensitivity analysis is carried out in this study regarding the methodologies applied, i.e. in relation to the resulting contextualized set of indicators. The suggested ranking of sustainability dimensions is based on responses from local experts and do not represent any generic weighting in the case of application of the indicators in a sustainability assessment. It does however, support the inclusion of the institutional dimension as an important aspect in this context.

Future steps to further support an implementation of the suggested contextualized indicators should include development of methods and units to assess the suggested indicators with the low and lower-middle income country context in mind. Since data availability is a weakness in this context, an important next step is to build a sustainability assessment framework that will also encourage and support data collection for better, and more quantitative, evaluation of the suggested indicators. As a start, methods such as the traffic light method (Benavides et al., 2019), that implies the construction of rather simple semi-quantitative (or purely qualitative) scales can be used for sustainability assessment when data is scarce. The participation of local experts and stakeholders for providing information available to guide in the construction of these scales and to validate their accuracy, and potentially to be involved in providing weights for different indicators is needed to ensure the applicability and usefulness of such sustainability assessment.

5. Conclusions

The main conclusions from this study are:

- The final gross contextualized set of sustainability indicators suggested in this study can be used for both the planning and operational phases, but need to be adapted according to data availability.
- The addition of the institutional dimension in sustainability assessments of WWTPs was supported in the focus group meetings and workshops with local stakeholders.
- Sewage network functionality was identified as a new indicator, not found in the literature review but emphasized by the local stakeholders. Furthermore, the Institutional capacity, Public health risk, Awareness, Aesthetics, Participation and Expertise indicators were found to be most relevant to the local context and matched the full list of sustainability indicators.
- The local stakeholders attached less value to some of the standard indicators developed in high and upper-middle income country contexts (i.e. Energy use and Global warming potential), and a higher level of knowledge about global effects is required at the local level as it is important that these are included in a sustainability assessment.
- Finally, locally-adapted methods and units for assessing the suggested indicators should be developed and evaluated for application in low and lower-middle income context.

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Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2020.100028.

Appendix

Table A
Full list of 40 sustainability indicators from the 43 selected studies. Indicators in bold type and capital letters are the standard indicators that are included in at least one-third of the studies. The columns to the right show the percentage and number of studies in which the indicator was included and the number of studies in which the indicator was applied in either the planning or the operational phase.

Dimensions and indicators	%	No. of studies	Planning	Operation
Environmental dimension				
ENERGY USE	**47**	**20**	**14**	**6**
GLOBAL WARMING POTENTIAL	**47**	**20**	**12**	**8**
REMOVAL OF BOD, TSS, TN, TP AND FC	**44**	**19**	**9**	**10**
LAND AREA	**44**	**19**	**16**	**3**
QUALITY OF EFFLUENT AND SLUDGE	**37**	**16**	**9**	**7**
POTENTIAL RECYCLING	**35**	**15**	**10**	**5**
Sludge production	30	13	7	6
Use of natural resources (water and raw materials)	30	13	7	6
Eutrophication potential	19	8	5	3
Economic dimension				
INVESTMENT COSTS	**63**	**27**	**18**	**9**
OPERATING AND MAINTENANCE COSTS	**42**	**18**	**12**	**6**
Tariff	16	7	1	6
Cost effectiveness	9	4	2	2
Affordability	9	4	2	2
Ensure economic sustainability of the utility	7	3	1	2
Technical dimension				
RELIABILITY	**47**	**20**	**14**	**6**
COMPLEXITY OF CONSTRUCTION AND O&M	**37**	**16**	**12**	**4**
Durability	19	8	5	3
Robustness	16	7	5	2
Adaptability	14	6	4	2
Upgrading, extending, or modifying the scope of future development	9	4	3	1
Quantity of treated wastewater as a percentage of the total volume of wastewater	5	2	–	2
Actual people equivalent (PE) as a percentage of design PE	2	1	–	1
Load generated by pollutants entering the WWTP (per inhabitant connected; per catchment area; per population density)	2	1	–	1
Treatment level	2	1	–	1
Social dimension				
PUBLIC ACCEPTANCE	**37**	**16**	**10**	**6**
AESTHETICS	**37**	**16**	**9**	**7**
Public health risk	26	11	4	7
Coverage	23	10	1	9

(continued on next column)

Table A (*continued*)

Dimensions and indicators	%	No. of studies	Planning	Operation
Participation	21	9	5	4
Occupational health and safety	21	9	4	5
Local employment	16	7	5	2
Staff requirements	16	7	5	2
Satisfaction (employees)	14	6	1	5
Stimulation of sustainable behaviour	12	5	3	2
Awareness	12	5	2	3
Expertise	7	3	1	2
Institutional dimension				
Interactions	14	6	1	5
Institutional capacity	14	6	–	6
Information	5	2	–	2

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