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Sustainability assessment of sanitation systems in El Alto, Bolivia

A pre-study

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Abstract

Sustainability assessment of sanitation systems in El Alto, Bolivia: A pre-study

Malin Smith

The Sustainable Development Goal (SDG) Target 6.2 aims at providing access to adequate and equitable sanitation and hygiene for all and to end open defecation by 2030. Yet, 47 % of the population in Bolivia lacked access to basic sanitation services in 2012. There is a risk of actors focusing on only the construction of toilet facilities, without looking at the need for related service required for a sustainable development. El Alto is a rapidly growing city in Bolivia where the sanitation service is expanding fast. In order to enhance knowledge about the sustainability of existing sanitation systems in El Alto and to give recommendations for future development, this sustainability assessment was conducted. Two sanitation systems in El Alto were assessed against five sustainability criteria, related to: 1) health, 2) environment, 3) technical function, 4) socio-culture (institutional and user related) and 5) economy. The conventional sanitation system with sewers and an alternative small-scale sanitation system with urine-diverting dry toilets (UDDTs) were selected as system options.

Results show that the "conventional system" entails higher health risks than the "UDDT system". For example, blockages in the main sewer lines cause overflows in the streets during rainy season when storm water gets mixed with potentially infectious wastewater. The UDDT system has a higher performance than the conventional system regarding the environment criterion, which is related to nutrients recovery and removal. Results related to the technical function criterion show that the conventional system has a better capacity to endure a change in quality or quantity of input products to the system. Both systems can handle the freezing temperatures in El Alto but the UDDT system has better resilience against climate change impacts such as flooding or drought events. The levels of complexity are reasonable in a local context for both systems. If assuming that the aspiration for flush toilets is as low in entire El Alto as in the area of investigation, results show that users of the UDDT system are more satisfied than uses of the conventional system. The dissatisfaction expressed by users of the conventional system mainly derives from malodors appearing during the wastewater overflows in the streets. The institutional capacity is stronger for the conventional system, making it harder for the UDDT system to expand. In addition, the UDDT system has difficulties with financing.

Recommendations for future development are to inspect and renew the sewer network and to review and expand treatment capacity of the centralized treatment plant. Financial resources should be focused on the UDDT system where there is no sewer network.

Keywords: Sustainable sanitation, peri-urban, urine-diverting dry toilet, waste stabilization pond, stakeholder

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REFERAT

Hållbarhetsanalys av sanitetssystem i El Alto, Bolivia: En förstudie
Malin Smith

Det globala hållbarhetsdelmålet 6.2 syftar till att senast 2030 säkerställa att alla har tillgång till fullgod och rättvis sanitet och hygien och att ingen behöver uträtta sina behov utomhus. År 2012 hade fortfarande 47% av Bolivias befolkning inte tillgång till acceptabel sanitet. Det finns en risk för att aktörer fokuserar på enbart snabb utbyggnation av toaletter, utan att ta hänsyn till behovet av relaterad service som krävs för en hållbar utveckling. För att sanitetssystem ska räknas som hållbara krävs, förutom att de skyddar hälsan, även att de är ekonomiskt genomförbara, socialt accepterade, tekniskt och institutionellt anpassade och att de skyddar miljön och hushåller med naturresurser. Med syftet att öka kunskapen kring hållbarheten av de existerande sanitetssystemen i El Alto, en snabbt växande stad i Bolivia, och för att ge rekommendationer till framtida utveckling av sanitetssystemen, genomfördes en hållbarhetsanalys av två existerande sanitetssystem i området. Det ena var det konventionella systemet tillhörande avloppsledningar och det andra var ett alternativt småskaligt system tillhörande urinsorterande torrtoaletter (UDDT).

Resultaten visar på att det ”konventionella systemet” innebär högre hälsorisker än ”UDDT systemet” för arbetarna och för boende som vistas i områdena där systemen finns. Det dåligt underhållna avloppssystemet var den avgörande faktorn, eftersom under regnperioder orsakas översvämningar av avloppsvatten på gatorna. Det konventionella systemet orsakar ungefär sex gånger så höga utsläpp av övergödande ämnen som UDDT systemet. UDDT systemet har potential att återvinna ungefär 64 % av inkommande kväve medan den motsvarande siffran för det konventionella systemet är endast 9%. Det konventionella systemet klarar bättre av förändringar i kvalitet och kvantitet av inflöden än UDDT systemet men båda systemen klarar av perioder då minusgrader inträffar. UDDT systemet förväntas, till skillnad från det konventionella systemet, att kunna hantera eventuell torka eller översvämning bättre som kan inträffa till följd av klimatförändringar. Till stor del på grund av de årligt förekommande översvämningarna av avloppsvatten på gatorna verkar användarna av det konventionella systemet vara mindre nöjda med sitt sanitetssystem än vad användarna av UDDT systemet verkar vara. Det gäller då att viljan att skaffa vattentoaletter är lika låg i hela El Alto som i området där intervjuer gjordes. Den institutionella kapaciteten är högre för det konventionella systemet än för UDDT systemet, vilket gör det svårare för UDDT systemet att expandera. Dessutom har UDDT systemet finansiella svårigheter.

Rekommendationer för framtida utveckling av sanitetssystemen i El Alto är delvis att underhålla och förnya avloppsledningarna och att expandera kapaciteten på det konventionella vattenreningsverket innan fler hushåll ansluts till ledningsnätet. Finansiella medel rekommenderas fokuseras på UDDT systemet i områden där avloppsledningar inte täcker.

Nyckelord: Hållbar sanitet, peri-urban, urinsorterande torrtoalett, stabiliseringsdamm, intressent

RESUMEN

Evaluación comparativa sobre la sostenibilidad de los sistemas de saneamiento en el Municipio de El Alto, Bolivia
Malin Smith

El Objetivo de Desarrollo Sostenible 6 Meta 2 incluye que hasta el 2030, se logre el acceso a servicios de saneamiento e higiene adecuados y equitativos para todos y poner fin a la defecación al aire libre. Todavía, 47 % de la población en Bolivia carecía de acceso a saneamiento básico en 2012. Para alcanzar la meta sin comprometer los otros objetivos de desarrollo sostenible, la Alianza Sustenable de Saneamiento (SuSanA) identificó cinco criterios de sostenibilidad para el desarrollo de sistemas de saneamiento. Estos criterios son relacionados con: 1) salud e higiene, 2) medio ambiente y recursos naturales, 3) tecnología 4) asuntos financieros y económicos, y 5) aspectos socioculturales e institucionales (SuSanA, 2008). Con el objeto de mejorar el conocimiento sobre la sostenibilidad de los sistemas de saneamiento existentes en El Alto, una ciudad en rápido crecimiento en Bolivia, y para dar recomendaciones para el futuro desarrollo, se realizó una evaluación comparativa sobre la sostenibilidad de dos de los sistemas. Se evaluó el "sistema convencional", que tiene conexiones al alcantarillado y una planta de tratamiento centralizado. Tabmbien se evaluó el "sistema UDDT", que tiene baños secos ecológicos de los cuales existen en menor escala en El Alto.

Los resultados muestran que existe alto riesgo para la salud derivados del alcantarillado del sistema convencional. Durante la temporada de lluvia suele ocurrir bloqueos taponamientos en la red del alcantarillado. Los bloqueos causan desbordes de aguas residuales en las calles que se mezclan con aguas pluviales. Los resultados muestran también que emisiones de eutrofización son aproximadamente seis veces más altas que el sistema convencional en comparación con el sistema UDDT. El potencial para el reciclaje de nitrógeno se puede estimar en 64 % del sistema UDDT y solo 9 % del sistema convencional. Los resultados sobre robustez muestran que el sistema convencional tiene una mejor capacidad para soportar un cambio en la calidad o cantidad de productos de entrada al sistema. Ambos sistemas pueden manejar las temperaturas de congelación en El Alto, pero el sistema UDDT tiene una mejor resistencia contra los impactos del cambio climático, como una inundación o una sequía. Existe insatisfacción que expresan los usuarios del sistema convencional debido a los desbordes anuales de aguas residuales en las calles. En general, los usarios del sistema UDDT estaban satisfechos. Parece que la aspiración de inodoros con descarga de agua es más baja en El Alto comparado con una ciudad más al sur de Bolivia. Por que la capacidad institucional es más fuerte para el sistema convencional comparado con el sistema UDDT, es más fácil para el sistema convencional expandirse. Además, los recursos financieros no están asegurados para el sistema UDDT.

Las recomendaciones para el futuro desarrollo del situación de saneamiento es inspeccionar y renovar la red de alcantarillado existente y revisar y ampliar la capacidad de tratamiento de la planta de tratamiento centralizada antes de expandir la red de alcantarillado. Los recursos financieros deben centrarse en el sistema UDDT donde ya no existe una red de alcantarillado.

PREFACE

This master's thesis is the completive part of the Master's Program in Environmental and Water Engineering at Uppsala University (UU) and the Swedish University of Agricultural Sciences (SLU). The thesis covers 30 credits and was conducted in collaboration with Research Institutes of Sweden (RISE) and Stockholm Environment Institute (SEI). The Institute for Advanced Development Studies (INESAD) provided with local help and an office during data collection in La Paz, Bolivia. Elisabeth Kvarnström, Urban Water management department at RISE, was supervisor for the thesis. Subject reviewer was Jennifer McConville, Department of Energy and Technology at SLU.

The thesis was developed as a pre-study for a three-year long project that SEI and RISE has in Bolivia aiming to influence the Bolivian sanitation sector. The Swedish International Development Cooperation Agency (Sida) funded the thesis through the Junior Field Officer Program of RISE, as the thesis could be made jointly with me (Malin Smith) as a Junior Field Officer for RISE based in La Paz, Bolivia between March and July 2019.

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My family and friends have given me valuable support throughout the work with this thesis and also throughout my entire time as a student. I would like to thank them for that and also for making my time as a student an unforgettable period full of fun and joy.

POPULÄRVETENSKAPLIG SAMMANFATTNING

Hållbarhetsanalys av sanitetssystem i El Alto, Bolivia: En förstudie
Malin Smith

Framgångarna har varit stora i Latinamerika under perioden 2000–2017 när det kommer till utvecklingen av sanitet och hygien. Tyvärr hade ändå nästan halva befolkningen i Bolivia inte tillgång till ordentliga toaletter under 2012. El Alto är en växande stad i Bolivia där avloppsledningsnätet nu breder ut sig snabbare än vad avloppsreningsverket hinner rena avloppsvattnet. Stora andelar orenat eller dåligt renat avloppsvatten släpps ut i naturen, som får som följd dålig vattenkvalitet i vattendragen ut från staden. Titicasjön, Sydamerikas största sjö, har blivit rejält övergödd av avloppsvattenutsläppen ifrån El Alto och det stora, utbredda avloppsledningsnätet med otillräcklig rening pekas i den här studien ut som en av anledningarna till miljöförstöringen.

Ett annat system för sanitetsservice som finns i mindre skala i El Alto fungerar så att avföringen separeras i toaletten för att sedan låta den hämtas upp i fordon. Kiss och bajs transporteras till en reningsstation, där det behandlas och återvinns. Vattnet från bad, tvätt och dusch filtreras ned i marken på tomten där man planterar prydnadsväxter. Detta småskaliga system står för ungefär sex gånger mindre utsläpp av övergödande näringsämnen till mark eller vattendrag jämfört med det stora systemet, relativt sett.

Under regnperioder händer det att regnvatten blandar sig med avloppsvatten i avloppsvattenledningarna till den stora reningsanläggningen och översvämmar gator. Översvämningarna luktar illa för de boende i områdena och sjukdomar riskerar att spridas med vattnet. Det småskaliga systemet riskerar mindre hälsorisker för arbetare och personer som bor i området än det stora systemet tillhörande avloppsledningarna, eftersom regnvatten inte riskerar att blandas med avföringen lika lätt. Översvämningarna på gatorna framkom vara den främsta anledningen till att användarna av det stora systemet inte var speciellt nöjda med sina toaletter. Det kom fram under intervjuer med användare i ett utvalt område i El Alto. Majoriteten av användarna av det småskaliga systemet uttryckte under intervjuer i ett utvalt område i utkanten av El Alto att de generellt sett var nöjda med sin toalett. Detta trots att toaletten inte är vattenspolande. Enligt många studier föredras vattenspolande toaletter framför torra toalettlösningar. Viljan att ha en vattentoalett verkar vara lägre i El Alto än till exempel en stad mer söderut i Bolivia. Detta faktum kan vara förklaringen till varför resultaten från den här studien visar på att användarna av separerande torr-toaletter verkar vara mer nöjda än användarna av vattenspolande toaletter.

I det fallet då boende kan göra ett val mellan olika toalettsystem krävs att systemen är bekväma och accepterade av användarna för att systemet ska kunna drivas ordentligt. I El Alto får fler och fler personer valet om de vill ansluta sig till det stora systemet, även de som redan använder det småskaliga systemet. Eftersom det stora systemet är välkänt och etablerat är det enklare för det att utvecklas vidare än för det lilla systemet. Det är svåra tider ekonomiskt sett för det småskaliga systemet och på grund av att det stora systemet är mer väletablerat och får mer finansiering så riskerar det småskaliga systemet att få det svårt framöver.

Både det utbredda och det småskaliga sanitetssystemet kan producera näringsrika produkter som kan vara användbara i jordbruk om produkterna renas ordentligt. Genom att återanvända näringen i vår avföring hushåller vi med jordens resurser samtidigt som det kan genereras en inkomst från produkterna. Resultat från studien visar på att det kan finnas ett finansiellt värde i produkter från båda systemen. Potentialen är outvecklad i dagsläget, speciellt för det stora sanitetssystemet. Gällande ekonomisk hållbarhet så bör investerings- och drift- och underhållskostnader undersökas innan några större slutsatser kan dras.

Klimatförändringar kan resultera i mer frekvent förekommande extremväderhändelser så som översvämningar och torka. Resultat från den här studien visar på att det småskaliga systemet troligtvis kan klara av sådana händelser något bättre än vad det stora systemet kan göra. Transporten av avföring fungerar utan tillgång till vatten i det småskaliga systemet medan transporten inte alls skulle fungera för det stora systemet. Översvämningar skulle få liknande konsekvenser som de som nämnts sker under regnperioderna. Skulle plötsligt jättemånga personer använda toaletten i ett visst hushåll så skulle det stora systemet klara av det bättre än det lilla systemet, eftersom det inte finns en begränsad volym som kan fyllas upp. Det stora systemet skulle även klara bättre av ifall saker som inte ska vara i toaletten skulle råka hamna där.

Anledningen till att vi vill undersöka mer än bara hälsorelaterade aspekter till toalettbygge är för att försäkra oss om en långvarig hållbarhet. Det finns många definitioner kring hållbar utveckling men en väletablerad sådan definierar fem aspekter relaterade till sanitetssystem: hälsa, miljö, socialt sammanhang, teknik och institution samt ekonomi. För att nå FN:s globala hållbarhetsmål gäller det att alla dessa aspekter integreras i planeringen av toalettbygge. Ett sätt att göra det på är genom multikriterieanalys, vilket jag baserat den här studien på.

Resultaten från denna studie kan användas som stöd i den fortsatta planeringen av sanitetsservice i El Alto. Rekommendationer jag skulle vilja ge, baserat på resultaten, är delvis att avloppsledningarna i El Alto ses över och renoveras för att minska inläckage av regnvatten och utläckage av avloppsvatten. Det stora reningsverket bör underhållas bättre och byggas ut innan fler ansluter till ledningsnätet. Där nya anslutningar till avloppsledningsnätet planeras rekommenderar jag istället att skala upp det idag småskaliga urinseparerande systemet så att näringsämnen kan tas tillvara på. Med de här åtgärderna skulle övergödande utsläpp till Titikakasjön minska liksom smittsamma avloppsvattenströmmar. El Alto skulle bli bättre klimatanpassad och förhoppningsvis skulle de som bor i El Alto och använder toalettsystemen även bli mer nöjda än vad de är idag.

ACRONYMES

AAPS - Authority of Social Control of Drinking Water and Sanitation

BOD_5 - Biochemical Oxygen Demand

Conv. - ”Conventional system” (defined system option for this study)

EPSAS - Municipal Water and Sanitation Company

GAMEA - Autonomous Municipal Governmentof El Alto

FSH - Foundation Sumaj Huasi

IBNORCA - Bolivian Institute for Standardization and Quality

MCA - Multi-Criteria Analysis

MMAyA - Ministry of Environment and Water

OWP - Open Wastewater Planning

SDG - Sustainable Development Goal

SuSanA - Sustainable Sanitation Alliance

SSP - Sanitation Safety Planning (a tool created by the WHO)

ToR - Terms of Requirement

UDDT - Urine-Diverting Dry Toilet (The abbreviation ”UDDT.” might also stand for ”UDDT system”, which is a defined system option for this study)

VAPSB - Vice Ministry of Potable Water and Basic Sanitation

WHO - World Health Organization

WSP - Waste Stabilization Pond

WWTP - Wastewater Treatment Plant

WORDLIST

Criteria - refer to the five aspects of sustainable sanitation: Health, Environment, Technical function, Socio-culture and Economy (this study)

Mesophilic conditions - temperature is around 35 °C

Indicator - refers to assessment methodologies for subcriteria (this study)

Input/output products - refer to all products that flow into, within and out from the defined system options (this study)

Peri-urban area - former rural area in rapid urbanization

Subcriteria- refer to subgroups of the five criteria related to sustainable sanitation (this study)

System options - refer to the two sanitation systems defined in this study (the UDDT system and the conventional system)

Triangulation - the use of three methods in a qualitative research

Contents

1 INTRODUCTION

There has been a great progress in work aiming to achieve the Sustainable Development Goal (SDG) 6 - to ensure availability and sustainable management of water and sanitation for all. Between 2000 and 2017, the proportion of the global population using safely managed sanitation services increased from 28% to 45%. Latin America has had one of the greatest increases in safely managed sanitation services during this period (ECOSOC, 2019). Despite this progress, there is still a lack of safe water, sanitation and hand-washing facilities for billions of people worldwide. For example, 47 % of the population in Bolivia lacked access to basic sanitation services in 2012 (INE, 2015). The SDG Target 6.2, to achieve access to adequate and equitable sanitation and hygiene for all and to end open defecation by 2030, would require the double annual rate of progress to be reached on time (ECOSOC, 2019).

The SDG 6 interconnects all the seventeen existing SDGs and reaching targets within this goal mutually supports a large number of targets for other goals and vice versa (UN-Water, 2016). For example, the SDG 2 about zero hunger includes a target about sustainable food production systems, which can be supported if wastewater is safely reused in agriculture. The SDG 14, which aims at protecting the life below water, would be mutually supported. Striving to reach the SDG target 6.2 would also reinforce the work associated to social aspects such as gender equality (SDG 5), when women and girls can handle their menstrual hygiene and thereby go to work or school (UN-Water, n.d.). Supporting one SDG could also result in contradicting another SDG. When striving to reach the SDGs, the nine so called ”Planetary Boundaries” must be addressed, as explained in a report from Stockholm Resilience Center (Randers et al., 2018). The Planetary Boundaries regulate the stability and resilience of the Earth system and crossing them would increase the risk of generating large-scale abrupt or irreversible environmental changes. Two Planetary Boundaries are already at high risk of being crossed: the biogeochemical flows of nitrogen and phosphorous and the biosphere integrity of genetic diversity. Climate change and land-system change (area of forested land as a proportion of forest-covered land prior to human alteration) are at an increasing risk. The ”Doughnut of Social and Planetary Boundaries” is an approach connecting the Planetary Boundaries and the Sustainable Development Goals with an ”ecological ceiling” representing the Planetary Boundaries and a ”social foundation” representing the SDGs with twelve ”dimensions”. There is a ”safe space” under the environmental ceiling and within the social foundation, where humanity can operate safely. The Planetary Boundaries that are at increasing or high risk of being crossed are represented by ”overshoots” in the ecological ceiling (see Figure 1) (Raworth, n.d.). ”Shortfalls” are in the red area under the social foundation showing how far SDGs are from being met. All dimensions have shortfalls, including dimensions related to the SDG 6.2, for example: water, health, social equity, gender equality and income and work. The health dimension is related to the SDG Target 6.2 because the SDG Target 6.2 aims at preventing diseases from spreading and groundwater and surface water serving as drinking water sources from being polluted. The dimensions about social equity, gender equality, income and work are related to the target for example because the target aims at helping women to work outside their homes and girls to attend school, as a result of improved menstrual hygiene management.

It is clear that the sanitation sector needs to be improved as forecasts indicate that the sustainable development goal 6 will not be met by 2030, the biogeochemical flows of nitrogen and phosphorous overshoot the ecological ceiling and that dimensions in the Doughnut of Social and Planetary Boundaries, many related to sanitation, shortfall the social foundation.

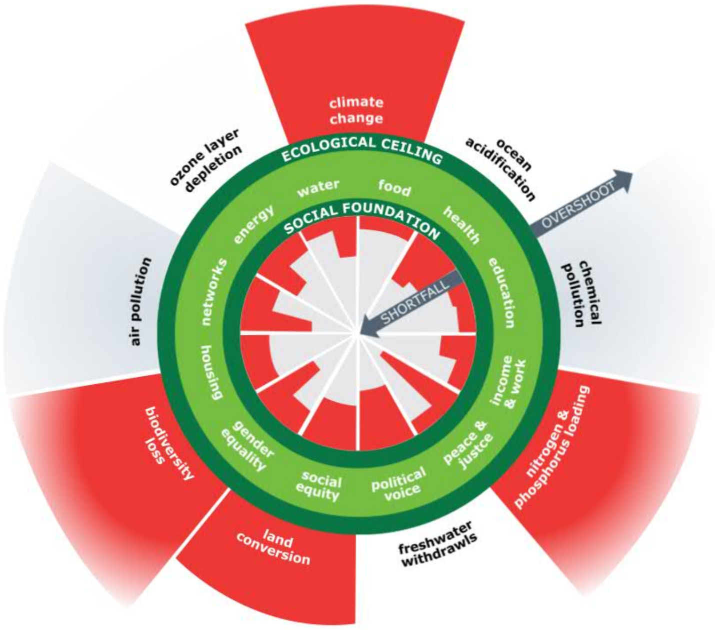

Figure 1: *The Doughnut of Social and Planetary Boundaries (Raworth, n.d.). The Planetary Boundary biogeochemical flows of nitrogen and phosphorous is described by "nitrogen and phosphorous loading". Biosphere integrity of genetic diversity is described by "biodiversity loss" and land system change is "land conversion". All these Planetary Boundaries, including climate change, overshoot the ecological ceiling in the Doughnut of Social and Planetary Boundaries.*

As sustainable sanitation management is interlinked with broad, complex systems, it is important to keep a wide perspective when striving to reach one specific SDG target. There is a great risk of actors focusing on the provision of latrines or toilets as an exclusive way of reaching availability of sanitation for all, missing the context and need for related service (Lennartsson et al., 2009). The main purpose of a sanitation system is to promote and protect human health, but for sanitation systems to be qualified as sustainable, they have to be economically viable, socially acceptable, technically and institutionally appropriate and protect the environment and natural resources (SuSanA, 2008). Sustainability assessments are a way of integrating this broader perspective when planning for sustainable sanitation systems. This study is a sustainability assessment of existing sanitation systems in El Alto, Bolivia, where 33% of the population did not have access to basic sanitation in 2012 (INE, 2015) and the sustainability of existing sanitation systems can be questioned.

1.1 PURPOSE AND AIMS

The aim of this study is to enhance knowledge about the sustainability of two existing sanitation systems in El Alto by expanding the simple ”sanitation coverage” approach and assess sustainability in a broader perspective, through a sustainability assessment. The aim is also to make the systems comparable, from a sustainability perspective.

The Stockholm Environment Institute (SEI) and the Research Institutes of Sweden (RISE) currently perform a comparative sustainability assessment of sanitation services in Bolivia for which this study function as a pre-study. The objective of the SEI/RISE project is to enhance knowledge about the sustainability of sanitation services and to influence the Bolivian sanitation sector.

1.2 RESEARCH QUESTIONS

In order to fulfill the aim of this study, the following research questions are answered:

- How do existing sanitation systems in El Alto perform, considering aspects of health, environment, technical function, socio-culture (including institutional aspects) and economy?
- What recommendations can be given for future development of sanitation systems in El Alto?

2 BACKGROUND

2.1 SUSTAINABLE SANITATION

The concept of sustainable development was launched in 1987 in a report from the World Commission on Environment and Development and was defined as: ”development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Three dimensions characterized the concept: environmental protection, economic growth and social equity. These dimensions have expanded in the field of sustainable sanitation and a widely endorsed definition among stakeholders has been defined by the Sustainable Sanitation Alliance (SuSanA). For a sanitation system to qualify as sustainable, it has to promote and protect human health, be economically viable, socially accepted, technically and institutionally appropriate and protect the environment and natural resources, as mentioned in the introduction (SuSanA, 2008).

To make the concept of sustainable sanitation systems holistic, operational and practically useful, it is beneficial to categorize it through the use of sustainability criteria and underlying subcriteria (SuSanA, 2008; Hellström et al, 2000; Balkema et al., 2002; Molinos-Senante et al., 2014; Salisbury et al., 2018; Lennartsson et al., 2009; Kvarnström et al., 2004). The terminology *criteria* is used for the overall categorization of the concept sustainable sanitation in this report and *subcriteria* is used for a detailed division of each criteria into subgroups important in a local context. *Indicator* relates to assessment methodologies for the subcriteria. Hellström et al. (2000) and Lennartsson et al. (2009) reflect the definition of sustainable sanitation by SuSanA (2008) through five main criteria: health (and hygiene), environment, economy, socio-culture (institutional and user related) and technical function. This five-criteria approach has been applied by for example Seleman and Bhat (2016) in a sustainability assessment of sanitation technologies in rural Tanzania. Another sustainability assessment of sanitation systems applying the five-criteria approach is conducted by Salisbury et al. (2018) but with the economic aspect named financial.

A subcriterion under the health criterion is in literature repeatedly reflected as the risk of infection for people in direct or indirect contact with the sanitation system. Environmental criteria can be distinguished between impact from emissions and resource use. Subcriteria related to emissions are repeatedly mentioned as the release of carbon dioxide, eutrophying agents and hazardous substances such as heavy metals, persistent inorganic compounds or medical residues. Requirement of and potential for reuse of water, energy, land and material are common subcriteria under the environmental criteria as well as the potential to reuse nutrients. Technical functionality in a short-term perspective can be reflected for example by the subcriteria level of complexity and robustness. In a long-term perspective, it can be reflected by flexibility towards a change in societal structures, vulnerability against climate change impact or durability of the technology. The socio-culture criterion in a sustainability assessment can be represented by subcriteria related to for example convenience, social acceptance, reliability, affordability and social equity. Complexity is a subcriterion that is commonly assessed under the socio-culture criterion as well. The economic criterion is reflected by the subcriteria investment costs, operation and maintenance costs and financial value of recycled products. Subcriteria that are repeatedly used under varying criteria are for example institutional capacity, information requirement, accordance with municipal plans, current legal acceptability and ease of monitoring the system.

2.2 SUSTAINABILITY ASSESSMENTS IN DECISION-MAKING PROCESSES

There are many tools for sustainability assessments. Since sustainability is a concept in constant development, the tools are designed to target specific perspectives (Poveda, 2017). They can have the objectives of investigating either a number of sustainability criteria and subcriteria or only one. Life cycle analysis (LCA) and mass flow analysis are examples of tools mainly focusing on only one criterion. Main concepts of an LCA are described in Section 2.2.1. Multi-criteria analysis (MCA) is a tool focusing on several criteria. A risk analysis can also focus on integrated assessments. MCA and an example of a risk assessment tool focusing on health aspects are briefly described in Sections 2.2.2 and 2.2.5. Open Wastewater Planning (OWP) is a planning tool suitable to apply in a decision-making process of sustainable sanitation systems implementation (Bodík & Ridderstolpe, 2008). It is based on a multi-criteria approach and is described in Section

2.2.4. Regarding institutional sustainability, there is yet no clear consensus on definitions and no uncontested indicators have been developed for assessment according to Kayaga et al. (2013). Investigating institutional sustainability is, however, basically to investigate the institutional capacity.

2.2.1 Life cycle assessment

"LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences" (Klöpffer & Grahl, 2014). The life cycle of a product interconnects processes to a system and systems that have a specific function are analyzed in an LCA in order to assess the performance of specific functions. Two important steps in an LCA are to define a "functional unit" and "system boundaries". A functional unit is introduced to make systems comparable and enables assessment of product systems consisting of both tangible products and services. The system can be described in a system flow chart, where processes are described by boxes and arrows displaying their interrelations. System boundaries define input and output products to the system and what is in it (Klöpffer & Grahl, 2014).

2.2.2 Multi-criteria analysis

"MCA is a decision-making tool developed for complex multi-criteria problems that include qualitative and (or) quantitative aspects of the problem in the decision-making process" (CIFOR, 1999). It is a way of aggregating individual opinions and providing indications for an overall performance of identified options (DCLG, 2009). Qualitative and quantitative indicators are formulated and used for rating the options against defined sustainability criteria and (or) subcriteria on a scale from for example one to five. Quantitative data is data that can be collected, analyzed and synthesized meanwhile qualitative data is mostly conceptual. A higher score represents a better performance. Weightings are made for each criteria and (or) subcriteria in order to reflect the relative importance of the criteria according to the decision-making team. The standard for an MCA is to elaborate a *performance matrix* as a final product for the assessment. A performance matrix is a table where each column represents an option and rows describe the performances of the options against each criteria or subcriteria (CIFOR, 1999). Institutional aspects such as legal framework and institutional capacity can be hard to analyze in matrix form (Lennartsson et al., 2009). A definition of institutional capacity is given in the following subsection in order to facilitate the analysis of institutional aspects in this study. An approach that allows lower scores to be compensated by higher scores is called a *compensatory MCA technique* and can for example imply calculating average scores. *Non-compensatory MCA techniques* do not allow for any compensation (DCLG, 2009). A commonly used methodology for validation of results from an MCA is conducting a sensitivity analysis. A sensitivity analysis aims at evaluating how uncertainties in results can be allocated to different sources (Saltelli, 2002).

2.2.3 Institutional capacity

Institutional capacity is by Kayaga et al. (2013) defined by five core capabilities (see figure 2). According to the authors, the most important core capability is the *capability to commit and engage*. It is about power, legitimacy, confidence, motivation and identity. Through empowerment, the ability to motivate unresponsive partners to plan, decide and engage in collaborative work is created and along with that, independent action is created. All other capabilities of institutional capacity are affected by the level of independence and empowerment from the capability to commit and engage (Kayaga et al., 2013).

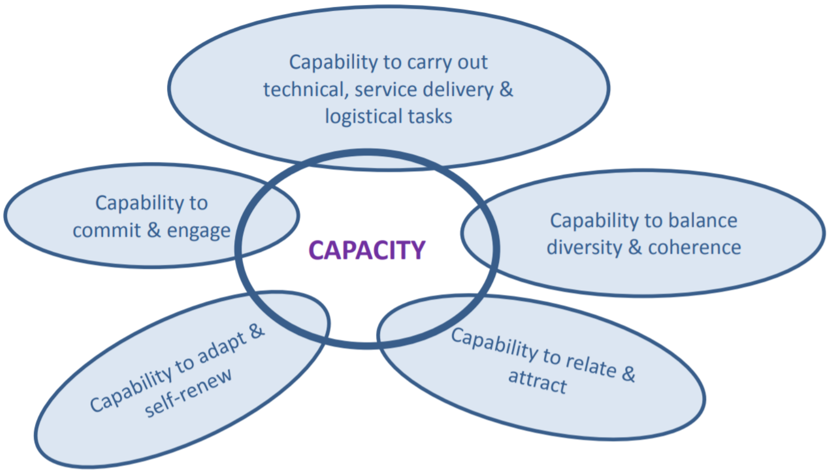

Figure 2: *The definition of institutional capacity can be described by five core capabilities, where the core capability to commit and engage is the most important one (Kayaga et al., 2013).*

Capability to carry out technical, service delivery & logistical tasks includes the abilities to produce acceptable levels of performance at the same time as creating and sustaining outcomes and adding value for the customers.

The *capability to relate and attract resources and support* is about the ability to create and sustain beneficial relationships with external actors. It is about creating legitimacy and dealing effectively with competition, politics and power relations.

The *capability to adapt and self-renew* is the ability to understand and react to global and societal changes by pro-actively preparing for change and new challenges. A resilience is developed in order to enhance continued coping with changing contexts.

The *capability to balance diversity & coherence* is what enables the leadership to manage diverse perspectives of the people in the organization. It is about developing shared short- and long- term strategies and visions (Kayaga et al., 2013).

2.2.4 Open wastewater planning

The OWP is a tool for participatory planning of sanitation services investments, based on the concept of sustainable sanitation as according to SuSanA (2008). The tool aims at presenting a sanitation solution that ”protects and promotes human health, does not contribute to environmental degradation or depletion of natural resources, is technically and institutionally appropriate, economically viable and socially accepted”. Five main steps characterize the OWP tool, which are briefly described below (Bodík & Ridderstolpe, 2008):

- Step 1: Identification of the problem and initial ideas for solutions
- Step 2: Identification of planning prerequisites and definition of system boundaries
- Step 3: Articulating Terms of Requirement (ToR) and possible technical principle solutions
- Step 4: Analysis of possible solutions
- Step 5: Choice of the most appropriate solution

Step 1: Identification of the problem and initial ideas for solutions aims at identifying the problem and delineating the current situation. It is made through the involving relevant stakeholders and initiating discussions regarding possible future targets for the sanitation situation. Relevant stakeholders to involve are for example: users; planners, regulators and political decision makers (such as municipal planning and environmental authorities); land owners; contractors (that may be involved in the construction and (or) operation and maintenance of the system); farmers; community-based organizations; neighbors with freshwater wells; people living downstream; engineers or funding agencies.

Step 2: Identification of planning prerequisites and definition of system boundaries aims to identify planning conditions within defined system boundaries. Defining system boundaries of the technical sanitation system is important because the result will reflect the objective of the assessment within these defined system boundaries. Output products from the system will depend on the input products and a system approach is developed. Important planning conditions to identify are: the number of people connected at present, and in the foreseeable future; loads of water and pollution; natural conditions (such as groundwater conditions, locations of nearby lakes and streams, precipitation patterns, topography or soil conditions); existing systems; possibilities of nutrient recycling; solid waste flows; socio-economic patterns and the cultural context; the legal framework and financing possibilities.

Step 3: Articulating Terms of Requirement (ToR) and possible technical principle solutions seeks to use the outcomes from Step 2 to express minimum levels of possible achievements that are practically and economically reasonable.

Step 4: Analysis of possible solutions aims at investigating and describing different possible solutions. System options that comply with the defined ToR should be formulated including description of technical components and cost estimations.

Step 5: Choice of the most appropriate solution is made together with involved stakeholders. One way of facilitating the choice-making is through creating a performance matrix (more about performance matrices in Section 2.2.2).

2.2.5 Health risk assessment

The World Health Organization (WHO) provides with guidelines for a safe use of wastewater, excreta and greywater (WHO, 2006). The Sanitation Safety Planning (SSP) manual is a management tool for risk assessment of sanitation systems developed by the WHO, which facilitates the implementation of these guidelines (WHO, 2016). The SSP manual focuses on safe management of human waste and analyzes the entire sanitation service chain, from a user interface to final use and (or) disposal of end products (more about the sanitation service chain in Section 2.4). Health risks are systematically identified and a guide for investment and promotion of safe sanitation management is provided based on the actual risks. A practical step-by-step guide is described, that is composed by six modules (see Figure 3).

Figure 3: *The SSP manual for risk assessment consists of six modules, starting by preparations including team formation and system description and ending up with a follow-up on the implementation of improvement plans (WHO, 2016).*

Module 1 focuses on priority areas, purpose, scope and limitations of the assessment. A multidisciplinary team is created in this module, representing all parts of the sanitation service chain. Module 2 focuses on describing the sanitation system and gathering contextual information. Potential exposure groups are identified and waste streams and associated health hazards are outlined in this module. Factors affecting the system performance and vulnerability are identified as well. In Module 3 is a list of prioritized hazardous events is created. A risk assessment table is provided consisting of a list of hazards, hazardous events, exposure groups and routes and existing control measures and their effectiveness. Module 4 is the development and implementation of an incremental plan for improvements. The plan is followed-up in Module 5 through the development of operational and verification monitoring plans and a revision. Periodical reviews are made in Module 6, assuring an up-to-date implementation of all SSP outputs.

2.3 SITE DESCRIPTION

El Alto is a peri-urban city located at high altitude on a flat plateau in the department of La Paz, the capital of Bolivia. The city is surrounded by mountains and the altitude vary between 3800 and 4000 meters above sea level (MMAyA, 2014). Due to rapid immigration of rural families, El Alto has become one of the fastest growing cities in Bolivia. The expansion has resulted in a large fraction of the population lacking adequate sanitation service and many people suffer from water borne diseases and endure unsafe disposal of excreta (Murad & Dickin, 2016). In combination with climate change, water scarcity has become an urgent issue. In 2012, there were about 850000 inhabitants in El Alto (INE, 2015a) and the city is expected to expand with almost 100.000 people until 2020 (INE, 2019). Urban and industrial discharges from El Alto have their outlet to a large extent in the Katari watershed, where Lake Titicaca is located. Lake Titicaca, the highest navigable lake in the world, is strongly eutrophicated and contain bacterial contamination originating mainly from the wastewater discharge from El Alto and agricultural activities in the watershed. The poor surface water quality in the watershed implies a risk for human health and animals having their habitat in the area (Archundia et al., 2017). Increases in temperature and changes in precipitation patterns due to the climate change are forecasted to have a strong impact on the glaciers and bofedales (high Andean wetlands) in Bolivia and the overall ecosystem. If the temperature rises by four degrees, the availability of fresh drinking water and water for irrigation will be strongly affected. Mass loss of glaciers might cause heavy flooding followed by drought in dry season. Regions at high altitude, such as El Alto, are especially affected by temperature increase due to the low pressure (Hoffman & Requena, 2012).

A rainy season occurs between October and March in El Alto, with January being the wettest month. The average precipitation in January is 136 mm. The dry period is in the period April to September with an average precipitation of 7 mm in June, the driest month. The average temperature is 7.6 °C. The period between May and August are the coldest, reaching an average temperature of -3.14 °C (GAMEA, 2019). The municipality is divided into fourteen districts (see Figure 4). Areas with over 95% coverage of sewers are the Districts 1, 2 and 3. Districts 4, 5 and 6 have over 50 % coverage and Districts 7, 8, 9, 12 and 14 have under 50 % coverage. There is in general no sewer coverage in Districts 10, 11 and 13 (GAMEA, 2019).

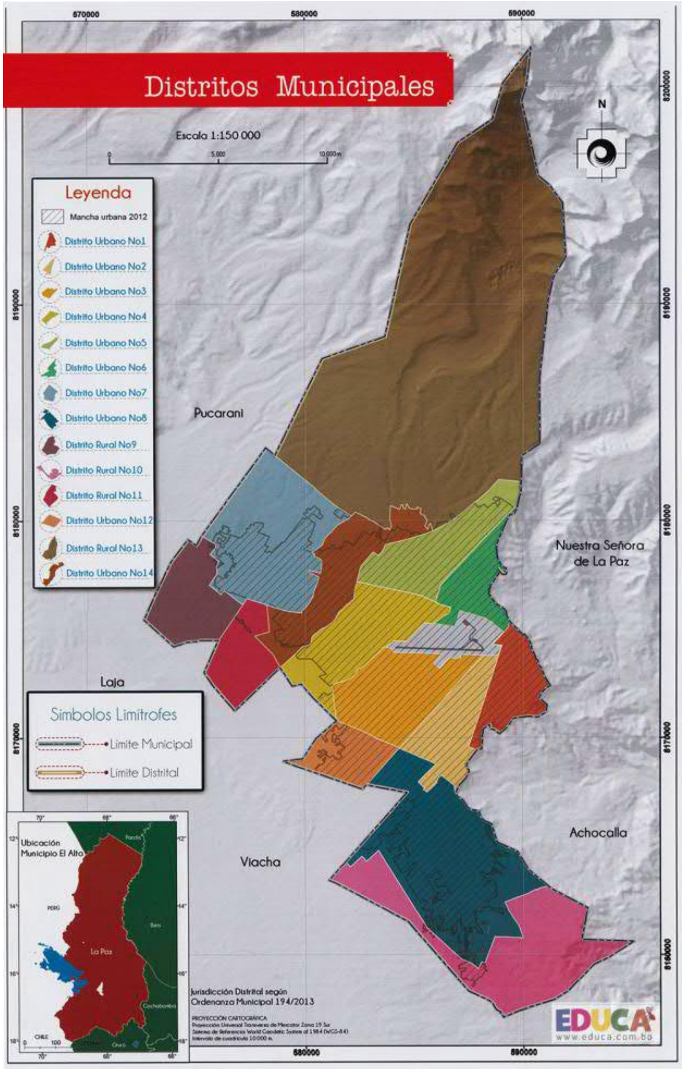

Figure 4: *Districts of en Alto in 2013 (Educa, 2013). Current situation is changed due to rapid immigration of rural families.*
Distritos municipales = municipal districts, distrito rural = rural district, distrito urbano = urban district, ubicación = location

2.4 TREATMENT TECHNOLOGIES FOR WASTEWATER AND EXCRETA IN BOLIVIA

MMAyA has developed a technical guide assigned to professionals and technicians who design and execute sanitation projects in Bolivia (MMAyA, 2010). This guide includes alternative technologies that according to MMAyA have potential develop in Bolivian contexts. Included in this guide are technologies for the entire ”sanitation service chain”. A sanitation service chain consists of: user interface; on-site collection and storage or treatment; conveyance; (semi-) centralized treatment and use and (or) final disposal of products (Tilley et al., 2014). One technology for user interface mentioned in the technical guide from MMAyA is ecological urine-diverting dry toilets (UDDTs). This technology is described in Section 2.4.1. Some on-site and off-site treatment technologies for separate treatment of urine and faeces mentioned in the guide are described in Section 2.4.2 and 2.4.3. Simplified (condominial) sewers and human-powered transportation are mentioned as alternative solutions for the conveyance phase in the technical guide from MMAyA. Waste stabilization ponds (WSPs) are a centralized wastewater treatment solution used in Bolivia. The technology is described in Section 2.4.4. For the treatment phase are also on-site septic tanks, various options for treatment of faecal sludge and artificial wetlands mentioned as suitable technologies. Aritficial wetlands can be surface constructed or subsurface-flow constructed (Tilley et al., 2014). Section 2.5 explains the nutrient dynamics in biological treatment processes in general. The manual encourages agricultural reuse of end products since urine and faeces contain large amounts of nutrients that can be recycled. Infiltration methodologies for final discharge of urine and landfill disposal of treated faeces are promoted as well.

2.4.1 Urine-diverting dry toilets

A UDDT operates without water and separates urine from faeces. Urine is separated in the front and faeces in a hole in the back of the toilet. Either a squat slab or a pedestal can be used for the separation (see Figure 5). Drying material such as lime, ash or earth should be added after defecation depending on the collection and (or) storage treatment technology.

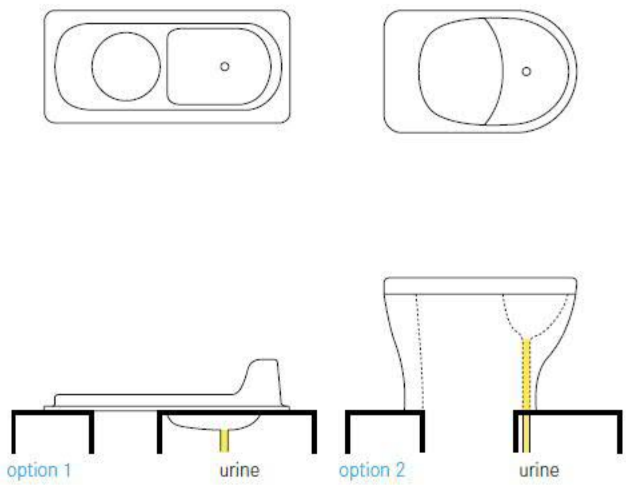

Figure 5: A urine-diverting dry toilet (UDDT) with separation of urine through a squat slab (option one) or pedestal (option two).

2.4.2 Separate treatment of faeces

Faeces separated in for example a UDDT can be treated both on-site or off-site (Rieck et al., 2012). Faeces can be collected in a chamber or in mobile recipients and a low temperature composting of the faeces begins when the faeces enter its collection recipient and is stored. Except from this primary treatment, secondary treatment is recommended if the faeces are stored in a UDDT with only one chamber for collection or if mobile recipients are used. If the UDDT has two chambers for collection - one active and the other inactive - secondary treatment is not required if the faeces aim to be disposed for landfill. To comply with the WHO guidelines for safe use of excreta in agriculture, a secondary treatment is usually necessary. Secondary treatment methods can be combined in order to reach a higher removal of pathogens. Moisture content, duration, temperature and pH value are the four most important factors influencing the treatment process. Dehydration of feaces is a natural process during storage. Pathogen loads get reduced by an increased pH during storage as alkaline cover material such as wood ash or lime increases the pH naturally (Rieck et al., 2012). Storage of faeces in two years is by MMAyA (2010) recommended as a suitable on-site treatment methodology for faeces in Bolivia. The decomposition process is aerobic and drying material is required for the drying process. Solar drying is a method for further drying of faeces mentioned by MMAyA (2010) but is not yet a proven method for complete sanitation (Rieck et al., 2012). Vermicomposting is the decomposition of faeces by earthworms and other microorganisms in mesophilic conditions. The method has not yet proven a complete sanitisation of faecal matter but is mentioned as an alternative for treatment of faeces in Bolivia by MMAyA (2010). Yadav et al (2009) describe vermicomposting as very effective when it comes to nutrients recycling and that it is a rapid and cost effective process.

2.4.3 Separate treatment of urine

Urine that in the user interface has been separated in for example a UDDT can according to MMAyA (2010) be directly infiltrated into soil or stored for pathogen reduction in order to be reused in agriculture. A cheap and practical treatment option for urine with the purpose of using urine as fertilizer is storage in closed containers. Pathogen levels can be reduced significantly. Storage time, temperature and pH are three factors determining the pathogen die-off (Rieck et al., 2012). Methods that can be used to reduce the large volumes of urine in order to facilitate a usage in agriculture, for example struvite precipitation (Andersson et al., 2016), are not discussed in the guide from MMAyA (2010).

2.4.4 Waste stabilization ponds

WSPs are large, man-made water bodies aiming to treat blackwater, greywater and (or) sludge from a neighborhood or an entire city. Three types of WSPs exist - anaerobic, facultative and aerobic (also called maturation) ponds (see figure 6) (Tilley et al., 2014). WSPs can be constructed individually or in combination. In general, the most efficient treatment is achieved when WSPs are combined in a series, starting with an anaerobic pond followed by a facultative and a maturation pond. Most of the organic matter settle as sediment in the anaerobic pond and produce sludge (Tilley et al., 2014). The anaerobic pond is deep in order for anaerobic bacteria to degrade the sludge subsequently. The facultative pond is shallower than the anaerobic pond. The bottom layer in a facultative pond is anoxic or anaerobic and solids settle and are degraded by anaerobic bacteria. Oxygen added to the top layer of the pond through natural diffusion, wind and photosynthetic activity plays an important role in the treatment process since aerobic bacteria in this layer work together with the anaerobic bacteria in order to remove more organic matter. Maturation ponds are designed for pathogen removal. They are shallow in order for solar radiation to reach the depth of the pond. Conditions are therefore aerobic and photosynthetic activity is the main process in a maturation pond. Oxygen is produced by the algae and carbon dioxide from the bacteria is consumed in a maturation pond. A pre-treatment is required to prevent larger solids from hindering the treatment in waste stabilization ponds.

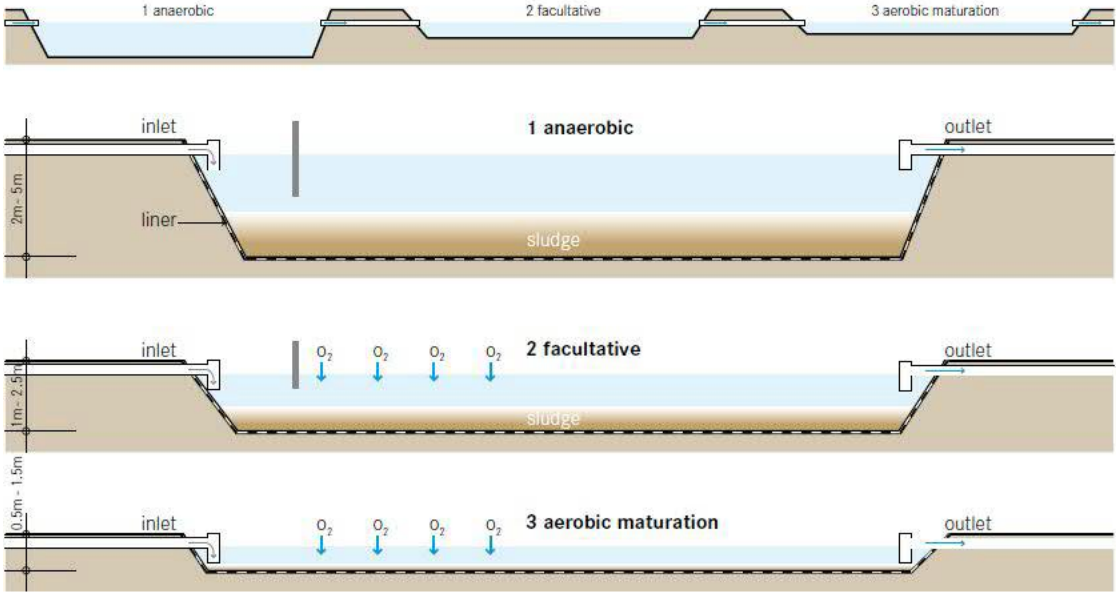

Figure 6: WSPs are commonly constructed in series, starting with an anaerobic pond and followed by a facultative and a maturation pond. Anaerobic bacteria in the anaerobic pond and the bottom layer of the facultative pond work together with aerobic bacteria in the bottom layer of the facultative pond ant the maturation pond in order to treat the incoming wastewater (Tilley et al., 2014)

2.5 NUTRIENT DYNAMICS IN BIOLOGICAL TREATMENT PROCESSES

The biogeochemical flows of nitrogen and phosphorous are at high risk of exceeding the planetary boundaries (Randers et al., 2018) (see Section 1). As wastewater flows contain large amounts of nitrogen and phosphorous (Jönsson et al., 2004), knowledge on the dynamics of these nutrients in treatment processes of urine, faeces, greywater and domestic wastewater are important to possess. The knowledge can be useful when analyzing eutrophying emissions and potential for nutrient recycling.

Compost treatment of faeces, treatment of faeces in a vermicompost and wastewater treatment in WSPs are all biological processes. Biological nitrogen removal processes include an aerobic zone and an anoxic zone (Metcalf & Eddy, 2014, pp. 797). Nitrification occurs in the anaerobic zone and denitrifying bacteria reduce nitrites and nitrates to nitrogen gas in the anoxic zone. In addition, ammonia nitrogen can assimilate into biomass or volatilize to the atmosphere in biological treatment processes and insoluble organic nitrogen sediment into bottom sludge, if the treatment process is in water (Middlebrooks et al., 1999). Phosphorous in biological treatment processes is removed by incorporation into cell biomass and subsequent accumulation into bottom sediment as sludge, if treatment process is in water (Metcalf & Eddy, 2003, p. 625). Settled solids can release phosphorous in form of phosphate into the supernatant and a cycle of release and settle of phosphorous in the sediments is created (Vendramelli et al., 2016). Temperature and pH are two factors repeatedly mentioned in literature that affect the removal mechanisms of phosphorous and nitrogen (Middlebrooks et al., 1999).

Organic matter is also an eutrophying agent because it feeds microorganisms. Organic matter removal from wastewater treatment technologies is commonly measured as Biochemical Oxygen Demand during a period of five days (BOD_5) (Metcalf & Eddy, 2014, pp. 115). It indicates the amount of dissolved oxygen consumed by microorganisms when decomposing organic matter (Metcalf & Eddy, 2014, pp. 115).

3 METHOD

This sustainability assessment is based on a multi-criteria approach similar to the OWP tool (see Section 2.2.4). The problem identification was made as in the OWP tool Step 1. Stakeholders within the sanitation sector in El Alto were contacted and involved in order to gather information about the existing sanitation systems and to aid the formulation of important subcriteria. Section 3.1 outlines the stakeholders that were involved. Step 2 in the OWP tool involves defining system boundaries and identifying planning prerequisites about the local environment and situation. Planning prerequisites are described in the background and system boundaries were defined as:

- From generation of urine, faeces and greywater, to transportation and final product for reuse, disposal or discharge.

Steps 3-5 in the OWP tool aim to describe and analyze possible sanitation system options through an MCA in order to facilitate a decision-making. Existing sanitation systems were identified and are described in Section 3.2. The two system options selected for assessment are described in the Sections 3.2.1 and 3.2.2. Criteria and subcriteria for the assessment were formulated and are described in Section 3.3 and underlying subsections. Indicators used for assessment of the subcriteria are either quantitative, qualitative and or semi-quantitative. A compensatory MCA technique was used. Detailed methodologies for assessment of the system options against each subcriteria are described under the subsections in Section 3.3. The indicators for assessment were defined through applying the functional unit explained below:

- Treatment and management of urine, faeces and greywater generated from one person during one year.

Performances of the sanitation system options were assessed against each sustainability subcriteria on a five-point scale. The scores were inserted in a performance matrix where the system options easily can be compared to each other. No weightings were made to reflect the relative importance of each criteria since no decision-making team was involved. In order to validate the results, a sensitivity analysis was conducted by testing varying input parameters for all subcriteria and analyzing changes in the results. A part of the sensitivity analysis was made separately and is described in Section 3.4.

3.1 INVOLVED STAKEHOLDERS

At a municipal level, autonomous municipal governments have the responsibility to execute sanitation projects and to provide the service through municipal lenders in El Alto. The municipal government in El Alto is named the Autonomous Municipal Government of El Alto (GAMEA). Municipal water and sanitation companies (EPSA) have the role of providing the sanitation services. In El Alto it is named EPSAS, since it is one company. Departmental autonomous governments are also executors of sanitation projects and should support the municipal governments. Public entities that are involved in the sanitation sector at a central level in Bolivia are the Bolivian Ministry of Environment and Water (MMAyA), the Vice Ministry of Potable Water and Basic Sanitation (VAPSB), the National Service for Sustainable Sanitation Services (SENASBA), the Authority of Social Control of Drinking Water and Sanitation (AAPS), the Executing Agency for Environment and Water (EMAGUA) and the Productive Social Investment Fund (FPS). MMAyA has the role of formulating, executing, evaluating and controlling political plans. VAPSB contribute to the formulation an promotion of new policies, plans and standards for development. SENASBA has the role to strengthen the management capacity of the EPSAs. The entity responsible for regulating the activities carried out by operators, juridical and private persons of sanitation services is AAPS. EMAGUA and FPS execute investment programs for development. FPS also provide with technical assistance for municipal governments (Mejía et al., 2017).

Two local organizations involved in the sanitation sector in Bolivia and El Alto are the Foundation Sumaj Huasi (FSH) and Agua Tuya. FSH develops and implements alternative sanitation solutions aiming to improve health and the environment for the most disadvantaged populations (FSH, n.d.). Agua Tuya implements participatory and innovative solutions for wastewater treatment that contribute to a sustainable management of the water cycle, protect the environment and improve people's life quality (Agua Tuya, n.d.).

In order to gather information about the sanitation situation in El Alto and to formulate important sustainability subcriteria to assess, a number of these stakeholders were contacted and involved. An interview was conducted on 11 June 2019 at AAPS with the Executive Director of AAPS, the Director of Environmental Regulation in Water Resources of AAPS and an Engineer in Wastewater Treatment Plants of AAPS. The Municipal Secretariat of Water, Sanitation, Environmental Management and Risks at GAMEA was contacted and interviewed on 23 May 2019. Unfortunately, EPSAS could not be interviewed because of complications with arranging a legally permitted interview within the set time frame. Coordinator of the Technical Area of FSH was interviewed on 22 March and 18 June 2019. The coordinator also arranged a study visit to the treatment station of theirs in El Alto on 9 April including personal meetings with other staff at FSH and three users of their sanitation system. On 25 October 2019, the Executive Director of FSH was telephone interviewed. The Chairman at the Board of Agua Tuya was interviewed on 29 August 2019. In addition, a psychologist specialized in social areas and also neighbor in El Alto District 3 was interviewed on 13 June 2019. The mentioned interviews are referred to in this report as ”interviews at institutional level”. Except from these interviews, personal meetings were held with personnel at the Embassy of Sweden and Unicef, who are both involved in the sanitation sector sector in Bolivia. These meetings are not documented interviews and are not directly referred to in the report. However, observations that were made during these personal meetings or during any of the formal interviews or the study visit, are referred to as ”observations” in the report.

Interviews were conducted at a household level with ten users of the conventional system and ten users of the UDDT system through doorstepping in June 2019. The main purpose of these interviews was to provide with information for assessment of the subcriteria related to socio-cultural and health aspects. Nevertheless, answers from the interview sessions were useful in the assessment of other subcriteria as well. Open-ended questions were asked including, for some, prearranged answers for the interviewer to conclude on. The interview session with users of the conventional system was held in households on three different streets in one neighborhood of District 3 in El Alto. Interviews with users of the UDDT system were held on six different streets in a neighborhood in District 7 in El Alto. The interviews aimed at reaching different ages and gender and all interviewees were asked about permission of being recorded and representative in this study. The interviews are referred to as ”interviews at a household level” in the report. How all interviews at the institutional and household level as well as the observations are used in this study is explained in the subsections of Section 3.3. The interview questions at a household level are found in Appendix A.

3.2 SANITATION SYSTEMS IN EL ALTO

There are three main sanitation services provided in El Alto (INE, 2015). Firstly, there is a conventional sewer network system. About 75% of the population in El Alto are connected to the sewer network according to recent information from the providers (EPSAS, 2019). The service related to the sewer network was selected as system option for the assessment and is further described in Section 3.2.1. Secondly, the two on-site sanitation technologies septic tanks and soak pits are commonly used on the outskirts of El Alto where coverage of sewer network is poor. Soak pits are either used for direct discharge of raw wastewater or for treating effluent from septic tanks (Mejía et al., 2019). About 2 % of the population in El Alto had septic tanks in 2012 and about 13 % used only soak pits (INE, 2015). These systems could not be selected as system options for the assessment because of difficulties finding information about them within set time frame of the study. On-site ecological urine-diverting dry toilets (UDDTs) are not a main sanitation service in El Alto but at least 1198 UDDT units were initially installed in areas where the coverage of sewer network and water supply have been poor. This sanitation service was selected as system option and is described in Section 3.2.2. According to INE (2015), the fraction of the population not using any of the mentioned services ”do no not have a toilet”, supposedly meaning that they practice open defecation.

3.2.1 Conventional system

The conventional system begins in the user interface, where urine, faeces and flushwater are mixed in a flush toilet. Greywater enters the system and the mixed domestic wastewater is transported in a sewer network (conveyance phase). The sewer network leads to a wastewater treatment plant (WWTP) named Puchukollo, which is localized in the western outskirts of El Alto (MMAyA, 2013). A system flow chart of the conventional system is visualized in Figure 7, where the entire sanitation service chain is visible and a grey dashed line demonstrate the system boundary defined for the assessment of the conventional system in this study. Input and output products between the phases user interface, collection and storage/treatment, conveyance, centralized treatment and use and/or disposal are shown in the figure.

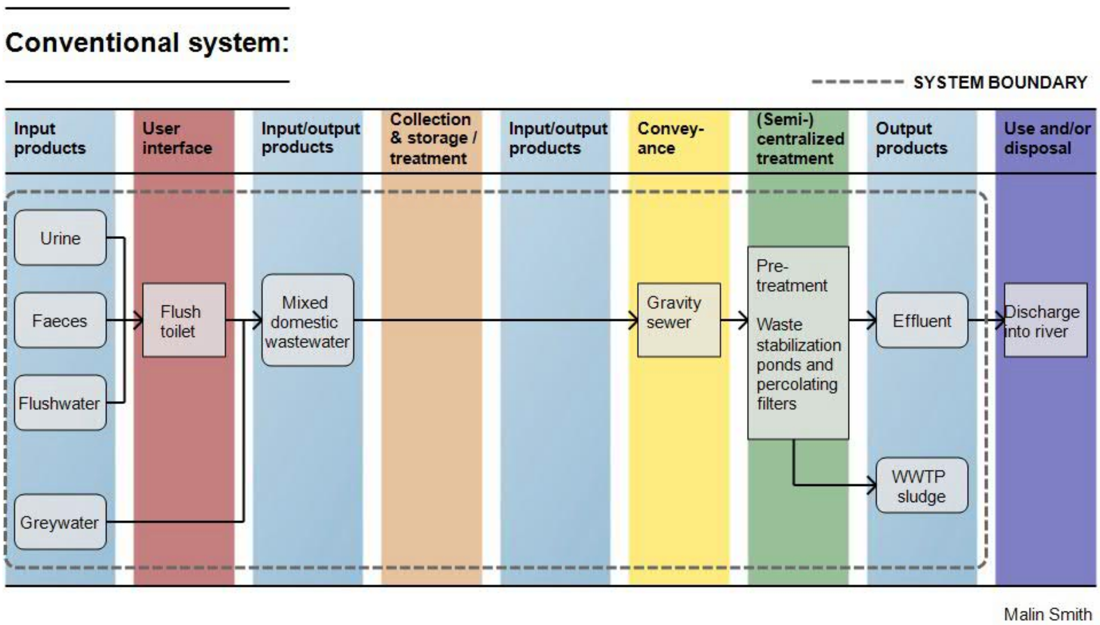

Figure 7: *Sanitation service chain for the ”conventional system”. The system boundary is marked with a grey dashed line and the system includes all input and (or) output products within this line. Input products are urine, faeces, flushwater and greywater. Output products from the system are WWTP sludge that sediment in the WSPs and effluent that get discharged to the Seco river.*

Alternative condominial sewers connect to about one per cent of the households (Programa de Agua y Saneamiento, 2001). Conventional gravity-fed sewers were assumed to be the principal technology used for the sewer network. The Puchukollo WWTP has a capacity of treating 542 liters of wastewater per second (personal communication AAPS, 11

June 2019). Bar screens and a grit chamber function as pre-treatment (MMAyA, 2013). The secondary treatment is through WSPs (WSP) in two series, and percolating filters. Treated wastewater and sludge that accumulate in the bottom sediments of the WSPs are the output products of the conventional system. The effluent gets discharged into the Seco River, which flows to Lake Titicaca. Thereby, the Puchukollo WWTP plays an important role for the prevention of contamination of the lake. Each series of ponds consists of one anaerobic pond, two facultative ponds and three maturation ponds (personal communication AAPS, 11 June 2019). Typically, WWTPs are provided with a coarse screen and a fine screen in the pre-treatment stage of WWTPs and they are either manual or mechanical (Metcalf & Eddy, 2014). Old or small WWTPs typically have manual bar screens (EPA, 2003) and since Puchukollo WWTP has operated for at least twenty years (MMAyA, 2013), an assumption was made that the bar screens are manual. Provider of the sanitation service is EPSAS, from the conveyance phase to final discharge of output products (Mejía et al., 2017). The conventional system is abbreviated ”Conv.” in the report.

3.2.2 UDDT system

The UDDT system begins with UDDTs and urinars in the user interface, where urine and faeces are separated (FSH, 2015). About 460 of the 1198 initially installed UDDT units are currently in operation according to a household survey in 2018 (Unpublished FSH, 2018). Since the first installations, the service related to the UDDT units has developed and the most modern bathroom with UDDTs is named MOSAFA-ECO. The MOSAFA-ECO version of bathrooms with UDDTs is representative for the ”UDDT system” in this study and is displayed in Figure 8. The MOSAFA-ECO unit is characterized by having only one chamber, where a mobile recipient for faeces is located. The faeces are temporary stored in this recipient. Collected urine is lead through pipes to a jerrycan located outside the bathroom, where it is temporary stored. Greywater is treated on-site in an artificial wetland constructed at the owners' yard, called a ”greywater garden” (see Figure 8). A grease trap is installed to collect solid material and grease from the shower and sink before entering the greywater garden (FSH, 2015). The owner is supposed to grow ornamental plants in this greywater garden.

The owners of the UDDT units are responsible for carrying the jerrycan(s) with urine and container(s) with faeces to the front door at scheduled day for collection and transportation to the treatment station (conveyance phase). FSH is the organization responsible for transportation, treatment and final reuse of the input products urine and faeces. They own two vehicles that run a pre-ordered route for transportation to their treatment station, which is located in the outskirts of El Alto. Urine is transferred from the jerrycans into larger tanks in the vehicles. Faeces are kept in the mobile recipients (see Figure 8). When entering the treatment station, urine is transferred to larger tanks for storage (FSH, 2015). Feaces are transferred to treatment beds for vermicomposting with subsequent solar drying (Rieck et al., 2012). Californian red worms are used for the treatment. Output products from the system are ECO humus and stored urine, which are used in agriculture (FSH, 2015). The treatment capacity at the station is almost reached when about 650 households are connected to the system (Proyecto NODO, 2014). Purified greywater is also an output product from the system, which is absorbed by ornamental plants.



(a) ***(b)*** ***(c)***


(d) ***(e)*** ***(f)***

Figure 8: *User interface, collection and storage/treatment phase and conveyance phase of the UDDT system. (a) The most modern bathroom with a UDDT constructed under governance of the FSH is named MOSAFA-ECO. (b) Urine and faeces are separated in a UDDT or in a urinar. (c) Ornamental plants in a greywater garden. (d) Mobile recipient for faeces collection and storage. (e) Jerrycan for collection and storage of urine. (f) A vehicles that in conveyance phase transport urine in a tank and faeces in mobile recipients.*

A system flow chart of the UDDT system is displayed in Figure 9, where the entire sanitation service chain is visualized including input and output products. The dashed line in grey represents the system boundary of the UDDT system defined in this study. The UDDT system is in the report abbreviated as ”UDDT.”

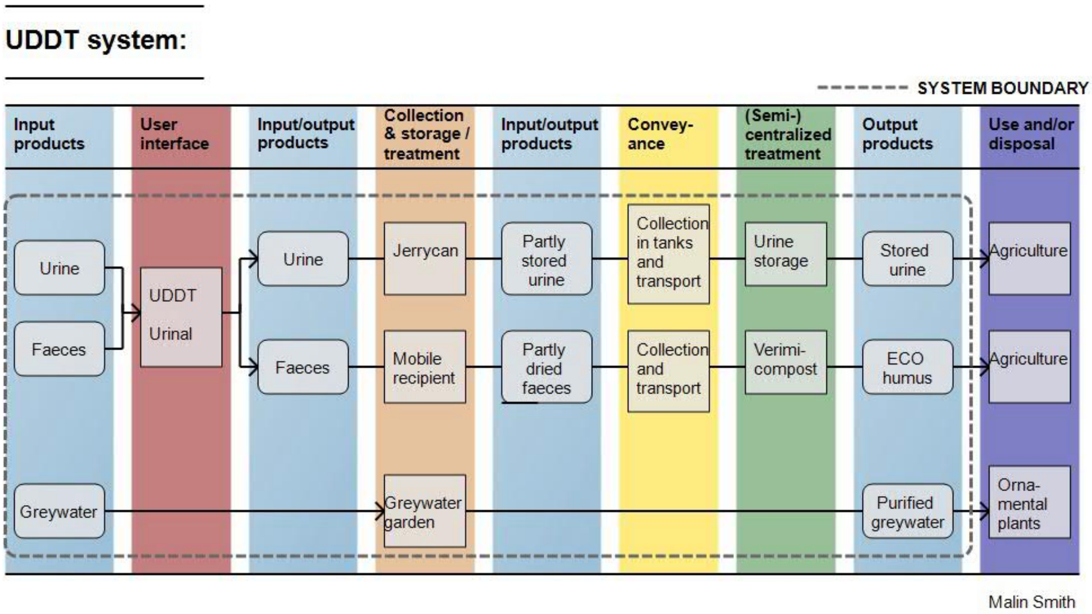

Figure 9: *The sanitation service chain for the UDDT system. The system boundary is marked with a grey dashed line and the system includes all input and (or) output products within this line. Input products are urine, faeces, flushwater and greywater. Output products from the system are stored urine and ECO-humus that is used in agriculture and purified greywater that is taken up by ornamental plants.*

3.3 PERFORMANCE ASSESSMENTS AGAINST SUSTAINABILITY CRITERIA

A five-criteria approach for sustainability was applied in this study. Subcriteria under the health, environment, economy, socio-culture and technical function criteria were formulated in order to be assessed for each system option. A framework with suggested subcriteria suitable in urban, peri-urban and rural areas compiled by Kvarnström et al. (2004) was used as guidance during the formulation. Appendix B outlines these subcriteria including suggested indicators for assessment. Additional literature was reviewed in order to define all subcriteria so that they became suitable in the local context (Balkema et al., 2002; Hellström et al., 2000; Lennartsson et al., 2009; Molinos-Senante et al., 2014; Kärrman et al., 2012; Seleman et al., 2016; Salisbury et al., 2018).

For the health criterion, the subcriterion *health risks from biological and chemical hazards* was formulated. As much as 5.9 % of the population in El Alto suffered from diarrhea and gastroenteritis in 2014 (GAMEA, 2019), probably largely due to the poor sanitation services. For the environment criterion, the subcriteria *eutrophying emissions* and *potential for nutrient recycling* were formulated. The subcriteria eutrophying emissions was selected because of the severe eutrophication in Lake Titicaca. Potential for nutrient recycling was selected because the biogeochemical flows of nitrogen and phosphorous are at high risk of exceeding the planetary boundaries. *Complexity* and *robustness* were the formulated subcriteria under the technical function criterion. Complexity, because El Alto needs technologies that can easily and rapidly expand due to the rapid immigration of rural families. Robustness was selected in order to reflect how the system options would endure climate change impacts that already have started troubling the city and to evaluate how a varying quality and quantity of input products to the system affect the system operation. Since temperature is a factor affecting the efficiency of biological treatment processes, and freezing temperatures annually occur in El Alto, the capacity to endure freezing temperatures was included in the assessment of robustness. Socio-cultural subcriteria were formulated to *satisfaction with current system*, *ease of use*, *comfort considering smell*, *reliability* and *social status* with the motive of providing information on how users would choose between the system options if they had a choice. Helgegren et al. (2018) reported from a study in Cochabamba, Bolivia, that pour-flush toilets were preferred over latrines mainly because latrines were perceived as inconvenient, unpleasant, smelly, un-hygienic and low status alternatives. Similar potential patterns in user perceptions of the system options were investigated in this study under this socio-cultural criterion. The subcriterion *institutional capacity* was formulated under the socio-culture criterion in order to provide information on how well the local capacities in form of institutions are established in El Alto. The sanitation concept must be able to reach future users (Kvarnström et al., 2004). For the economy criterion, *financial value of recycled product* was formulated as a subcriterion because an additional financial value can lower the cost for users and thereby affect the willingness to pay for the sanitation system. Construction and operation and maintenance costs are the most important subcriteria under the economy criterion but were not investigated in this study due to study limitations.

3.3.1 Health risks from biological and chemical hazards

The subcriterion health risks from biological and chemical hazards refers to the potential hazards that people in direct or indirect contact with the system options are exposed to, from generation of urine, faeces and greywater to final treatment, discharge or disposal of output products. The heath risks were investigated through a semi-quantitative risk assessment approach based on the SSP manual for safe use and disposal of wastewater, greywater and excreta (see background Section 2.2.5) (WHO, 2016). Main principles from the modules in the tool that reflect the objective of this study were selected for the assessment. Module 2 - ”Describe the sanitation system” and Module 3 - ”Identify hazards, assess existing controls and assess exposure risks” are representative and the selected main principles from these modules are outlined below:

(a) Map the system - Mod. 2

(b) Characterize the waste fractions - Mod. 2

(c) Identify potential exposure groups - Mod. 2

(d) Identify hazards, hazardous events and transmission routes - Mod. 3

(e) Identify and assess existing control measures - Mod. 3

(f) Assess and prioritize the exposure risk - Mod. 3

(a) Map the system

The system options are mapped in Figure 7 and 9 and served to help understanding the pathways of the input/output products within the systems.

(b) Characterize the waste fractions

Potential biological and chemical hazards that are associated with the input/output products displayed in Figure 7 and 9 were identified. A table provided in the SSP manual that summarizes all the potential hazards associated with typical waste fractions (input/output products) in sanitation systems was used for guidance (see Appendix C). The identified potential health hazards associated with the respective input/output products are marked with a cross in the table in Appendix D. Biological and chemical hazards imply viruses, bacteria, helminths, vector-related diseases, toxic chemicals and heavy metals.

(c) Identify potential exposure groups

In order to distinguish between groups being differently exposed to health hazards, potential exposure groups were defined. An SEI report about microbial exposure and health assessments in sanitation technologies and systems developed by Stenström et al. (2014) was used to identify the potential exposure groups. Potential exposure groups are according to Stenström et al. (2014):

- *Worker* - A person responsible for maintaining, cleaning, operating or emptying the technology.
- *User* - A person using the technology on a regular basis.
- *Community* - Anyone who lives near to or downstream from the technology and may be passively affected.

Health risks for the exposure group ”user” was excluded from this health risk assessment because the risks depend to a large extent on hygienic behavior and if the systems with flush toilets are pour flushed or cistern flushed (Stenström et al., 2014). This information was not reached.

The outcomes from mapping the system options, characterizing the waste fractions and identifying the potential exposure groups provided with enough background information for the subcriteria to be assessed through the (d) to (f) main principles selected from from Module 3.

(d) Identify hazards, hazardous events and transmission routes

In order to in detail identify who might be at risk in what occasions during operation of the system options, hazardous events were formulated. A *hazardous event* refers to a situation when someone is exposed to a hazard. One hazard may cause several hazardous events. Exposure groups may differ for the hazardous events (WHO, 2014). Hazardous events were identified by analyzing the typical operation and maintenance tasks described in Appendix E. An F diagram, which displays infectious transmission routs from excreta, functioned as guidance during the identification (see Appendix F). Typical system failures that might affect the vulnerability of the systems and thereby cause hazardous events were detected during the interviews conducted at a household level and discussed during the interviews at an institutional level. The hazardous events identified for specific exposure groups are displayed in Table 1.

(e) Identify and assess existing control measures

In order to determine how well protected those at risk are, one important control measure was identified and briefly assessed. Usage of protective equipment is according to the SSP manual an important control measure. The provision of and (or) habits regarding usage of protective equipment was assessed. The assessment was based on perspectives of the Chairman at the Board at Agua Tuya, the Coordinator of the Technical Area at FSH and the Executive director at AAPS. It was assumed that the ones at risk in the community do not use any protective equipment when (if) getting exposed to raw or partly treated input/output products from the system options.

(f) Assess and prioritize the exposure risk

The last step of the health risk assessment was to determine the highest health risk for each exposure group. A semi-quantitative approach from the SSP manual was applied, which assesses and combines the likelihood and severity of each hazardous event. The scale for likelihood ranges from very unlikely to very likely in five steps and the scale for severity ranges between insignificant to catastrophic in five steps. Appendix G shows the scales. A ”per user and year” perspective was used when assessing the likelihood. Table 2 displays how to combine the likelihood and severity score in order to determine a *risk score* and thereby a *risk level* for each hazardous event. (The risk score and level will be used for a final scoring of this subcriterion.)

Table 1: *Hazardous events associated with biological and chemical health hazards for the exposure groups workers and community in the conventional system and the UDDT system enumerated from one to eleven.*

Conventional system			
No.	**Hazardous event**	**Exposure group**	**Potential hazards**
1	Exposure to high concentration of sewer gases during inspection and maintenance tasks in conveyance phase	Worker	Noxious and flammable sewer gases
2	Exposure to raw sewage during inspection and maintenance tasks in conveyance phase	Worker	Pathogens, vector-related diseases
3	Exposure to raw sewage during manual cleaning in pre-treatment phase or sampling for laboratory analyzes in WSPs	Worker	Pathogens, vector-related diseases
4	Exposure to raw sewage during desludging of WSPs	Worker	Pathogens, vector-related diseases
5	Exposure to raw sewage from spillage in conveyance phase	Community	Pathogens, vector-related diseases
6	Exposure to raw or insufficiently treated output products in area of disposal or discharge	Community	Pathogens, vector-related diseases
UDDT system			
No.	**Hazardous event**	**Exposure group**	**Potential hazards**
7	Exposure to fresh excreta during collection and transportation of urine and faeces	Worker	Pathogens, vector-related diseases
8	Exposure to fresh excreta during recharge of urine into storage tanks and faeces into compost beds	Worker	Pathogens, vector-related diseases
9	Exposure to fresh excreta during manual operation tasks in compost beds and sampling for laboratory analyzes	Worker	Pathogens, vector-related diseases
10	Exposure to fresh excreta spillage in conveyance phase	Community	Pathogens, vector-related diseases
11	Exposure to fresh excreta or insufficiently treated output products in area of disposal or discharge	Community	Pathogens, vector-related diseases

			Severity (S)				
			Insignificant	Minor	Moderate	Major	Catastrophic
			1	2	4	8	16
Likelihood (L)	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)			< 3	4 - 6	7 - 12	13 - 32	> 32
Risk level			Very low	Low	Medium	High	Very high

Table 2: *Multiplying the likelihood with severity gives a risk score for each hazardous event. The risk level stretches from very low to very high and is based on the risk score. Modified from WHO (2016).*

The likelihood of the hazardous events were assessed through a triangulation between interviews with involved stakeholders and interviews at a household level, observations during a study visit to El Alto and existing literature (Tilley et al., 2014; Stenström et al., 2011; MMAyA, 2010; MMAyA, 2014; USEPA, 2002). The interviews at household level provided with information regarding typical system failures occurring locally and their likelihood. Stakeholders involved in the assessment of likelihood were the Chairman of the board at Agua Tuya, the Coordinator of the Technical Area at FSH and the Executive Director at AAPS. The chairman at Agua Tuya helped motivating conclusions based on the household interviews. The validation of protective equipment usage (made in (e)) was used in favor of the assessment of likelihood. If there was a policy regarding usage of protective equipment, the likelihood for the hazardous events involving workers were assessed lower than if such a policy was lacking. The Executive Director of AAPS contributed by pointing out that an important maintenance task had never been realized at the Puchukollo WWTP. This fact affects the likelihood of the hazardous event related to that maintenance task. The likelihood of hazardous events for the community was assessed through 1) the risk of leakage from products containing faeces in the conveyance phase and 2) the quality of output product discharged downstream or into soil. The severity of the hazardous events were assessed from existing literature (Stenström et al., 2011; WHO, 2006; Wisconsin DHS, 2017; Tilley at al., 2014).

The risk event with highest risk level determined the final score for the subcriterion health risks from biological and chemical hazards. The sanitation systems were scored separately for each exposure group. A four-point scale defined in the SSP manual was used for the scoring, but a ”very low risk” was added in order to make it a five-point scale:

- 1 if the highest risk score was above 32 (very high risk)
- 2 if the highest risk score was between 13-32 (high risk)
- 3 if the highest risk score was between 7-12 (medium risk)
- 4 if the highest risk score was between 3-6 (low risk)
- 5 if the highest risk score was under 3 (very low risk)

3.3.2 Eutrophying emissions

The subcriterion eutrophying emissions refers to the total nitrogen, total phosphorous and BOD_5 discharge to receiving waters or groundwater recharge from domestic households. It was assessed quantitatively in kilograms per person and year through estimating the composition of input products to the system options and analyzing accessed data on the output products. Relevant data, assumptions and calculations are shown in Appendix J.

The national standard for effluent discharge of BOD_5 in Bolivia is 80 mg O_2/l and the standard for discharge of nitrogen is 4 mg/l as ammonia according to the National Law of the Environment no. 1333 from 1992. There is no national standard for discharge of phosphorous. Agua Tuya and the Bolivian Institute for Standardization and Quality (IBNORCA) currently have an ongoing discussion about renewing the national standard for nitrogen to 15 mg/l (total nitrogen) and adding a national standard for total phosphorous discharge of 2 mg/l. Chairman of the board at Agua Tuya confirmed this in an email received on 27 October 2019. The new suggested national standards for discharge of nitrogen (15 mg/l) and phosphorous (2 mg/l) and the already established standard for discharge of BOD_5 (80 mg/l) created a basis for the scoring of system options against the subcriterion eutrophying emissions. The standards were converted to kilograms per person and year assuming a wastewater flow of 83 l/p,d (see Table 3). Scoring was made according to:

- 1 if discharge of all three eutrophying agents exceeded suggested standards
- 2 if discharge of two eutrophying agents exceeded suggested standards
- 3 if discharge of one eutrophying agent exceeded the suggested standard
- 4 if discharge of all three eutrophying agents met suggested standards (low margin allowed)
- 5 if discharge of all three eutrophying agents met suggested standards with large margins

Table 3: *Suggested effluent standards for total nitrogen, total phosphorous and BOD_5 in Bolivia converted to kilograms per person and year assuming a wastewater flow of 83 l/p,d.*

	Standards used for scoring
N [kg/p,y]	0.45
P [kg/p,y]	0.06
BOD_5[kg O_2/p,y]	2.42

Estimations on the per capita mass flow rates of nitrogen, phosphorous and BOD_5 in input products to the system options show, for example, that urine contain most of the nitrogen and phosphorous (see Table 4). Table 5 displays the removal efficiency of the eutrophying agents in the treatment facilities.

Table 4: *Per capita mass flow rates of nitrogen, phosphorous and BOD_5 in input products to the system options and in mixed domestic wastewater.*

	Urine	Faeces	Excreta	Greywater	Mixed domestic wastewater
N [kg/p,y]	2.76	0.38	3.13	0.23	3.36
P [kg/p,y]	0.26	0.15	0.41	0.06	0.47
BOD_5 [kg O_2/p,y]			16.43	5.44	21.86

Mass flow rates of BOD_5 in faeces and urine are left blank because they were not estimated.

Table 5: *Removal efficiency of nitrogen, phosphorous and BOD_5 in treatment facility of the respective system options.*

	Conv.	UDDT.
Removal efficiency of N [%]	30	93* and 30**
Removal efficiency of P [%]	33	87* and 30**
Removal efficiency of BOD_5 [%]	83	75* and 85**

* Removal efficiency from separating excreta from greywater.
** Removal efficieny from treatment in greywater garden.

3.3.3 Potential for nutrient recycling

The subcriterion potential for nutrient recycling refers to the per capita mass flow rates of total nitrogen and total phosphorous in output products considered to have a recycling potential, in kilogram per person and year. The assessment was made quantitatively. Output products considered to have nutrient recycling potential are named recycled products in this report and imply the following products:

- ECO humus from the UDDT system
- Stored urine from the UDDT system
- Greywater from the greywater garden in the UDDT system
- WWTP sludge from the WSPs in the conventional system

Effluent water from the WWTP in the conventional system was not considered to have a recycling potential because the effluent is directly discharged into receiving waters. A structure for collection does not exist.

A mass flow analysis was conducted for nitrogen and phosphorous dynamics within the system options in order to distinguish for how much nitrogen and phosphorous that end up in the recycled products. The accessed data did not cover for all information required for the calculations and therefore, literature was used to make estimations. Calculations on mass flow rates and estimations are described in Appendix K. Scoring was made according to:

- 1 if 0-20 % of nutrients were in output products with recycling potential
- 2 if 21-40 % of nutrients were in output products with recycling potential
- 3 if 41-60 % of nutrients were in output products with recycling potential
- 4 if 61-80 % of nutrients were in output products with recycling potential
- 5 if 81-100 % of nutrients were in output products with recycling potential

An optimization analysis was conducted for this subcriterion. For an optimized potential for nutrients recycling of the conventional system, the same calculations that are made in Appendix K were made, but a removal efficiency suggested by MMAyA (2010) was used instead of calculating it from accessed data. Accessed information from the FSH on the highest measured concentration of nitrogen and phosphorous in stored urine and ECO humus was used to obtain an optimized potential for nutrients recycling for the UDDT system. Calculations were made as in Appendix K.

3.3.4 Technical functionality

Complexity

Complexity is a subcriterion that in this study refers to the frequency of high skills tasks required for operation and maintenance in the conveyance and treatment phase. Operation and maintenance tasks are described in Appendix E. ”High skill tasks” are tasks that require someone that should have knowledge on biological treatment processes. Operation and maintenance tasks considered to require knowledge on biological treatment processes are inspections, sampling for manual monitoring, direct manual monitoring, sampling for laboratory analyses, removal of sludge from WSPs and safe handling of sludge, ECO humus and stored urine. The system options were scored:

- 1 if three or more O&M tasks required high skills weekly
- 2 if two O&M tasks required high skills weekly
- 3 if one O&M task required high skills weekly
- 4 if O&M tasks required high skills several times a year
- 5 if O&M tasks required high skills yearly or more rarely

The frequencies of identified high-skill tasks were investigated qualitatively, based on literature (Tilley et al, 2014; Mara, 2003; Metcalf & Eddy, 2003; Proyecto NODO, 2014; personal communication FSH, 2019; USEPA, 2002). Supplemental information was received during the interview with the Executive Director at AAPS and the telephone interview with the Executive Director at FSH.

Robustness

Robustness is the subcriterion referring to the *capacity to endure shock loads* and *resilience against climatic variations* at a conveyance and treatment phase. Five indicators were used for the assessment: 1) capacity to endure shock loads - quantity of input products, 2) capacity to endure shock loads - quality of input products, 3) resilience against cold climate, 4) resilience against climate change impact - flooding and 5) resilience against climate change impact - drought. The capacity to endure shock loads in terms of quality of input products was investigated as how the systems are expected to respond if for example larger solids, grease or chemical waste enter the system. A suitable indication for how the system endures chemical waste was to look for its appropriateness to treat industrial wastewater. Industrial wastewater contains chemicals. The capacity to endure shock loads in terms of quantity of input products was assessed by envisioning a flow of input products ten times higher than normal during a period of one week. A cold climate referred to the climatic weather conditions in El Alto between May and August, when average temperatures reach -3.14 °C. The technology should thereby be capable of enduring freezing temperatures. To evaluate the resilience against climate change impact - flooding, the risk of seepage and overflow in the system and subsequent consequences were investigated. The system resilience against drought was evaluated as how the system option operates without access to water.

All indicators were scored separately and a rounded off average of the first two indicators set a score for the capacity to endure shock loads whilst a rounded off average value of the last three set a score for the resilience against climatic variations. The scoring reflects the degree of impact on the system operation and was made according to:

- 1 if the entire system risked to be out of service or not having capacity to treat incoming waste
- 2 if parts of the system risked to be out of service or not having capacity to treat incoming waste
- 3 if the system was expected to continue operating but with temporary operating errors, affecting the treatment capacity negatively
- 4 if the system was expected to operate but with temporary operating errors, affecting the treatment capacity minimally
- 5 if the system was not expected to be affected

The indicators were assessed qualitatively through existing literature (Sasse et al., 1998; Tilley et al., 2014; Proyecto NODO, 2014; EAWAG, 2019; EAWAG 2019a; Cossio et al., 2017). Supplemental information was obtained during the telephone interview with Executive Director at the FSH and observations from the study visit to the treatment station of FSH.

3.3.5 Socio-culture: user

Ten users of the conventional system and ten users of the UDDT system in El Alto were localized and interviewed in order to assess the socio-culture criterion in a qualitative way from a user perspective. Thereby, the information received come from people that are already familiar with the system options. Five questions were asked the interviewees and the answers formed five subcriteria. The subcriteria reflect how satisfied the users are with their current systems, how easy their system are to use, how comfortable they are considering potential smell, how reliable the systems are perceived to be and the social status associated with their bathrooms. The questions were open-ended but had pre-defined answers for the interviewer to judge, which all indicated a score. Once a pre-defined answer was selected, it was double-checked and agreed with the interviewee. An average score from the ten interviews was rounded of and determined the final score for the system options against the respective subcriterion. The following subsections show how the assessment was made and Appendix A shows the interview questions.

Satisfaction with current system

The subcriterion satisfaction with current system refers to how satisfied interviewed users are with the system options. Scoring was made according to:

- 1 if: not satisfied at all
- 2 if: not so satisfied
- 3 if: neither dissatisfied nor satisfied
- 4 if: satisfied
- 5 if: very satisfied

Ease of use

The subcriterion ease of use refers to how easy or complicated interviewed users find the system options when it comes to operation and maintenance at a household level. Scoring was made according to:

- 1 if: very complicated
- 2 if: complicated
- 3 if: neither complicated nor easy
- 4 if: easy
- 5 if: very easy

Comfort considering smell

The subcriterion comfort considering smell refers to how interviewed users perceive potential malodors deriving from the system options near their house. Scoring was made according to:

- 1 if: very uncomfortable
- 2 if: uncomfortable
- 3 if: neither uncomfortable nor comfortable
- 4 if: comfortable
- 5 if: very comfortable

Reliability

The subcriterion reliability refers to how reliable interviewed users of the system options find their systems with respect to its operation. Scoring was made according to:

- 1 if: very unreliable
- 2 if: unreliable
- 3 if: neither unreliable nor reliable
- 4 if: reliable
- 5 if: very reliable

Social status

The subcriterion social status refers to the local perceptions of social status in El Alto that are related to a certain type of bathroom. A family's social status in El Alto partly depend on the material of the house, including the material of walls and floor in the bathroom, as a psychologist specialized in social areas and neighbor in El Alto District 3 explained during an interview. The interviewees at a household level were asked about which material their bathroom has and scoring was made according to recommendations from the specialist:

- 1 : not applicable (very low status)
- 2 if: cement / adobe (low status)
- 3 if: brick or brick/tile/ceramic mixed with cement/adobe (medium status)
- 4 if: tile/ceramic (high status)
- 5: not applicable (very high status)

Scores for very low and very high status in the area of concern was not applicable according to the specialist.

3.3.6 Institutional capacity

The subcriterion institutional capacity refers to how well the system options perform considering three out of five main concepts of institutional capacity defined by Kayaga et al (2013) (see all five in the background in Section 2.2.3). The remaining two main concepts could not be assessed because of complications with arranging an interview with EPSAS within time frame of the study. The overall assessment of institutional capacity is limited due to lack of information and should therefore not be seen as a comprehensive assessment of institutional capacity. However, it gives a good hint of important arguments which can benefit further investigations of institutional capacity. The three core capabilities investigated were:

- Capability to carry out technical, service delivery and logistical tasks
- Capability to adopt and self-renew
- Capability to relate and attract resources and support

A tool for assessment of institutional capacity developed by NORAD (2000) was used in order to assess the institutional capacity of the three mentioned core capabilities, qualitatively. This tool was chosen because it aims to evaluate institutional capacity in universal international development interventions for water utilities. It defines twelve indicators under which a number of statements describe tasks an institution is obliged to carry out (see description of all indicators in Appendix M. These indicators are in this tool scored separately on a scale from zero to three, reflecting their level of agreement with each statement. Zero points mean no or missing agreement and three points mean agreement to a large extent. The indicators that reflect the concepts of the three core capabilities were selected and investigated for each system option. The system options were scored on a redefined scale from zero to two points. It was redefined because obtained information was not sufficient for a four-point scale evaluation. The indicators formulated and the redefined scale for assessment of all indicators are explained in Table 6. A triangulation between interviews with involved stakeholders and users, observations from the interviews and existing literature was used in the assessment. Where literature and stakeholders participated in the assessment is explained in Figure 6. The final scoring for the performance of each system option was based on the sum of points gathered from the indicators, according to:

- 1 if sum of points from indicators were bewteen 0 and 4
- 2 if sum of points from indicators were between 5 and 8
- 3 if sum of points from indicators were between 9 and 12
- 4 if sum of points from indicators were between 13 and 16
- 5 if sum of points from indicators were between 17 and 20

A conventional sanitation system is known and recognized by general and public institutions (Lennartsson et al., 2009). Legal and regulatory reforms, for example, are factors that create a formal institutional recognition of this kind and strengthen the institution. Independent action and empowerment is what one of the five core capabilities that is not assessed implies, the core capability to commit and engage. This core capability is the most important one according to Kayaga et al (2013), and a compensation for the exclusion of this core capability was made. The conventional system was given one score higher than the score resulting from the assessment of institutional capacity.

Core capability (Kayaga et al., 2013)	Indicator (NORAD, 2000)	Representative indicator - interpretation for this study	Score 0	Score 1	Score 2	Data source
Capability to carry out technical, service, delivery and logistical tasks *- Abilities to produce acceptable levels of performance at the same time as creating and sustaining outcomes and adding value for the customers.*	***Infrastructure*** *- Buildings and equipment are adequate. Infrastructure is well-maintained.*	***Compliance of long-term maintenance tasks*** *- Required long-term maintenance tasks related to sludge or excreta...*	...are not fulfilled	...are fulfilled until present, but insecure in near future	...are fulfilled until present and in near future	(Tilley et al., 2014; VAPSB, n.d.); Interviews institutional level
	Performance *- The institution meets its short-term targets. The institution delivers its "products" with reasonable costs.*	***Short/term targets*** *- Discharge of coliforms into recieving waters...*	...exceed national limits	... meet national limits, but other short-term targets of institution are not reached	... meet national limits, and other short-term targets of institution are reached	Interviews institutional level
	Financial resources *- Resources are available to cover major recurrent and capital expenditures. The institution is to a large extent self-sustained.*	***Financial resources*** *- Financial resources to cover major recurrent and capital expenditures...*	...are not available	...are available but might be insecure, since institution is not self-sustained	...are available and secure, and institution is self-sustained	(Sumaj Huasi, 2015); Interviews institutional level
	Personnel *- The supply of qualified personnel is adequate. The personnel are considered competent. Personnel policy is established/adequate.*	***Supply of personnel*** *- Supply of competent and qualified personnel...*	...is not considered adequate according to stake-holder	... is not known by stake-holder, but personnel reach 50% of interviewed users within one day if acute service is requested	...is considered adequate according to stake-holder	Interviews household level; Interviews institutional level
Capability to adapt and self-renew *- Ability to understand and react to global and societal changes by pro-actively preparing for change and new challenges. A resilience is developed in order to enhance continued coping with changing contexts.*	***Purpose and Strategy*** *- Purpose and strategies for the institution are clear. Purpose and strategies are relevant to country needs.*	***Adaptation to country needs*** *- Adaptation to rapid immigration and counteracting contamination in receiving waters...*	...is not reflected in the purpuse or the strategies	...is reflected in the purpose but not in the strategies	...is reflected in the purpose and the strategies	(EPSAS, 2019; GAMEA, 2019; Sumaj Huasi, 2015); Interviews institutional level
	Institutional competence *- The institution has the required skills to carry out its operations without external assistance. The institution has the required competence to support new projects.*	***Instititional competence*** *- The required competence provided by the institution itself support...*	...neither operational tasks nor new projects	...operational tasks but not new projects	...operational tasks and new projects	Interviews institutional level
Capability to relate and attract resources and support *- Ability to create and sustain beneficial relationships with external actors. It is about creating legitimacy, deal effectively with competition, politics and power relations.*	***Linkages and Networks*** *- The institution is linked to relevant national/international partners. Donors/financing institutions provide predictable support.*	***Linkages to partners*** *- Stakeholders involved in the sanitation sector in Bolivia are linked to the institution...*	...to a small extent (little or no communication)	...to a moderate extent (communication but with difficulties)	...to a large extent (communicaiton without difficulies)	Interviews institutional level; observations
		Support from donors *- Donors or financing institutions provide...*	...no predictable support	...partly predictable support	...predictable support	(Sumaj Huasi, 2015); Interviews institutional level
	Participation and Legitimacy *- Strong ownership and participation characterize the institution. External stakeholders respect and have confidence in the institution.*	***Participation among users*** *- Users have a chance of participating...*	...to a small extent (there is no number to call nor any office to visit)	...to a moderate extent (users know about a number to call or office to visit)	...to a large extent (the institution is in regular contact with users instead of users having to seek)	Interviews household level; observations
		Respect from other institutions *- Other institutions involved in the sanitation sector have confidence in the institution...*	...to a small extent (lack of confidence is observed during several interviews and (or) informal meetings with institutions)	...to a moderate extent (lack of confidence is observed during one interview or meeting with institutions)	...to a large extent (no lack of confidence is observed during interviews and (or) meetings with institutions)	(Mejía et al., 2017); interviews institutional level; observations

Table 6: *The methodology for assessment of institutional capacity is developed from the Kayaga et al. (2013) definition of institutional capacity and indicators from NORAD (2000). "Interviews institutional level" refers to interviews with either GAMEA, AAPS, FSH or Agua Tuya. "Interview household level" refers to the interviews conducted with ten users of the conventional system and ten users of the UDDT system. "Observation" refers to observations during interviews or personal meetings with involved stakeholders.*

3.3.7 Financial value of recycled product

The subcriterion financial value of recycled product refers to the per capita mass flow rates of nitrogen and phosphorous per year in output products that have a financial potential, multiplied with the local price of a common fertilizer in El Alto in terms of nitrogen and phosphorous (Richert et al., 2010). The assessment was made quantitatively. Products considered to have a financial potential were the following, with the motivation that they can all be sold on the local market, theoretically:

- WWTP sludge (Conv.)
- ECO humus (UDDT.)
- Urine (UDDT.)

Nevertheless, there should be a demand for the specific recycled product for it to practically have a financial value. In this study, the system options were scored:

- 1 if the products valued under 20 Bs/p,y
- 2 if the products valued between 20-29 Bs/p,y
- 3 if the products valued between 30-39 Bs/p,y
- 4 if the products valued between 40-49 Bs/p,y
- 5 if the products valued 50 Bs/p,y or more

The financial value of nitrogen in El Alto was calculated from information compiled by FSH (2015) on the locally available chemical fertilizer "Urea 46%" and its price on the local market in El Alto. Urea 46% is a crystalline solid with a total nitrogen content of 46% (Nuroil, n.d.). The financial value of phosphorous was calculated from information received from the website of the Ministry of Productive Development and Plural Economy. Information on the average price on the local market for the chemical fertilizer DAP 18-46-0 in Bolivia was used (Insumos Bolivia, n.d.). DAP 18-46-0 is the phosphate fertilizer most widely used among farmers (Mosaic, 2018) and normally contains 46 % available phosphate, 42 % water soluble phosphate and 18% total nitrogen. The zero stands for no potassium content (Mosaic, 2019). Complete calculations for the financial value of recycled products are attached in Appendix N.

3.4 SENSITIVITY ANALYSIS REGARDING DEGREE OF CONNECTION TO TREATMENT FACILITY

When identifying the sanitation systems in El Alto it was assumed that all input products get transported to the treatment phase. Along with the study, it was detected that a great part of the input products are not transported to the treatment phase neither in the conventional nor the UDDT system (MMAyA, 2013; Proyecto NODO; personal communication AAPS, 11 June 2019; FSH, 2018). Therefore, this part of the sensitivity analysis aimed at concluding for how large fractions of the input products that are not transported to treatment phase and what consequences this entails.

4 RESULTS AND DISCUSSION

4.1 PERFORMANCES OF SYSTEM OPTIONS AGAINST SUBCRITERION

In the following subsections, performances of the system options are presented and discussed against all sustainability subcriteria. The scores are presented in parentheses on a five-point scale, where a lower value means a lower performance and a higher value means a higher performance.

4.1.1 Health risks from biological and chemical hazards

In order to conclude for potential health risks from biological and chemical hazards within the system options, likelihood and severity of specific hazardous events were assessed. The assessment of likelihood is made in Appendix H. Concerning severity, the main hazards of being exposed to the input/output products in the system options were concluded to derive from faeces or faecal contamination (cross-contamination). The main hazard of urine is misplaced faeces in the urine. Few pathogenic organisms are excreted with urine. Faecal cross-contamination is also the main hazard of greywater (Stenström et al., 2011; WHO, 2006). Faecal pathogens transmitting through the environment mainly cause gastro-intestinal symptoms such as diarrhea, vomiting and stomach cramps. However, several pathogenic organisms may also cause more severe symptoms in other organs (Stenström et al., 2011; WHO, 2006). Vector-borne diseases such as malaria, lymphatic filariasis and dengue commonly emerge in tropical regions where there is rapid urbanization and poor sanitation (Knudsen & Slooff, 1992). However, El Alto has a semi-arid climate and malaria for example, can not be transmitted at altitudes above 2000 to 2500 meters above sea level (Bishop & Litch, 2000). With the motivation that El Alto is located 4000 meters above sea level, symptoms from vector-born diseases were not prioritized. Diarrhea, vomiting and stomach cramps were concluded be the severity of all hazardous events implying exposure to raw sewage, excreta or greywater. Hazardous events implying exposure to these input/output fractions were assessed to have a moderate (4) severity. Only one hazardous event, which implies exposure to highly accumulated noxious and flammable gases, was evaluated differently. The severity was assessed to catastrophic (16). Sewer gases produced in the man holes of a sewer network can in high concentrations lead to consequences such as unconsciousness, explosion, fire or even loss of life (Wisconsin DHS, 2017). The Tables 7 and 8 show identified hazardous events, which hazards they derive from and for which exposure group, transmission routs, validation of existing control measure, likelihood of occurrence of each hazardous event, severity of the hazardous events, risk score and associated risk level.

Conventional system										
Hazard identification					Existing control		Risk assessment			
No.	Hazardous events	Exposure group	Potential hazards	Transmission	Control measure	Validation of control	L*	S	Risk score	Risk level
1	Exposure to high concentration of sewer gases during inspection and maintenance tasks in conveyance phase	Worker	Noxious and flammable sewer gases	Inhalation or skin penetration	Protective equipment	Provided protective equipment might not be adequate	1	16	16	High
2	Exposure to raw sewage during inspection and maintenance tasks in conveyance phase	Worker	Pathogens, vector-related diseases	Ingestion, mosquito bites	Protective equipment	"Industrial safety and occupational health area" exists for control	3	4	12	Medium
3	Exposure to raw sewage during manual cleaning in pre-treatment phase or sampling for laboratory analyzes in WSPs	Worker	Pathogens, vector-related diseases	Ingestion, mosquito bites	Protective equipment	"Industrial safety and occupational health area" exists for control	3	4	12	Medium
4	Exposure to raw sewage during desludging of WSPs	Worker	Pathogens, vector-related diseases	Ingestion, mosquito bites	Protective equipment	"Industrial safety and occupational health area" exists for control	1	4	4	Low
5	Exposure to raw sewage from spillage in conveyance phase	Community	Pathogens, vector-related diseases	Ingestion, mosquito bites	n/a	n/a	5	4	20	High
6	Exposure to raw or insufficiently treated output products in area of disposal or discharge	Community	Pathogens, vector-related diseases	Ingestion, mosquito bites	n/a	n/a	4	4	16	High

Table 7: *Results for the conventional system from the health risk assessment of subriteria health risks from biological and chemical hazards. Six hazardous events for the exposure groups workers and community, deriving from potential health hazards, are enumerated. likelihood (L) and severity (S) are presented for each hazardous event and their product, that account for a risk score and associated risk level represented with colors. The control measure usage of protective equipment is presented together with a brief validation. n/a means not applicable.*
**Assessment is found in Appendix H.*

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UDDT system										
Hazard identification					Existing control		Risk assessment			
No.	Hazardous events	Exposure group	Potential hazards	Transmission	Control measure	Validation of control	L*	S	Risk score	Risk level
7	Exposure to fresh excreta during collection and transportation of urine and faeces	Worker	Pathogens, vector-related diseases	Ingestion, mosquito bites	Protective equipment	Strict policy regarding usage of protective equipment	3	4	12	Medium
8	Exposure to fresh excreta during recharge of urine into storage tanks and faeces into compost beds	Worker	Pathogens, vector-related diseases	Ingestion, mosquito bites	Protective equipment	Strict policy regarding usage of protective equipment	3	4	12	Medium
9	Exposure to fresh excreta during manual operation tasks in compost beds and sampling for laboratory analyzes	Worker	Pathogens, vector-related diseases	Ingestion, mosquito bites	Protective equipment	Strict policy regarding usage of protective equipment	3	4	12	Medium
10	Exposure to fresh excreta spillage in conveyance phase	Community	Pathogens, vector-related diseases	Ingestion, mosquito bites	n/a	n/a	2	4	8	Medium
11	Exposure to fresh excreta or insufficiently treated output products in area of disposal or discharge	Community	Pathogens, vector-related diseases	Ingestion, mosquito bites	n/a	n/a	2	4	8	Medium

Table 8: *Results for the UDDT system from the health risk assessment of subriteria health risks from biological and chemical hazards. Five hazardous events for the exposure groups workers and community, deriving from potential health hazards, are enumerated in following order after the hazardous event in the conventional system. likelihood (L) and severity (S) are presented for each hazardous event and their product that acccount for a risk score and associated risk level represented with colors. The control measure usage of protective equipment is presented together with a brief validation. n/a means not applicable.*
**Assessment is found in Appendix H.*

Table 9 shows the highest risk score and associated risk level for each exposure group (which determined the final scores for the system options against this subcriterion). The highest risk scores for the hazardous events within the conventional system are 16 for workers and 20 for the community, both implying a *high* risk level. Thereby, the system performance received score (2) for both workers and the community. The hazards derive mainly from poorly managed sewer lines causing regular overflows of untreated wastewater in the streets during rainy season in El Alto. Exposure groups within the UDDT system are as a maximum exposed to a medium risk level. The UDDT system was thereby scored (3) both for workers and the community.

Table 9: *Highest risk score and associated risk level, counting for a total score for the subcriteria health risks from biological and chemical hazards. The risks are assessed for the exposure groups workers and the community.*

WORKER		
	Conv.	**UDDT.**
Highest risk score	16	12
Risk level of highest risk	High	Medium
SCORE:	2	3
COMMUNITY		
	Conv.	**UDDT.**
Highest risk score	20	8
Risk level of highest risk	High	Medium
SCORE:	2	3

Of all input/output products is only one, WWTP sludge, associated with chemical health hazards. An assumption was made that the main source of toxic chemicals and heavy metals in the WWTP sludge come from industrial waste and storm water that seep into the sewer network. Neither industrial waste nor storm water are included input products to the systems in this study and health hazards originating from industry or storm water were therefore not prioritized in the assessment. This explains why the majority of potential hazards in the results are biological and only a few are chemical.

For a comprehensive assessment of all health hazards deriving from input/output products within the system options, potential physical health hazards in form of sharp objects, inorganic material and malodors can be added to the assessment (WHO, 2016). Potential malodors are in this study investigated as a socio-cultural aspect for users in Section 3.3.5. An interesting further investigation for this study could be to look at potential hazards from sharp objects and inorganic material.

Certain modules and main principles from the SSP manual were selected made when creating the methodology for assessment of this subcriterion. The selection is motivated here. As the study area and purpose of this study was already defined when initiating the assessment of this subcriterion, the assessment could start by directly applying Module 2 from the SSP manual. A complete system description was made via Module 2 by applying some main principles from the module. All main principles did not have to be applied because climatic conditions, demographics and contamination sources, for example, were already described in the background. To document legal and regulatory framework is part of Module 2 but it is not relevant for this subcriterion. Some main principles of Module 2 involve ensuring that the system description is complete and accurate. Instead of doing this for the subcriterion in this section, a validation of the system options was made as part of the sensitivity analysis in Section 3.4. All main principles of Module 3 were applied in the assessment as they produced relevant information required for rating the system options. The Modules 4, 5 and 6 were not relevant to apply in this study as they operate in an implementation and a follow-up phase of sanitation safety planning.

4.1.2 Eutrophying emissions

The per capita mass flow rates of nitrogen, phosphorous and BOD_5 emissions to receiving waters or to groundwater recharge accounted for the scores given the system options against this subcriterion (see Table 10). The conventional system received score (1) because emissions of all eutrophying agents exceed the suggested new Bolivian standards for effluent discharge. The UDDT system received score (4) because all eutrophying agents meet the standards, but with a low margin for phosphorous. Eutrophying emissions from the conventional system are about six times higher per person and year than from the UDDT system.

Table 10: *Per capita mass flow rate of eutrophying emissions into receiving waters or groundwater recharge from domestic households and scores for system options. The UDDT system is scored higher than the conventional system.*

	Conv.	**UDDT.**	**Standards***
Eutrophying emission of N [kg/p,y]	2.36	0.16	0.45
Eutrophying emission of P [kg/p,y]	0.32	0.05	0.06
Eutrophying emission of BOD_5 [kg O_2/p,y]	3.72	0.82	2.42
SCORE:	1	4	

*Suggested new Bolivian standards from Agua Tuya, converted from mg/l to kg/p,y using a wastewater flow of 83 l/p,d.

The current national standard for discharge of nitrogen in Bolivia (4 mg/l N as ammonia) is very low in comparison to corresponding standards in other Latin American countries such as Ecuador and Mexico (see Table 11). The current Bolivian standard for nitrogen is closer to European measures. Therefore, the suggested new national standard for nitrogen discharge that Agua Tuya and IBNORCA are working on was applied in the assessment. Results reasonable in a Bolivian context could thereby be received despite the fact that current standards were not used. Regarding the suggested new national standard for phosphorous used, is rather strict in comparison to Mexican and Ecuadorian standards. It is more alike European measures. If the phosphorous standard would have looked more like the Ecuadorian or Mexican, the UDDT system would have met the standard with a high margin. It would have resulted in a higher score given to the UDDT system. The Agua Tuya and IBNORCA suggested standard for discharge of BOD_5 is in between Ecuadorian and Mexican standards and thereby, results would not look differently if the assessment would have been made applying the standards used in Mexico and Ecuador.

Table 11: *National effluent standards in Bolivia, Ecuador and Mexico and European standards for effluent from WWTP (Unpublished UNICEF Bolivia, 1992; MAE Ecuador, 2003; SEMARNAT, 1997; Europeiska rådet, 1991).*

	National effluent standards in Bolivia	**Suggested new effluent standard in Bolivia**	**Effluent standards in Ecuador: to freshwater**	**Effluent standards in Mexico: for protection of aquatic environment**	**Effluent standards in the EU: from WWTP**
Tot-N [mg/l]	-	15	-	60	10*
N as ammonia [mg/l]	4	-	-	-	-
N as nitrate and nitrate [mg/l]	-	-	10	-	-
Tot-P [mg/l]	-	2	10	10	1*
BOD_5 [mg O_2/l]	80	80	100	60	25

*For effluent to sensitive areas (subjects to eutrophication).

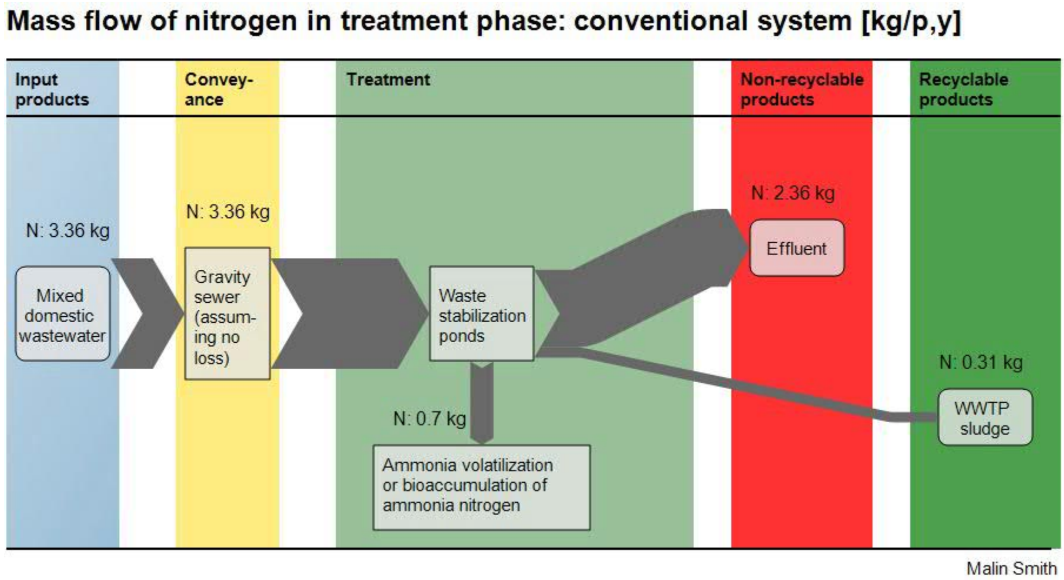
No distinction was made between eutrophying emissions into soil and eutrophying emissions into waters. An interesting further investigation could involve an assessment of these kind, since soil properties and groundwater level are two factors affecting the level of eutrophication.

Sensitivity analysis

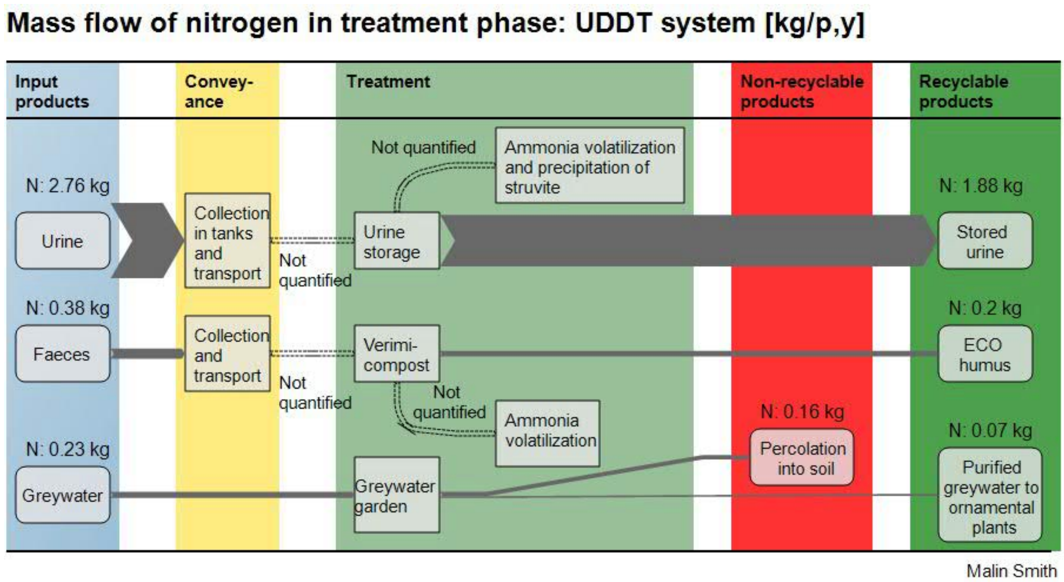
When converting the suggested new Bolivian standards for discharge of nitrogen, phosphorous and BOD_5 from milligram per liter to kilogram per person and year, a wastewater flow of 83 l/p,d was used. This flow was used because it is the estimated water consumption in a peri-urban municipality of a developing country with in-house access to water (Oteng-Peprah et al., 2016). However, if the estimated wastewater flow would decrease some ten liters per person and day, the standard for phosphorous would be converted to 0.05 kg/p,y, meaning that it would not be met for the UDDT system. The UDDT system would receive a lower score. If the wastewater flow would instead increase to 100 l/p,d, scores would remain the same.

4.1.3 Potential for nutrient recycling

Mass flow analyzes of nitrogen and phosphorous in the treatment processes of the respective system options were made in order to conclude for how large the potential for nutrient recycling is (see Figures 10 and 11).

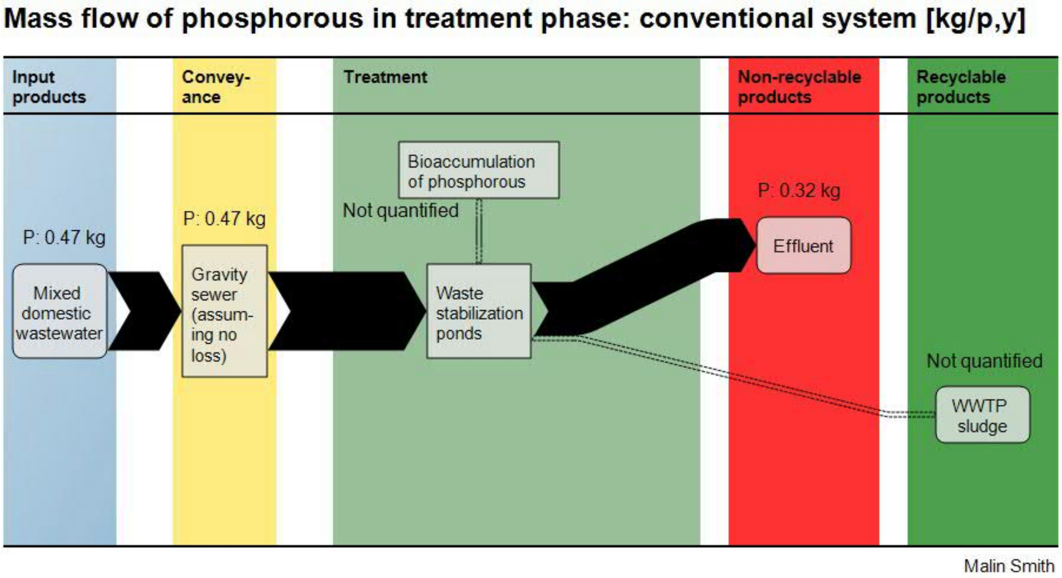


(a)

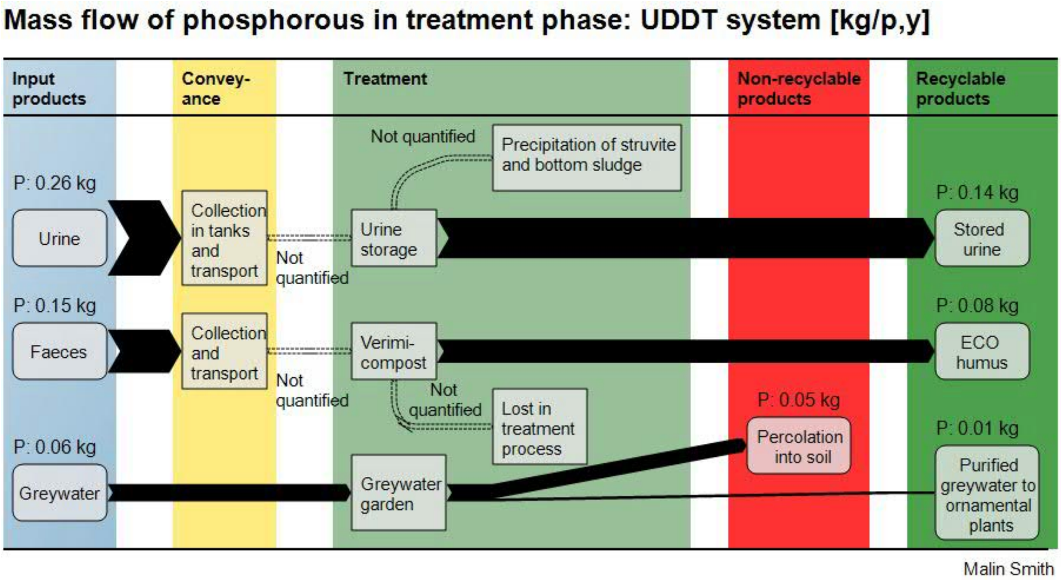


(b)

Figure 10: *(a) Mass flow analysis of nitrogen in treatment phase of the conventional system. Losses in conveyance phase are not included. (b) Mass flow analysis of nitrogen in the UDDT system with losses in conveyance phase included.*



(a)



(b)

Figure 11: *(a) Mass flow analysis of phosphorous in the conventional system. Losses in conveyance phase are not included and flow to WWTP could not be quantified. (b) Mass flow analysis of phosphorous in the UDDT sytem, including losses in conveyance phase.*

The conventional system recovers about nine per cent of the nitrogen in urine, faeces and greywater from one person during one year in bottom sediments as sludge (see Table 12). The rest escapes with effluent or get volatilized or accumulated into biomass in the stabilization ponds. No result on phosphorous recovery in stabilization ponds was obtained since no data was available on the sludge nor any trend in literature could be detected. The nitrogen recovery from the UDDT system is about 68% from urine, 54% from faeces and 30 % from greywater. The phosphorous recovery from the UDDT system is about 54% from urine, 52% from faeces and 20% from greywater (see Table 12).

Table 12: *Per capita mass flow rates of nitrogen and phosphorous in the respective recycled products and nutrient recovery.*

	WWTP sludge	**Stored urine**	**ECO humus**	**Greywater to plants**
N [kg/p,y]	0.31	1.88	0.20	0.07
P [kg/p,y]		0.14	0.08	0.01
N recovery [%]	9	68	54	30
P recovery [%]		54	52	20

Per capita mass flow rate and recovery of phosphorous in WWTP sludge are left blank because no data was received on phosphorous content in the sludge and estimations could not be made from existing literature.

A study including urine storage made in tropical climate reported that 90% of the nitrogen in urine was lost due to ammonia volatilization if urine storage containers were open. When they were closed during the storage, only 7 % was lost, probably when samplings were taken (Wohlsager et al., 2010). Jönsson et al. (2004) also point out ammonia volatilization as a main reason for nitrogen losses, as storage tanks are opened for sampling. Results on nitrogen losses in the urine storage treatment process in this study in El Alto (22%) can therefore be considered reasonable. The 46 % loss of nitrogen in faeces can also be explained by ammonia volatilization. The treatment beds are mostly open, making it easy for ammonia to volatilize. The low pressure at the high altitude in El Alto (4000 meters above sea level) might also be an explanation to nitrogen losses in the treatment processes of urine and faeces (personal communication FSH, 25 October 2019). Greywater percolation into soil is another explanation to nitrogen losses within the UDDT system.

The 46 % loss of phosphorous in the urine storage treatment process is rather high compared to the 31% loss reported in another study (Tilley et al., 2008). Synthetic urine was used in the mentioned study and spontaneous precipitation of phosphorous as phosphate minerals explained the result. Naturally increased pH in the storage process triggered the reaction. According to Jönsson et al. (2004) does a ”large part” of the phosphorous in urine storage tanks form such bottom sludge. Poor mixing conditions before sampling can also be a reason to low phosphorous concentrations in samples from urine storage tanks. These two reasons probably explain the rather high phosphorous loss reported in this study from El Alto. Spillage in the conveyance phase might also have contributed phosphorous losses.

Yadav et al. (2011) report that 21% of the nitrogen was removed in a vermicompost of faeces, signifying a recovery of 79%. In contrast, Yadav et al. (2009) report a 32% loss of nitrogen in another vermicompost of faeces, signifying a recovery of 68 %. Comparing these recovery with the recovery obtained form this study in El Alto (20%), the El Alto result is poor. Nevertheless, if the calculations on recovery would have been based on the highest measured concentrations of nitrogen in ECO humus instead of median values, a recovery similar as for Yadav (2009) would have been obtained (more about this in the *optimization analysis* further down).

Jönsson et al. (2004) mention nitrogen but not phosphorous to be at risk of getting lost in secondary treatment processes of faeces. The result on phosphorous losses during vermicomposting of faeces (48%) in this study from El Alto can therefore be considered high. Spillage in the conveyance phase is the most probable reason for the loss. In contrast to the mass flow analysis made for the conventional system, the mass flow analysis for the UDDT system includes spillage in the conveyance phase (see Figures 10 and 11). Some phosphorous and nitrogen are lost for example when urine is poured from jerrycans to tanks in the vehicles used for transportation and when faeces are transferred from the mobile recipients to the compost beds. The loss of nutrients in the conveyance phase in the conventional system was not accounted for but is discussed in the sensitivity analysis in Section 3.4. Recovery for all recyclable products summed up for both system options and scores for the respective system options are presented in Table 13.

Table 13: *Nitrogen and phosphorous recovery from recycled products in the conventional system and from recycled products in the UDDT system. The UDDT system is scored higher than the conventional system.*

	Conv.	**UDDT.**
N recovery [%]	9	64*
P recovery [%]		49**
SCORE:	1	4

Phosphorous recovery from the conventional system is left blank because no data was received on phosphorous content in the sludge and estimations could not be made from existing literature.
* 56% from stored urine, 6 % from ECO humus and 2 % from greywater garden plants.
** 30% from stored urine, 17 % from ECO humus and 3 % from greywater garden plants.

Before drawing any conclusion on the practical potential for nutrient recycling, the quality of the recycled products should be investigated. The WHO guidelines for safe use of wastewater, excreta and greywater are recommended to use (WHO, 2006).

Assumptions made in order to develop the mass flow analyzes can be motivated. Ammonia volatilization, ammonia accumulation into biomass and sedimentation of organic nitrogen were assumed to be the most prominent processes of nitrogen removal in WSPs, as according to a theory of Middlebrooks et al. (1999). The proportions of nitrogen volatilizing to air, accumulating into biomass and sedimenting to bottoms were estimated from the relative size of arrows visualizing the flows in an illustration (see Appendix K). Favorable conditions for the processes in terms of temperature, pH, hydraulic loading rate and mixing conditions were assumed. However, it is widely discussed in literature which is the dominant process for nitrogen removal in WSPs and which are the main factors affecting the processes. Camargo-Valero and Mara (2010) report that the widely accepted conclusion about ammonia volatilization being the main mechanism for permanent removal of nitrogen might not be accurate. A number of reports published more recent than the ones on which Middlebroks et al. (1999) build his results show that ammonia volatilization only make a small contribution or no contribution at all to nitrogen removal. This conclusion should be applicable in both a warm and a cold climate. Nevertheless, there are very few general studies on the proportion of nitrogen that sediments into bottoms in WSPs. The widely accepted theory from Middlebrooks et al (1999) was thereby applied. An attempt to simulate nitrogen dynamics in primary facultative ponds by Senzia et al. (2002) reports that sedimentation is the primary mechanism for nitrogen removal, accounting for 9.7 % of the total inflowing nitrogen. Nitrification is concluded to be the second major mechanism for nitrogen removal in the study. The proportion of nitrogen that sediments into bottoms according to Seniza et al. (2002) is similar to the result from this study in El Alto (9%). Despite the fact that ammonia volatilization accounted for almost no removal of nitrogen in the mentioned simulation, the reported result strengthens the results from this study in El Alto regarding sedimentation of nitrogen. After all, it was the nitrogen in bottom sediments that determined the potential for nutrient recycling in this study.

Concerning phosphorous recovery in WSPs, a specified value was not obtained in this study. However, the recovery is probably not very high in the WSPs in El Alto. Vendramelli et al. (2016) confirm in a study about phosphorous removal mechanisms in facultative ponds that the main process for phosphorous removal in facultative ponds is assimilation into biomass. At high pH during algal bloom, the concentration of dissolved phosphorous is low. When algal activity decreases, which is followed by a decrease in pH, the concentration of dissolved phosphorous increase. More phosphorous can thereby escape with the effluent. In alkaline conditions, phosphorous is bound to cations and can precipitate. At a pH between 7 and 8.5, calcium phosphate begins precipitating. However, a pH greater than 9 needs to be reached to lead to a significant phosphorous removal (Vendramelli et al., 2016). Annual average measurements of pH in the lagoons of Puchukollo WWTP from 2015-2018 were all under nine (personal communication AAPS, 11 June 2019). The precipitation of phosphorous can therefore be assumed low, meaning that the potential for phosphorous recycling is probably low for the conventional system. Estimating a value for the precipitation into bottom sediments would create large uncertainties and thereby, the assessment of phosphorous recovery was excluded from the study. The score for the conventional system against the subcriterion potential for nutrient recycling would, however, probably not be higher if the potential for phosphorous recycling was added to the assessment.

Sensitivity analysis

One estimation made was, for example, about the number of people per household in El Alto (3.5). The average number of people per household in Bolivia is 3.5 (INE, 2018). The estimation was used in calculations on the potential for nutrient recycling from faeces and urine in the UDDT system. It was discussed whether 3.5 or five persons per household was the most suitable estimation. Both 3.5 and five persons per household are reasonable estimations according to FSH (personal communication FSH, 25 October

2019). The motivation was that many families using the UDDTs are large at the same time as a large number consist of only two family members. Calculations using five persons per household resulted in nitrogen and phosphorous losses of 52% respectively 62 % (instead of 32% respectively 46%) from the urine storage treatment process. Nitrogen and phosphorous losses from the vermicompost were 62% respectively 64% (instead of 46% respectively 48%). The results using 3.5 persons per households are better motivated in comparison to literature values (see discussion above) and was therefore used as estimation.

The fact that EPSAS could not provide with any information nor participate in any interview affects the preciseness of the study. Estimations and assumptions had to be made instead of basing calculations on the potential for nutrient recycling for the conventional system on actual data. The estimations and assumptions are, however, well motivated and reasonable.

Optimization analysis

According to the technical guide for design and execution of water and sanitation projects elaborated by MMAyA (2010), the removal efficiency of nitrogen is 30-40% in WSPs. Assuming a 40 % removal in an optimized treatment process in the WSPs would result in a nitrogen accumulation in bottom sludge of 12% instead of the reported 9%. The highest annual average removal efficiency of nitrogen in the Puchukollo WWTP between 2015 and 2018 was in 2015, when 38 % of the nitrogen was removed. Hence, an optimal potential for nitrogen recycling was almost reached in 2015.

Laboratory test results from FSH on the highest measured concentrations of nitrogen and phosphorous in ECO humus and stored urine were used to find out how an optimized potential for nutrient recycling would look like. Results shewed a remarkably higher potential for nutrient recycling than the results reported in this study (which were calculated from median values of the obtained test results). Nitrogen and phosphorous recovery from urine in an optimized case is 78 % respectively 58% instead of 68 % respectively 54%. Nitrogen recovery from feaces is 69 % instead of 54% and phosphorous recovery is 80 % instead of 52%.

4.1.4 Technical functionality

Complexity

So called ”high skill” operation and maintenance tasks, their recommended frequency according to sources and their recommended frequency as reported in this study served as a basis for scoring the system options against this subcriterion (see Table 14). It should be noted that the recommended frequencies of high skill operation and maintenance tasks are not necessarily fulfilled in practice.

Table 14: *High skill operation and maintenance tasks, recommended frequency according to sources and recommended frequency as reported in this study. Recommended frequency is not necessarily fulfilled.*

High skill technical O & M task	Recommended frequency according to sources	Recommended frequency as reported in this study
	Conventional system	
Routine inspection in man-holes or pumping stations in sewer network	It is recommended that manhole inspections should be made in approximately 20 % of a sewer network yearly (EPA, 1999)	Yearly or more rarely
Taking samples for laboratory analyzes	Once a week (personal communication AAPS, 11 June 2019)	Weekly
Removing and safe handling of sludge from WSP ponds	Anaerobic pond every 2-5 years. Facultative more rarely and maturation pond hardly never	Yearly or more rarely
	UDDT system	
Control of humidity and temperature in faeces/ECO humus	Twice a week (personal communication FSH, 25 October 2019)	Weekly
Monitoring of humidity in faeces/ECO humus through addition of water	Twice a week (personal communication FSH, 25 October 2019)	Weekly
Taking samples for laboratory analyzes	Twice a year (personal communication FSH, 25 October 2019)	Several times a year
Safe handling of ECO humus and treated urine	ECO humus every 6-8 months. Urine every 4-5 months. (personal communication FSH, 25 October 2019)	Several times a year

The conventional system received score (3) because only one high skill task is required weekly. The UDDT system received score (2) with the motivation that two high skill tasks are required weekly. Results are shown in Table 15.

__Table 15:__ The complexity of the UDDT system is scored higher than the complexity of the conventional system because one more high skill task is required weekly.

	Conv.	**UDDT.**
Recommended frequency of tasks requiring high skills	One task require high skills weekly. Three tasks require high skills yearly or more rarely.	Two tasks require high skills weekly. Two tasks require high skills yearly.
SCORE:	3	2

The two system options are in general not very complex. WSPs are a recommended treatment technology in developing countries according to for example Mara (2003) and as the results show, the UDDT system is not much more complex than the conventional system. However, the fact that the UDDT system is slightly more complex than the conventional system can have significance for for example economic aspects. It is more expensive to employ more personnel requiring knowledge on biological treatment processes.

Since EPSAS could not be contacted and asked, one assumption was made that there are manually raked screens in the pre-treatment phase of the conventional system. If there in practice are mechanical bar screens, an electromechanical technician would have been needed at the treatment plant (Mara, 2003). The conventional system would have required another high skill task, that depending on its frequency could have lowered the score for the conventional system against this subcriterion.

Robustness

Robustness was assessed through investigating five different indicators related to the capacity to endure shock loads and the resilience against climatic variations. The comprehensive assessment is explained in Appendix L and scores given each system option for the capacity to endure shock loads and resilience against climatic variations are displayed in Table 16.

Table 16: *Scoring of robustness is made separately for the two indicators concerning capacity to endure chock loads and the three indicators concerning resilience against climatic variations.*

Capacity to endure shock loads		
	Conv.	**UDDT.**
Capacity to endure shock loads - quality of input products	3	3
Capacity to endure shock loads - quantity of input products	5	2
SCORE	**4**	**3**
Resilience against climatic variations		
	Conv.	**UDDT.**
Resilience against cold climate	3	3
Resilience against climate change impact - flooding	1	2
Resilience against climate change impact - drought	1	2
SCORE	**2**	**2**

The conventional system received score (4) for the capacity to endure shock loads and score (2) for the resilience against climatic variations. The system is in general resistant to a change in quality or quantity of incoming waste but chemical waste may cause inhibition of the biological treatment mechanisms. Sewers can be clogged by oil or grease but endure freezing temperatures well. The conventional system is highly dependent on water and would not operate if the water supply was limited, for example during a drought. Flooding would cause overflows both by the entrance to the Puchukollo WWTP and in the sewer lines.

The UDDT system was scored (3) for the capacity to endure shock loads and (2) for the resilience against climatic variations. Vermicomposting is sensitive towards a change in pH in the compost, which can occur if for example sawdust is used as drying material. The treatment process would be affected negatively. Jerrycans and containers for collection of urine and faeces can be filled up if sudden large quantities of urine and faeces are generated. Concerning resilience against climatic variations, the conveyance phase would operate in a drought event as well as the treatment of urine and greywater. Vermicomposting, on the other hand, requires access to water weekly.

Even though the resilience against climate change impact is poorer for the conventional system compared to the UDDT system, resilience against climatic variations was scored similarly for the two system options. It can be explained by the fact that a compensatory MCA technique was used. The good resilience against a cold climate that the conventional system has, compensates for its bad resilience against climate change impacts. The reason to why a compensatory MCA technique was applied was because one score for robustness aimed at reflecting capacities that can be strengthened by behavioral change (capacity to endure shock loads). The other score aimed at reflecting performances that are harder to strengthen by behavioral change among users (resilience against climatic variations). The scores for resilience against climatic variations thereby reflect how well the systems are adapted to conditions that can not be adjusted. Both system options should be overseen in order to get better adapted to existing and possible varying climatic conditions. How the low pressure at the high altitude affects the robustness could be an interesting further investigation. Concerning the results on capacity to endure shock loads, it is important to inform users of both system options what can and can not be disposed in the toilets. For the UDDT system, it is also important to provide information on how to deal with the sanitation service if more people than usual use the toilet during a limited time. For example, extra jerrycans for urine collection and mobile recipients for collection of faeces might be needed.

4.1.5 Socio-culture: user

Answers from interviews with ten users of the conventional system and ten users of the UDDT system created a basis for the assessment of the subcriteria under the criterion socio-culture (from a user perspective). The answers are displayed in bar charts in Figure 12. Scores given to each system option for the respective subcriterion are presented in Table 17. Most users of the conventional system expressed that they were not so satisfied. However, the average answer resulted in score (3) given to the conventional system because some interviewees had expressed that they were satisfied or very satisfied. The main reason to why users were not satisfied was due to blockages in the main sewer lines, leading to system failures and overflows in the streets especially during rainy season. The ease of use was perceived similarly between users of the conventional and of the UDDT system. An average answer on that subcriterion resulted in the score (4) given to both systems. The average user perceived the conventional system as uncomfortable because of the malodors that appear during wastewater overflows in the streets during rainy season. Only one user did not express disgust concerning this fact and the score (2) was given the conventional system for the subcriterion comfort considering smell. The average user of the UDDT system expressed that he or she found his or her toilet system comfortable despite some odor appearing near the toilet. The UDDT system was given score (4) for the subcriterion comfort considering smell. Users of the conventional system perceived, in average, their toilet system as very unreliable, because of own experiences and experiences from neighbors having blockages in the main sewer line. The conventional system was given score (1) for the subcriterion reliability. Users of the UDDT system did in average find their toilet system reliable and score (4) was given. Social status associated to the construction material in the bathroom was found to be high for the users of the conventional system as ceramic or tile material was used to a higher extent in their bathrooms compared to the bathrooms of UDDT users. The conventional system was given score (4) and score (3) was given the UDDT system.

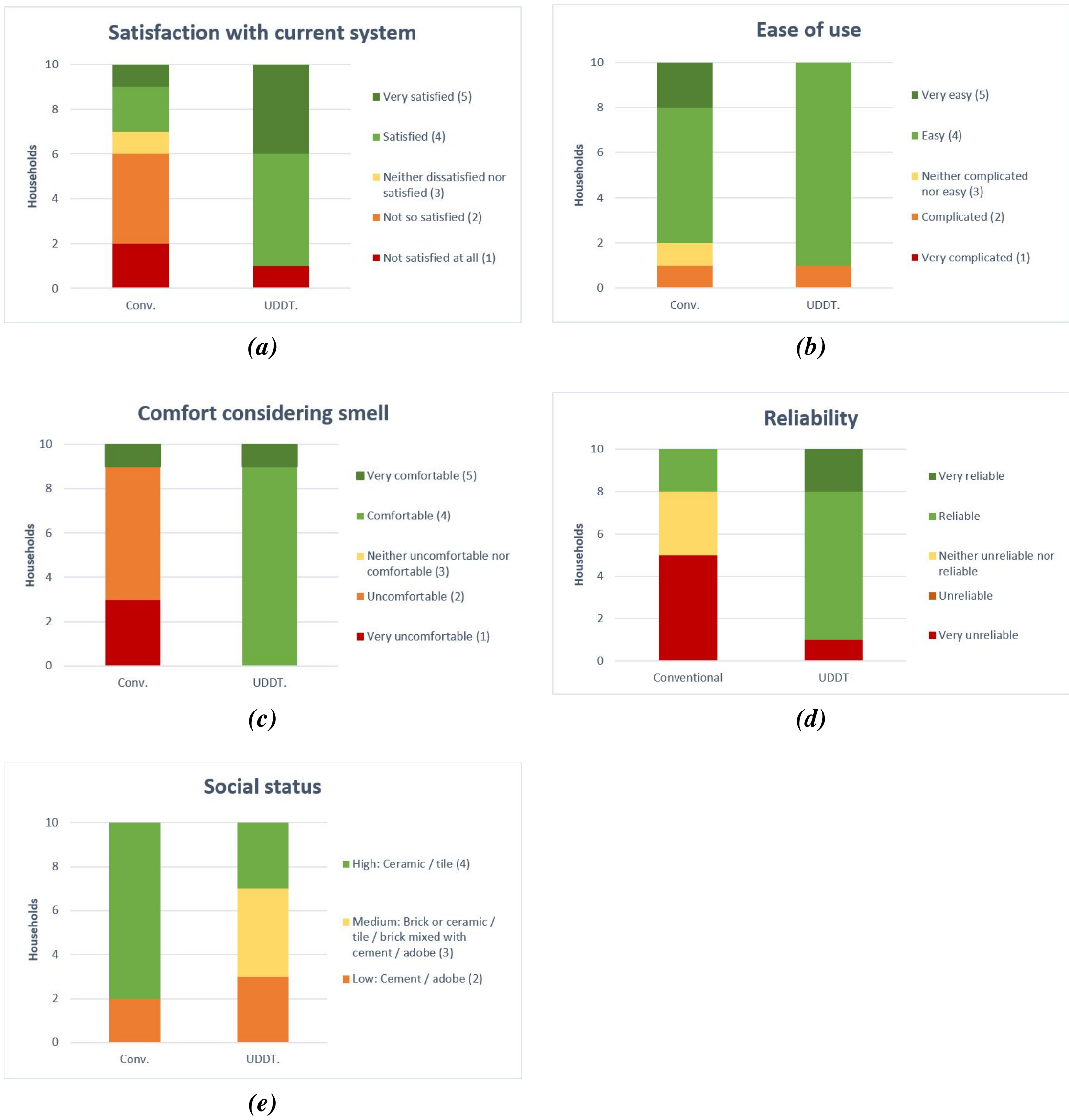


Figure 12: *User answer frequency on all five questions regarding the socio-culture aspect: Satisfaction with current system, ease of use, comfort considering smell, reliability and social status.*

Table 17: *A rounded off, average score based on answers from interviews with ten users of each system option reflect the final score for user satisfaction with current system, ease of use, comfort considering smell, reliability and social status.*

Satisfaction with current system		
	Conv.	**UDDT.**
SCORE:	3	4
Ease of use		
	Conv.	**UDDT.**
SCORE:	4	4
Comfort considering smell		
	Conv.	**UDDT.**
SCORE:	2	4
Reliability		
	Conv.	**UDDT.**
SCORE:	1	4
Social status		
	Conv.	**UDDT.**
SCORE:	4	3

Only one interviewee of the UDDT system was not satisfied at all and he was also the the one finding the UDDT system very unreliable. He explained that the people managing the collection vehicle had stopped passing by his door and that he had to start emptying his urine and faeces himself. Once the sewer network had reached his house, he had therefore connected to the conventional system as well. As explained in the system description of the UDDT system in Section 3.2.2, only 460 of the 1198 initially installed UDDTs in El Alto are currently a part of the UDDT system. This fact implies that the problem discovered from this dissatisfied user might be a problem in larger scale in El Alto.

Some interviewees wanted to add their opinions about other sanitation systems than their own and it was discovered among several users of the UDDT system that they were anxious about the shift from FSH to EPSAS being responsible for the collection of urine and faeces. Several users expressed they did not know if EPSAS could keep collection times as good as FSH. Other concerns were that EPSAS would not treat the incoming products, because users claimed that large parts of the sewer network is not connected to a wastewater treatment plant. This fact can be used to strengthen the result regarding reliability, that users find the providers of the UDDT system (FSH) more reliable than what they find the provider of the conventional system (EPSAS).

As earlier mentioned, Helgegren et al. (2018) reported from a study in Cochabamba, Bolivia, that pour-flush toilets were preferred over latrines mainly because latrines were perceived as inconvenient, unpleasant, smelly, un-hygienic and low status alternatives. In contrast, results from this study in El Alto show that users of the UDDT system are more satisfied and less bothered by smell than users of the conventional system, who use flush toilets. Results regarding social status are similar between the two studies. Another study conducted in El Alto District 7 (the same district as interviews in this study were conducted in with users of the UDDT system), reports that acceptance among users of UDDTs is ”high” in the district (Silveti & Andersson, 2019). The authors point out that the high acceptance can be explained by the fact that aspiration for flush toilets in District 7 is not very high. However, Silveti and Andersson (2019) also report that the acceptance is much lower in for example a municipality of South Africa than in District 7 in El Alto because the eagerness of having flush toilets is widespread in that municipality (Silveti & Andersson, 2019). Perceptions on dry toilets and aspirations for flush toilet in other districts than District 7 in El Alto could possible vary.

It can be concluded that users of the UDDT system might connect to the conventional system if the sewer lines expand to their homes, as one interviewee had done. It is, however, not necessary that the sewer network expands to areas where the UDDT system still operates, since most users there seem to be satisfied. In addition, the lack of maintenance in the sewer lines cause dissatisfied users of the conventional system. It would be recommended to inspect and renew parts of the sewer lines before prioritizing an expansion of the sewer network to areas where the UDDT system operates.

Sensitivity analysis

Two different people interpreted answers during the interviews with users of the conventional system and the interviews with users of the UDDT system. Therefore, there might have been a slightly different perception of the answers. Because of language barriers, the translation of one interview question to Spanish changed the original aim of the question. The subcriterion satisfaction of current system was initially intended to reflect user friendliness. Satisfaction with current system is, however, also a relevant subcriterion since it gives an indication for if the user would choose between the system options if he (she) had a choice. One misinterpretation of the question regarding ease of use was detected after the interview session. The interviewee had interpreted the question as ease of understanding of the sewer system functionality and expressed that is was difficult. However, her answer does not affect the score given the subcriterion ease of use, because a clear majority had answered that the system was easy to use.

4.1.6 Institutional capacity

The institutional capacity of the system options was assessed through investigating twelve indicators and giving the system options zero, one or two points for each indicator. More points resulted in a higher score for the system option against the subcriterion. The results are displayed in Table 18.

Table 18: Scores for representative indicators of institutional capacity - interpretation for this study from NORAD (2000). Final score is based on the sum of scores from each indicator.

	Conv.	UDDT.
Compliance of long-term maintenance tasks	0	1
Short-term targets	0	2
Financial resources	1	0
Supply of personnel	1	2
Adaptation to country needs	1	2
Institutional competence	2	2
Linkages to partners	1	1
Support from donors	1	0
Participation among users	1	2
Respect from other institutions	1	0
Total sum of points received for indicators	9	12
SCORE:	4	3

The indicator *Compliance of long term maintenance tasks* for the conventional system received (0) points because desludging had not been realized on a recommended regular basis. It is recommended to remove sludge from the anaerobic pond every two to five years years (Tilley et al., 2014) and from the facultative pond every five to ten years (MMAyA, 2010). This task had never been realized during the 20 years of operation (personal communication AAPS, 11 June 2019). For the UDDT system, required long-term maintenance tasks related to excreta seemed to be fulfilled. All collected urine and faeces were safely handled by FSH after their completed treatment twice a year. However, FSH might lose authority over the UDDT system from September 2019 (personal communication FSH, 22 March 2019). A safe treatment of excreta could thereby not be assured "in near future" and only (1) point was given.

Moving on to *Short-term targets* - One short-term target EPSAS has is to expand the sewer network rapidly. EPSAS seem to reach this short-term target but at the price of environmental contamination (personal communication GAMEA, 23 May 2019). Annual mean values from 2015-2018 on faecal coliforms in the effluent from Puchukollo WWTP exceed national standards (see Appendix I) and (0) points were therefore given. Considering the UDDT system, the current main short-term goal of FSH is to simply continue operating and maintaining their treatment station (personal communication FSH, 22 March 2019). This goal is according to the Coordinator of the Technical Area at FSH reached. Faecal coliforms are not discharged into receiving waters since the ECO humus and stored urine are separated from the greywater and used in agriculture. The UDDT system was given (2) points.

Financial resources for basic sanitation services are in general in El Alto uncertain, with maintenance of the services being the most neglected part (personal communication GAMEA, 23 May 2019). Financing for infrastructure investments are easier to get through credits and international donations. A conclusion was thereby made for all systems that they are not self-sustained. However, EPSAS currently have financial resources available as understood during the interview with GAMEA. It seemed that major recurrent expenditures are covered. Therefore, (1) point was given the conventional system. The projects of FSH in El Alto have since their start been financed by the Embassy of Sweden (FSH, 2015). However, this financing is not to proceed and FSH will have to move on by creating new projects and looking for other financing (personal communication FSH, 18 June 2019). Due to the current financial state of the UDDT system, (0) points were given.

Regarding *Personnel*, competent personnel required at the Puchukollo WWTP are provided (personal communication AAPS, 11 June 2019). During the interview at AAPS, it could not be specified if adequate personnel required for operation and maintenance tasks in the sewer network was provided. Hence, results from the household interviews with users was used to get a perception of the supply of adequate personnel. The results showed that four out of eight interviewees who were regularly in acute need of service during rainy season did have to wait only a few hours up to one day for EPSAS to come. Four interviewees expressed that EPSAS used to come after at least four days or more. Since 50% of the users expressed that they used to get acute service, (1) point was given the conventional system. Supply of personnel for the UDDT system was concluded adequate. All personnel was changed during 2018 to fulfill the needs of FSH and (2) points were given (personal communication FSH, 18 June 2019).

Considering *Purpose and strategy*, EPSAS do expand their sewer network to areas where there is rapid immigration of rural families, for example in District 7 (EPSAS, 2019) where sewer coverage is under 50 % (GAMEA, 2019). They also aim to reach contamination goals. For example, it was observed some ten years ago that there were dead areas in some of the ponds. Plastic walls were therefore installed in the ponds (personal communication AAPS, 11 June 2019). However, the capacity to treat all incoming wastewater is still not sufficient. Contamination mitigation goals are not reached (see Appendix I). Since purpose but not strategies reflect the mentioned relevant country needs, (1) point was given the conventional system. FSH reflects both adaptation to the rapid immigration of rural families and counteracting contamination in receiving waters in their purposes and strategies. They operate in areas where there is rapid immigration of rural families (FSH, 2015) and do not discharge contaminating effluents into receiving waters. The UDDT system was given (2) points.

The *Institutional competences* of both EPSAS and FSH were considered supportive for operational tasks as well as new projects. Both the conventional and the UDDT system were therefore given (2) points. This conclusion was based on the fact that the institutions do operate and maintain their systems and have plans for further development. For example, FSH has plans to search for new areas in order to be able to continue operating when EPSAS takes over the operation of existing UDDT units in El Alto (personal communication FSH, 18 June 2019). Concerning the conventional system, EPSAS constantly executes new projects as understood during the interview at GAMEA (personal communication GAMEA, 23 May 2019).

Regarding *Linkages to partners*, it was discovered during several of the interviews and personal meetings with involved stakeholders that there are difficulties with communication between EPSAS and some partners. Therefore, (1) point was given the conventional system. Communication difficulties were discovered between FSH and some partners as well and (1) point was given the UDDT system.

For *Support from donors*, the conventional system received (1) point and the UDDT system (0) points. The motivation is the same as for the indicator financial resources.

Concerning *Participation among users*, EPSAS has offices in El Alto for the users to visit. They also have a service number to call that seem to be well known among users, as concluded from the interviews a at a household level. Since users themselves have to seek contact, the conventional system received (1) point. The UDDT system received (2) point because users are in regular contact with workers of FSH when collection of urine and faeces is scheduled. Several users expressed during interviews that they would speak to the personnel during scheduled collection service if they had anything to express. Nevertheless, it should be added that several users of the UDDT system did not know if there was a number to FSH to call.

Respect from other institutions: As mentioned in Section 3.1, the municipal government GAMEA has responsibility of executing sanitation projects and providing service through municipal lending entities. The role of EPSAS should be to simply provide the sanitation services. In practice, the roles are managed differently. Around year 2006, EPSAS intervened at a central level because of political motives that raised from social conflicts associated with the authorizations to private companies (personal communication GAMEA, 23 May 2019). It was observed during interviews at the institutional level that especially one involved stakeholder lack confidence in EPSAS. Thereby, (1) point was given the conventional system. The UDDT system received (0) points because several involved stakeholders seemed to lack confidence in FSH.

The conventional system received in total (9) points and the UDDT system received (12) points from the indicators, which means that they are both in the same interval for scoring and should receive score three. Nevertheless, the conventional system received one score higher than the UDDT system from the compensation of the exclusion of one of the five the core capabilities, the *capability to commit & engage*. It should be noted that the fifth core capability, *to balance diversity & coherence* was not integrated in the assessment. How the institutions manage diverse perspectives of people within the institution in order to formulate visions and strategies was thereby not assessed.

4.1.7 Financial value of recycled product

The financial values of recycled products, in bolivianos per person and year, created a basis for the scoring of the subcriterion (see Table 19).

Table 19: *Financial value of nitrogen and phosphorous in the recycled products WWTP sludge, stored urine and ECO humus.*

	WWTP sludge	Stored urine	ECO humus
N [Bs/p,y]	3 - 4	17 - 25	2 - 3
P [Bs/p,y]		1	0 - 1
N and P [Bs/p,y]		18 - 26	2 - 4

Financial value for phosphorous and nitrogen and phosphorous combined from the conventional system are left blank because no data was received on phosphorous content in the sludge and estimations could not be made from existing literature.

Recovered nitrogen in stored urine and ECO humus accounted for the financial value of recycled products within the UDDT system. Recovered nitrogen in WWTP sludge accounted for the financial value of recycled products within the conventional system. Table 20 shows that the financial value from nitrogen in the recycled products is higher from the UDDT system compared to from the conventional system. The conventional system was scored (1) and the UDDT system was scored (2). Recovered phosphorous from WWTP sludge could not be quantified and therefore, the scores were based on only nitrogen recovery. However, the financial value of phosphorous in recycled products within the UDDT system was quantified and is displayed in the tables in this subsection. It exists but is low.

Table 20: *Financial value of nitrogen and phosphorous in recycled products are presented in a range because the value of nitrogen and phosphorous on the local market is fluctuating. The UDDT system is scored higher than the conventional system.*

	Conv.	UDDT.
N [Bs/p,y]	3 - 4	19 - 28
P [Bs/p,y]		1 - 2
N and P [Bs/p,y]		20 - 30
SCORE:	1	2

Financial value of phosphorous and nitrogen and phosphorous combined for the conventional system are left blank because no data was received on phosphorous content in the sludge and estimations could not be made from existing literature.

The financial value of urine produced by one person during one year is usually within the range of 4-7 euro (Richert et al., 2010), which is about 30-50 bolivianos. The scale used for assessment was developed so that score five represented a financial value of 50 Bs/p,y or more. Score three represented 30-39 Bs/p,y. Both system options accounted for financial values of recycled products under 30 Bs/p/y. If the optimized values on recovered nitrogen would have been used in the calculations, the financial value would probably have been significantly higher, especially for the UDDT system. If a higher financial value was obtained as a result of optimized treatment facilities, it could aid a sanitation system such as the UDDT system to cover some expenditures and lower the cost for users.

If population growth would continue as expected in El Alto and if half of the population were connected to the conventional system and the other half to the UDDT system in 2020, nitrogen content in bottom sludge from stabilization ponds in the conventional system would have a theoretical financial value of about 1.6 million Bs/y. Nitrogen in ECO humus and stored urine from the UDDT system would have a financial value of 11 million Bs/y.

Uncertainties derive from the same sources as uncertainties explained in Section 4.1.3, about the potential for nutrient recycling.

4.2 SENSITIVITY ANALYSIS REGARDING DEGREE OF CONNECTION TO TREATMENT FACILITY

The proportions of input products that do not go to treatment phase in the respective system options can be estimated to:

- **Conv.:** 30-40 % of the sewer connections to households generating input products do not lead to the Puchukollo WWTP. Mixed domestic wastewater from these households get discharged directly into the Seco River. In addition, overflows occur by the entrance of the WWTP during rainy season every year and a non-quantified part of the untreated wastewater gets discharged directly into the Seco River through a bypass by the entrance (personal communication AAPS, 11 June 2019).
- **UDDT.:** 23% of the generated input products are not transported to the treatment station of FSH. They either get discharged directly into rivers, get deposited onto places nearby the households or get reused untreated as fertilizer (FSH, 2018).

A relatively large part of the input products to both system options are not transported to the treatment facilities. This fact create uncertainties of the results regarding especially the subcriteria eutrophying emissions, health risks from biological and chemical hazards, potential for nutrient recycling, institutional capacity and financial value of recycled product. Health risks from biological and chemical hazards would for both system options be larger for the exposure group community. The UDDT system score for eutrophying emissions would be (1) instead of (4) if two thirds of 23% of the input products were discharged into rivers or disposed onto soil. The conventional system would recover four per cent of the nitrogen in input products instead of nine, receiving the same score (1) for potential for nutrient recycling. The UDDT system would recover 49% of the nitrogen instead of 64% and therefore receive (3) in score instead of (4). The financial value of recycled products would also decrease.

If users of UDDTs that do not deliver their urine and faeces for collection were interviewed for the socio-culture criterion, the results regarding satisfaction with current system, ease of use, comfort considering smell and reliability for the UDDT system would probably look different. These people would have to deal themselves with the excreta. On one hand, it could imply less satisfaction, ease of use, comfort considering smell and reliability. On the other hand, more positive results could be obtained form the people using their urine and (or) faeces in agriculture. Results for the conventional system regarding the socio-cultural criterion would probably not be affected since their excreta get transported from the household even if it is directly discharged into a river. Results from the assessment of subcriteria under the technical functionality criterion would not be significantly affected by the fact that wastewater is discharged directly into rivers.

4.3 Comparison of system options against criteria in performance matrix

Performances of the system options against the subcriteria selected for assessment are presented in a performance matrix in Table 21. System options that are scored (4) for a specific subcriteria are colored in green. Subcriteria that are scored (3) are colored in yellow. Subcriteria scored (2) are colored in orange and the scores (1) are colored in red. The UDDT system perform higher than the conventional system considering the health criterion, the environmental criterion, many of the socio-culture subcriterion form a user perspective and the economy criterion (financial value of recycled product). The conventional system perform higher than the UDDT system on the technical function criterion and the socio-culture criterion from an institutional perspective. It performs similarly as the UDDT system on one user-related socio-culture subcriterion.

Criteria and subcriteria: each subcriteria scored on a five-point scale where 5 represents highest performance and 1 represents the lowest.	**Conventional system:** flush toilet connected to sewer network leading to centralized WWTP Puchukollo	**UDDT system:** Dry urine diversion with semi-centralized treatment of urine and faeces and greywater treatment in greywater garden
Health		
Health risks from biological and chemical hazards: worker	2	3
Health risks from biological and chemical hazards: community	2	3
Environment		
Eutrophying emissions	1	4
Potential for nutrient recycling	1	4
Technical function		
Complexity	3	2
Robustness: capacity to endure shock loads	4	3
Robustness: resilience against climatic variations	2	2
Socio-culture		
User: Satisfaction with current system	3	4
User: Ease of use	4	4
User: Comfort considering smell	2	4
User: Reliability	1	4
User: Social status	4	3
Institutional: Institutional capacity	4	3
Economy		
Financial value of recycled product	1	2

Table 21: *Performance matrix visualizing performances of the two sanitation system options against selected subcriteria under five sustainability criteria. A lower score represents a lower performance (red) and a higher score a higher performance (green). More green results were obtained for the UDDT system compared to the conventional system.*

5 CONCLUSIONS

The alternative semi-centralized sanitation system option with UDDTs in El Alto performs higher than the conventional centralized sanitation system option in El Alto concerning the health criterion for workers and the community, mainly due to the poorly maintained sewer network. The UDDT system performs much higher than the conventional system regarding the environmental criterion including eutrophying emissions and potential for nutrient recycling. Concerning the technical function criterion, the performance is assessed slightly higher for the conventional system than for the UDDT system, except from regarding resilience against climate change impacts. The UDDT system performs higher than the conventional system considering user-related subcriteria under the socio-culture criterion if generalizing a low aspiration for flush toilets. The institutional capacity subcriterion under the socio-culture criterion is for the conventional system assessed to have higher performance than the UDDT system. Considering the economy criterion, the financial value of recycled products is slightly higher for the UDDT system than for the conventional system but is low for both systems.

Recommendations for future developments of sanitation systems in central El Alto would be to:

- inspect and renew large parts of the conventional sewer network in order to ensure minimal seepage of storm water and
- increase treatment capacity of and expand the treatment facilities of the conventional system before connecting more households to the sewer network. Removal of bottom sludge would be a good start.

In areas where the coverage of sewer network is poor, the recommendation would be to:

- focus financial resources on on-site sanitation solutions such as the UDDT system.

These measures would imply less risk of infection derived from infectious wastewater flows, less discharge of emissions eutrophying Lake Titicaca, a higher potential for nutrient recycling which creates a higher potential for financial value of recycled products and more satisfied users.

6 REFERENCES

Agua Tuya (n.d.). *¿Qué hacemos?*. Available: https://aguatuya.org/que-hacemos [2019-11-15]

Andersson, K., Rosemarin, A., Lamizana, B., Kvarnström, E., McConville, J., Seidu, R., Dickin, S. & Trimmer, C. (2016). *Sanitation, Wastewater Management and Sustainability: from Waste Disposal to Resource Recovery.* Nairobi and Stockholm: United Nations Environment Programme and Stockholm Environment Institute. Available: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/2636 [2019-11-15]

Archundia, D., Duwig, C., Spadini, L., Uzu, G., Guédron, S., Morel, M.C., Cortez, R., Ramos Ramos, O., Chincheros, J. & Martins, J.M.F. (2017). How Uncontrolled Urban Expansion Increases the Contamination of the Titicaca Lake Basin (El Alto, La Paz, Bolivia). *Water, Air & Soil Pollution*, vol. 228 (44). DOI: https://doi-org.ezproxy.its.uu.se/10.1007/s11270-016-3217-0

Balkema, A.J., Preisig, H.A., Otterpohl, R. & Lambert, F.J.D. (2002). Indicators for the sustainability assessment of wastewater treatment systems. *Urban Water*, vol. 4 (2), pp. 153-161. DOI: https://doi.org/10.1016/S1462-0758(02)00014-6

Bishop, R.A. & Litch, J.A. (2000). Malaria at High Altitude. *Journal of Travel Medicine*, vol. 7 (3), pp. 157-158. DOI: https://doi.org/10.2310/7060.2000.00049

Bodík, I. & Ridderstolpe, P. (2008). *SUSTAINABLE SANITATION IN CENTRAL AND EASTERN EUROPE – addressing the needs of small and medium-size settlements*. 2. ed. Slovenia: Global Water Partnership Central and Eastern Europe. Available: https://wrs.se/wp-content/uploads/2014/03/Ridderstolpe_GWP_SustainableSanitation-in-CEE_2008.pdf [2019-11-21]

Camargo-Valero, M.A. & Mara, D. (2010). Ammonia volatilisation in waste stabilisation ponds: A cascade of misinterpretations? *Water Science & Technology*. DOI: 10.2166/wst.2010.856

Cáceres Magnus, H. (2018). *Principios para la construcción y mantenimiento de tu sistema de saneamiento*. Available: https://cutt.ly/qrxAHQu [2010-01-14]

CIFOR (Center for International Forestry Research) (1999). Jakarta: CIFOR. Available: https://www.cifor.org/acm/download/toolbox9.zip [2019-11-22]

Cossio, C., Rauch, S., Mcconville, J.R. & Mercado, A. (2017). *Wastewater management in developing countries: Bolivia case studies. Proceedings of the 40th WEDC International Conference* IN: Shaw, R.J. (ed). Local action with international cooperation to improve and sustain water, sanitation and hygiene (WASH) services, Paper 2776, 4pp, 24-28 July 2017, Loughborough, UK. Available: https://pdfs.semanticscholar.org/2b78/

74eab942d14f1cf3196fd2d6f1428893777d.pdf [2019-08-28]

DCLG (Department for Communities and Local Government: London) (2009). *Multi-criteria analysis: a manual*. West Yorkshire: Communities and Local Government Publications. Available: http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf [2019-11-27]

Dowd, F.V. (1935). Explosions in Sewers. *Canadian Public Health Journal*, vol. 26 (9), pp. 440-446. Available: https://www.jstor.org/stable/41977280 [2019-10-18]

EAWAG (Swiss Federal Institute of Aquatic Science and Technology) (2019). *Waste Stabilisation Ponds*. Available: https://sswm.info/factsheet/waste-stabilisation-ponds#Operation_and_Maintenance [2019-09-20]

EAWAG (2019a). *UDDT*. Available: https://sswm.info/taxonomy/term/2660/uddt [2019-09-20]

EAWAG (2008). *Sandec Training Tool 1.0 - Module 5: Faecal Sludge Management (FSM)*. Available: https://sswm.info/sites/default/files/reference_attachments/EAWAG%20SANDEC%202008%20Module%205%20FSM%20Lecture.pdf [2019-09-26]

ECOSOC (Economic and Social Council - United Nations) (2019). *Special edition: progress towards the Sustainable Development Goals*. Available: https://undocs.org/E/2019/68 [2019-11-04]

Educa (2013). *Distritos Municipales - Municipio de El Alto*. Available: https://www.educa.com.bo/geografia-municipios/distritos-municipales-municipio-de-el-alto

Edwin, G.A., Gopalsamy, P & Muthu, N. (2014). Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review. *Applied Water Science,* vol. 4, pp. 39-49. https://doi.org/10.1007/s13201-013-0128-8

EPA (United States Environmental Protection Agency) (2003). *Wastewater Technology Fact Sheet: Screening and Grit Removal*. Available: https://www3.epa.gov/npdes/pubs/final_sgrit_removal.pdf [2019-11-12]

EPA (1999). *Collection Systems O&M Fact Sheet: Sewer Cleaning and Inspection*. Available: https://www3.epa.gov/npdes/pubs/sewcl.pdf [2019-11-12]

EPSAS (2019). *EPSAS inicia ampliación del alcantarillado sanitario - Sexta Fase- en el distrito 7 El Alto* Available: https://www.epsas.com.bo/web/epsas-inicia-ampliacion-del-alcantarillado-sanitario-sexta-fase-en-el-distrito-7-el-alto/. [2019-08-13].

Europeiska rådet (1991). Rådets direktiv ac den 21 maj 1991 om rening av avoppsvatten fån tätbebyggelse (91/271/EGG). *Europeiska gemenskapernas officiella tidning*, vol. 10 (15).

FAOSTAT (2017). *Food balance sheets: Bulk Downloads All Data*. Available: http://www.fao.org/faostat/en/#data/FBS [2019-11-03]

Ferrara, R.A. & Avci, C.B. (1982). *Nitrogen Dynamics in Waste Stabilization Ponds*. Available: https://www.jstor.org/stable/25041314 [2019-09-17]

FSH (2015). *El saneamiento ecológico como propuesta hacia un nuevo proceso civilizatorio del Vivir Bien: Sistematización de experiencia de la Funcación FSH 2007-2013* 2.ed. La Paz: FSH.

FSH (2011). *Evaluación económica de las tecnologías de disposición de excretas para centros urbanos en Bolivia*. Available: http://www.sumaj.org/wp-content/uploads/2012/08/INFORME-FINAL-ver-2.pdf [2019-10-15]

FSH (n.d.). *Visión y misión*. Available: http://www.sumaj.org/vision-y-mision/ [2019-10-18]

GAMEA (2019). *Plan Territorial de Desarrollo Integral 2016-2020*. Available: https://www.elaltodigital.com/wp-content/uploads/2017/08/plan_territorial_desarrollo_elalto_2016_2020.pdf [2019-05-29]

Ghaitidak, D. & Yadav, K. (2013). Characteristics and treatment of greywater - A review. *Environmental science and pollution research international* DOI: 10.1007/s11356-013-1533-0

Heinss, U., Larmie, S.A. & Strauss, M. (1998). *Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropicals*. 2. ed. Duebendorf: EAWAG/SANDEC. (SANDEC Report, 1998:5). Available: https://www.ircwash.org/sites/default/files/342-98SO-14523.pdf [2019-11-03]

Helgegren, I., Rauch, S., Cossio, C., Landaeta, G & McConville, J. (2018). Importance of triggers and veto-barriers for the implementation of sanitation in informal peri-urban settlements – The case of cochabamba, Bolivia. *PLOS ONE*, vol. 13 (4). DOI: https://doi.org/10.1371/journal.pone.0193613

Hellström, D., Jeppsson, U. & Kärrman, E. (2000). A framework for systems analysis of sustainable urban water management. *Environment Impact Assessment Review*, vol. 20 (3), pp. 311-321. DOI: https://doi.org/10.1016/S0195-9255(00)00043-3

Hoffman, D. & Requena, C. (2012). *Bolivia en un mundo 4 grados más caliente: Escenarios sociopolíticos ante el cambio climático para los años 2030 y 2060 en el altiplano norte*. La Paz: Instituto Boliviano de la Montaña.

INE (Instituto Nacional de Estadística) (2018). *Población de El Alto alcanza a más de 922 mil habitantes*. Available: https://www.ine.gob.bo/index.php/prensa/notas-de-prensa/item/3118-poblacion-de-el-alto-alcanza-a-mas-de-922-mil-habitantes [2019-11-28]

INE (2015). *Censo de Población y Vivienda 2012 BOLIVIA: Características de la Vivienda*. Available: https://www.ine.gob.bo/index.php/prensa/publicaciones/visor-de-publicaciones/item/3301-censo-de-poblacion-y-vivienda-2012-bolivia-caracteristicas-de-la-poblacion [2019-11-11]

INE (2015a). *Censo de Población y Vivienda 2012 BOLIVIA: Características de la Población* Available: https://www.ine.gob.bo/index.php/prensa/publicaciones/visor-de-publicaciones/item/3301-censo-de-poblacion-y-vivienda-2012-bolivia-caracteristicas-de-la-poblacion [2019-11-28]

Insumos Bolivia (n.d.). *Insumos Bolivia cuenta con 82,240 bolsas de fertilizantes para pequeños productores*. Available: http://www.insumosbolivia.gob.bo/2-insumos-bolivia-cuenta-con-82-240-bolsas-de-fertilizantes-para-pequenos-productores [2019-10-15]

Jönsson, H., Richert Stinzing, A., Vinnerås, B & Salomon, E. (2004). *Guidelines on the Use of Urine and Faeces in Crop Production*. SEI and EcoSanRes Programme Report 2004-2). Available: http://www.ecosanres.org/pdf_files/ESR_Publications_2004/ESR2web.pdf [2019-12-02]

Jönsson, H. & Vinnerås, B. (2004). Adapting the nutrient content of urine and faeces in different countries using FAO and Swedish data. *Ecosan-closing the Loop, 2nd International Symposium on Ecological Sanitation. Luebeck, Germany* Available: https://www.researchgate.net/publication/285858813_Adapting_the_nutrient_content_of_urine_and_faeces_in_different_countries_using_FAO_and_Swedish_data [2019-09-16]

Kayaga, S., Mugabi, J & Kingdom, W. (2013). Evaluating the institutional sustainability of an urban water utility: A conceptual framework and research directions. *Utilities Policy*, vol. 27, pp. 15-27. DOI: https://doi.org/10.1016/j.jup.2013.08.001

Klöpffer, W. & Grahl, B. (2014). *Life Cycle Assessment (LCA): A Guide to Best Practice*. Weinheim: John Wiley & Sons, Incorporated. Available: Ebook Central. [2019-11-27]

Knudsen, A-B. & Slooff, R. (1992). Vector-borne disease problems in rapid urbanization: new approaches to vector control. *Bull World Health Organ*, vol. 70 (1), pp. 1-6. Available: https://www.ncbi.nlm.nih.gov/pubmed/1568273 [2019-11-14]

Knutsen, K. L., Guzzardo-Plewa, K., M. & Lopez, N., S. (2006). *Diseño del sistema séptico para el colegio Polifuncional Calama Santa Cruz, Bolivia: CE4905: Civil &*

Environmental Engineering Senior Design Project: Equipo: ISD (Las Ingenieras LSS) Mary Anderson, Kasey Cornwell and Melissa Trahan. Available: http://www.cee.mtu.edu/projects/Projects_2005/espanol/calama.pdf [2019-08-23]

Kujawa-Roeleveld, K. & Zeeman, G. (2006). Anaerobic treatment in decentralised and source-separation-based sanitation concepts. *Reviews in Environmental Science and Bio/Technology*, vol. 5 (1), pp. 115-139. DOI: 10.1007/s11157-005-5789-9

Kuwornu, A.L.K & Obiri-Danso, K. (2015). Assessment Of NPK In Human Male And Female Urine For Its Fertilising Potential In Agriculture. *International journal of scientific & technology research*, vol. 4 (8). Available: https://cutt.ly/xrxAiSR [2020-01-14]

Kvarnström, E., Bracken, P., Ysunza, A., Kärrman, E., Finnson, A. & Saywell, D. (2004). *People-centred approaches to water and environmental sanitation: Sustainability Criteria in Sanitation Planning. Proceedings of the 30th WEDC International Conference*. 2004, Vientiane, Lao PDR. Available: https://repository.lboro.ac.uk/articles/Sustainability_criteria_in_sanitation_planning/9594950/files/17235197.pdf [2019-11-04]

Kvarnström, E., Emilsson, K, Richert Stintzing, A., Johansson, M, Jönsson, H, af Petersens, E., Schönning, C., Christensen, J., Hellström, D., Qvarnström, L., Ridderstolpe, P & Drangert, J-O. (2016). *Urine Diversion: One Step Towards Sustainable Sanitation*. (SEI and EcoSanRes Programme Report 2006-1). Available: https://www.sei.org/mediamanager/documents/Publications/SEI-Report-Kvarnstrom-UrineDiversion-2006-1.pdf [2019-06-09]

Kärrman, E., Arnell, M., Rydhagen, B, Svensson, G & Wittgren, H-B. (2012), *Multikriterieanalys för integrerade systemlösningar i H+ området*. (Urban Water Management, Assignment number 120010) Available: https://hplus.helsingborg.se/wp-content/uploads/sites/74/2016/11/delutredning_02_h-evaa_urban_water_20121009.pdf [2019-11-06]

Lennartsson, M., Kvarnström, E., Lundberg, T., Buenfil, J. & Sawyer, R. (2009). *Comparing Sanitation Systems Using Sustainability Criteria*. (SEI, EcoSanRes Series Report, 2009-1). Available: http://www.ecosanres.org/pdf_files/ESR2009-1-ComparingSanitationSystems.pdf [2019-08-22]

MAE Ecuador (Ministerio del Ambiente de la República del Ecuador) (2003). Norma de Calidad Ambiental y de Descarga de Efluentes: Recurso Agua. Available: http://extwprlegs1.fao.org/docs/pdf/ecu112180.pdf

Mara, D. (2003). *Domestic Wastewater Treatment in Developing Countries*. London: Earthscan. Available: https://www.pseau.org/outils/ouvrages/earthscan_ltd_domestic_wastewater_treatment_in_developing_countries_2003.pdf

Mara, D., Drangert, J-O., Anh, N.V., Tonderski, A., Gulyas, H. & Tonderski, K. (2007). Selection of sustainable sanitation arrangements. *Water Policy*, vol. 9 (3), pp. 305-318. DOI: https://doi.org/10.2166/wp.2007.009

Maurer, M., Schwegler, P. & Larsen, T.A. (2003). Nutrients in urine: energetic aspects of removal and recovery. *Water Science and Technology,* vol. 48 (1), pp. 37–46. Available: https://iwaponline.com/wst/article-pdf/48/1/37/422966/37.pdf [2019-10-09]

Mejía, A., Uzcátegui, G. & Valverde, O. (2017). *Agua y saneamiento en el Estado Plurinacional de Bolivia*. Development Bank of Latin America Report. DOI: 978-980-422-078-4

Metcalf & Eddy. (2003). *Wastewater Engineering, Treatment and Reuse* New York: The McGraw-Hill Companies.

Metcalf & Eddy. (2014). *Wastewater Engineering: Treatment and Resource Recovery.* 5. ed. New York: The McGraw-Hill Companies.

Middlebrooks, E.J., Reed, S.C., Pano, A & Adams, D. (1999) *Nitrogen Removal in Wastewater Stabilization Lagoons. Proceeding of the 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop.* Kansas City, Missouri 64105, August 2-4, 1999. Available: https://www.researchgate.net/publication/238695616_Nitrogen_Removal_in_Wastewater_Stabilization_Lagoons [2019-11-01]

MMAyA (2014). *Plan Maestro Metropolitano de Agua Potable y Saneamiento La Paz - El Alto, Bolivia: Estudio de Identificación No.6 Mejoramiento y Ampliación de la Planta de Tratamiento de Aguas Residuales "Puchukollo" de la Ciudad de El Alto*. La Paz: Estado Pluronacional de Bolivia.

MMAyA (2013). *Sistematización sobre tratamiento y reúso de aguas residuales*. La Paz: GIZ. Available: http://www2.congreso.gob.pe/sicr/cendocbib/con4_uibd.nsf/BAAB4A78988575BD052581840071238E/$FILE/22.1.aguas-residuales-reuso.pdf [2019-10-22]

MMAyA (2010). *Guía Técnica de Diseño y Ejecución de Proyectos de Agua y Saneamiento con Tecnologías Alternativas*. Available: http://saludpublica.bvsp.org.bo/textocompleto/bvsp/boxp68/guia-tecnica-agua.pdf [2019-10-16]

Molinos-Senante, M., Gómez, T., Garrido-Baserba, M., Caballero, R. & Sala-Garrido, R. (2014). Assessing the sustainability of small wastewater treatment systems: A composite indicator approach. *Science of The Total Environment*, vol. 497-498, pp. 607-617. DOI: 10.1016/j.scitotenv.2014.08.026

Mosaic (2019). *Data Sheet: Diammonium Phosphate 18-46-0*. Available: http://www.mosaicco.com/documents/Diammonium_Phosphate.pdf [2019-10-15]

Mosaic (2018). *Diammonium Phosphate (DAP) 18-46-0*. Available: http://www.mosaicco.com/products/crop_nutrition_phosphates_daimmonium_phosphate.htm [2019-10-15]

Murad, S. & Dickin, S. (2016). *Benefits and barriers to safe use of ecological sanitation in El Alto, Bolivia – a need for improved hygiene education?*. [Brochure]. Stockholm: SEI. Available: https://mediamanager.sei.org/documents/Publications/SEI-2016-DB-Dickin-Murad-ElAlto.pdf [2019-08-21]

Neczaj, E. & Grosser, A. (2018). *Circular Economy in Wastewater Treatment Plant - Challenges and Barriers. Proceedings of the 3rd EWaS International Conference on "Insights on the Water-Energy-Food Nexus"*. Faculty of Infrastructure and Environment, Czestochowa University of Technology 27–30 June 2018, Lefkada Island, Greece. Available: https://www.researchgate.net/publication/326739277_Circular_Economy_in_Wastewater_Treatment_Plant-Challenges_and_Barriers/fulltext/5b8986c9a6fdcc5f8b75b4d3/Circular-Economy-in-Wastewater-Treatment-Plant-Challenges-and-Barriers.pdf [2019-09-13]

NORAD (North American Aerospace Defense Command)(2000). *Handbook in Assessment of Institutional Sustainability*. Available: https://www.civicspace.eu/upload/library/handbook-in-assessment-of-institutional-sustainability-5d628ff8d1d9d.pdf [2019-09-03]

Nuroil (n.d.). *Urea 46% Nitrogen*. Available: http://www.nuroil.com/fertilizer-urea-46-nitrogen.aspx [2019-10-15]

Oakley, S. & Salguero, L. (2011). *Tratamiento de Aguas Residuales Domésticas en Centroamérica Un Manual de Experiencias, Diseño, Operación y Sostenibilidad* Available: https://www.academia.edu/32535291/Tratamiento_de_Aguas_Residuales_Dom%C3%A9sticas_en_Centroam%C3%A9rica [2019-06-12]

Oteng-Peprah, M., de Vries, N.K. & Acheampong, M.A. (2016). Greywater characterization and generation rates in a peri urban municipality of a developing country. *Journal of Environmental Management*, vol. 206, pp. 498-506. DOI: https://doi.org/10.1016/j.jenvman.2017.10.068 [2019-09-16]

Page, S.E. (2011). *Diversity and complexity*. New Jersey: Princeton University press.

Poveda, C. A. (2017). *SUSTAINABILITY ASSESSMENT: A Rating System Framework for Best Practices*. United Kingdom: Emerald Publishing. Available: https://books.emeraldinsight.com/resources/pdfs/chapters/9781787434820-TYPE23-NR2.pdf

Programa de Agua y Saneamiento (2001). *Sistemas condominiales de alcantarillado sanitario: Guia de prodcedimientos: Proyecto piloto El Alto - Bolivia.*. Available: https://www.wsp.org/sites/wsp/files/publications/35200761558_prueba4.pdf [2019-08-16]

Proyecto NODO (Proyecto NODO de Saneamiento Sostenible Descentralizado como Plataforma de Conocimiento y Generación de Impacto en Soluciones Sostenibles) (2014). *Documento de trabajo: Modelo Integral de Sostenibilidad de Saneamiento*

Ecológico Caso Fundación FSH. Available: http://www.snv.org/public/cms/sites/default/files/explore/download/modelo_integral_bes.pdf [2019-08-26]

Radin Mohamed, R. M. S., Mohamed Kassim, A. H. & Anda, M. (2013). A monitring of environmental effects from household greywater reuse for garden irrigation. *Environmental Monitoring and Assessment*, vol. 185, pp. 8473–8488. DOI: https://doi-org.ezproxy.its.uu.se/10.1007/s10661-013-3189-0 [2019-08-26]

Randers, J., Rockström, J., Espen Stoknes, P., Golüke, U., Collste, D. & Cornell, S. (2018). *Transformation is feasable: How to achieve the Sustainable Development Goals within Planetary Boundaries*. (Stockholm Resilience Center Report) Available: https://www.stockholmresilience.org/download/18.51d83659166367a9a16353/1539675518425/Report_Achieving%20the%20Sustainable%20Development%20Goals_WEB.pdf [2019-11-04]

Raworth, K. (n.d.). What on Earth is the Doughnut?.... *Kate Raworth: exploring doughnut economics*. [Blog]. Available: https://www.kateraworth.com/doughnut/ [2019-11-04]

Richert, A., Gensch, R., Jönsson, H., Stenström, T-A. & Dagerskog., L. (2010). *Practical Guidance on the Use of Urine in Crop Production* (SEI, EcoSanRes Series Report, 2010-1) Available: http://www.ecosanres.org/pdf_files/ESR2010-1-PracticalGuidanceOnTheUseOfUrineInCropProduction.pdf [2019-12-02]

Rieck, C., von Münch, E & Hoffmann, H. (2012). *Technology Review of Urine-diverting dry toilets (UDDTs): Overview of design, operation, management and costs*. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Salisbury, F., Brouckaert, C., Still, D. & Buckley, C. (2018). Multiple criteria decision analysis for sanitation selection in South African municipalities. *Water SA*, vol. 33 (3). DOI: http://dx.doi.org/10.4314/wsa.v44i3.12

Saltelli, A. (2002). Sensitivity Analysis for Importance Assessment. *Risk Analysis: An International Journal*, vol. 22 (3), pp. 579 - 590. DOI: 10.1111/0272-4332.00040

Sasse, L. (1998). *DEWATS Decentralised Wastewater Treatment in Developing Countries*. Germany: Bremen Overseas Research and Development Association (BORDA). Available: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/1933 [2019-09-23]

Seleman, A. & Bhat, M.G. (2016). Multi-criteria assessment of sanitation technologies in rural Tanzania: Implications for program implementation, health and socio-economic improvements. *Technology in Society*, vol. 46, pp. 70-79. DOI: https://doi.org/10.1016/j.techsoc.2016.04.003

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales) (1997). *Normas Oficiales Mexicanas*. Available: http://www.conagua.gob.mx/CONAGUA07/Publicaciones/

Publicaciones/SGAA-15-13.pdf [2019-10-22]

Senzia, M.A., Mayo, A.W., Mbwette, T.S.A., Katima, J.H.Y. & Jørgensen, S.E. (2002). Modelling nitrogen transformation and removal in primary facultative ponds. *Ecological modelling*, vol. 154 (3), pp. 207-215. DOI: https://doi.org/10.1016/S0304-3800(02)00018-2

Silveti, D. & Andersson, K. (2019). Challenges of Governing Off-Grid "Productive" Sanitation in Peri-Urban Areas: Comparison of Case Studies in Bolivia and South Africa. *Sustainability*, vol. 11 (12), pp. 3468. DOI: https://doi.org/10.3390/su11123468

SNV Bolivia (Servicio Holandés para el Desarrollo) (2017). *Diseño de una iniciativa piloto para la gestión de lodos fecales domiciliarios en áreas periurbanas de la ciudad de Santa Cruz - Bolivia*. Available: http://www.snv.org/public/cms/sites/default/files/explore/download/lodos_feales._informe_final.pdf [2020-01-11]

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., 14, Persson, L.M., Ramanathan, V., Reyers, B. & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, vol. 347 (9223, 1259855). DOI: 10.1126/science.1259855

Stenström, T.A., Seidu, R., Ekane, N. & Zurbrügg, C. (2011). *Microbial Exposure and Health Assessments in Sanitation Technologies and systems.* (SEI, EcoSanRes Series Report, 2009-1) Available: http://www.ecosanres.org/pdf_files/Microbial_Exposure_&_Health_Assessments_in_Sanitation_Technologies_&_Systems.pdf [2019-10-03]

SuSanA (2008). *Towards more sustainable sanitation solutions*. (SuSanA Report, version 1.2) Available: https://www.susana.org/_resources/documents/default/3-267-7-1452594644.pdf [2019-11-18]

Taucer Monrroy, E.R. (2019). *Diagnóstico Procedimientos para la Recolección, Transporte y Descarga Segura de Lodos Fecales Domiciliarios*. Available: http://documents.worldbank.org/curated/en/648221563785580999/pdf/Diagnostico-Procedimientos-para-la-Recolecci%C3%B3n-Transporte-y-Descarga-Segura-de-Lodos-Fecales-Domiciliarios.pdf [2019-10-13]

Tilley, E., Atwater, J. & Mavinic, D. (2008). Effects of Storage on Phosphorous Recovery from Urine. *Environmental Technology*, vol. 29 (7), pp. 807-816. DOI: https://doi.org/10.1080/09593330801987145

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). *Compendium of Sanitation Systems and Technologies*. 2nd Revised Edition. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Ewag).

Tiwari, R.R. (2008). Occupational health hazards in sewage and sanitary workers. *Indian*

Journal of Occupational and Environmental Medicine, vol. 12 (3), pp. 112-5. DOI: 10.4103/0019-5278.44691

UN-Water (2016) *Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development* Geneva: 2016. Available: https://www.unwater.org/app/uploads/2016/08/Water-and-Sanitation-Interlinkages.pdf [2019-11-18]

UN-Water (n.d.). *Target 6.2 – Sanitation and hygiene*. Available: https://www.sdg6monitoring.org/indicators/target-6-2/ [2019-11-18]

USEPA (United States Environmental Protection Agency) (2002). *Onsite Wastewater Treatment Systems Manual*. Available: https://www.epa.gov/sites/production/files/2015-06/documents/2004_07_07_septics_septic_2002_osdm_all.pdf [2019-08-28]

Vendramelli, R.A., Vijay, S. & Yuan, Q. (2016). Phosphorus Removal Mechanisms in a Facultative Wastewater Stabilization Pond. *Water, Air & Soil Pollution*, vol. 227 (417). DOI: 10.1007/s11270-016-3130-6

Vidal, B., Hedström, A., Barraud, S., Kärrman, E & Herrmann, I. (2019). y. *Environmental Science: Water Research & Technology*, vol. 5, pp. 1599-1615. DOI: 10.1039/c9ew00425d

Vijay, S. & Yuan, Q. (2017). Simplified empirical model for phosphorous removal in a facultative wastewater lagoon. *Journal of Environmental Environment*, vol. 201, pp. 1-5. DOI: https://doi.org/10.1016/j.jenvman.2017.06.023

Wagner, W. (2010). *Recomendaciones para la elección de plantas de tratamiento de agua residual aptas para Bolivia*. La Paz: ANESAPA, CIM, GTZ, PROAPAC. Available: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/870 [2019-11-10]

Water1st International (n.d.). *Paths of disease transmission*. Available: https://water1st.org/problem/f-diagram/ [2020-01-02]

WCED (World Commission on Environment and Development) (1087). *Report of the World Comission on Environment and Development*. (United Nations Report, A/43/427) Available: https://sswm.info/sites/default/files/reference_attachments/UN%20WCED%201987%20Brundtland%20Report.pdf [2019-11-27]

WHO (2016). *Sanitation Safety Planning: manual for safe use and disposal of wastewater, greywater and excreta*. France: WHO Press. Available: https://apps.who.int/iris/bitstream/handle/10665/171753/9789241549240_eng.pdf;jsessionid=1072B10CCF3C988E11DA9C5129F27006?sequence=1 [2019-08-20]

WHO (2014). *Preventing diarrhea through better water, sanitation and hygiene: exposures and impacts in low- and middle-income countries*. France: WHO Press. Available: https://apps.who.int/iris/bitstream/handle/10665/150112/9789241564823_eng.pdf; jsessionid=1D28B7D7033A500DF4D9C4D351ECA282?sequence=1 [2019-08-21]

WHO (2006). *GUIDELINES FOR THE SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER: Excreta and greywater use in agriculture*. France: WHO Press. Available: https://www.who.int/water_sanitation_health/publications/gsuweg4/en/ [2019-11-08]

Wisconsin DHS (Wisconsin Department of Health Services) (2017). *Sewer gas*. Available: https://www.dhs.wisconsin.gov/air/sewergas.htm [2019-10-18]

Wohlsager, S., Clemens, J., Nguyet, P.T., Rechenburg, A. & Arnold, U. (2010). Urine - A Valuable Fertilizer with Low Risk after Storage in the Tropics. *Water Environment Research*, vol. 82 (9), pp. 840-847. Available: https://www.jstor.org/stable/27870384 [2019-09-10]

Yadav, K.D., Tare, V. & Ahammed, M.M. (2011). Vermicomposting of source-separated human faeces by Eisenia fetida: Effect of stocking density on feed consumption rate, growth characteristics and vermicompost production. *Waste Management*, vol. 31 (6), pp. 1162 - 1168. DOI: https://doi.org/10.1016/j.wasman.2011.02.008

Yadav, K.D., Tare, V. & Ahammed, M.M. (2009). Vermicomposting of source-separated human faeces for nutrient recycling. *Waste Management*, vol. 30 (2010), pp. 50-56. DOI: 10.1016/j.wasman.2009.09.034

7 UNPUBLISHED MATERIAL

Personal communication with Executive Director of AAPS, Director of Environmental Regulation in Water Resources of AAPS and Engineer in Wastewater Treatment Plants of AAPS. 11 June 2019.

Personal communication with Chairman of the board of Agua Tuya. 29 August 2019.

Personal communication with Coordinator of the Technical Area of FSH. 18 June 2019.

Personal communication with Coordinator of the Technical Area of FSH. 22 March 2019.

Personal communication with Coordinator of the Technical Area of FSH. 9 April 2019.

Personal communication with Executive Director of FSH, 25 October Psychologist specialized in Social Areas. 13 June 2019.

Personal communication with Municipal Secreteriat of Water, Sanitation, Environmental Management and Risks at GAMEA. 23 May 2019.

Personal communication with Psychologist specialized in Social Areas and neighbor in

El Alto, Carla Ramirez Alanoca. 13 June 2019.

Unpublished documents from 2019, received from AAPS. 11 June 2019.

Unpublished document from 2018, received from FSH. April 2019.

Unpublished documents from 2011, received from FSH. 4 October 2019.

Unpublished document from 1992, received from UNICEF Bolivia. 27 September 2019.

APPENDICES

A Interview questions at a household level

Fecha y hora:
Nombre del entrevistado/a:
Edad del entrevistado/a:
Género del entrevistado/a:
Rol que ocupa en el hogar:
Número de personas que viven en el hogar:
Dirección del hogar:
Distrito del hogar:

Preguntas sobre aspectos socioculturales:

1. ¿Qué le parece la facilidad de uso de su sistema de inodoro?
   Muy satisfecho / satisfecho / ni satisfecho ni insatisfecho / no tan satisfecho / no satisfecho en absoluto
2. ¿Qué le parece el trabajo que requiere para manejar el sistema de inodoro?
   Muy fácil / fácil / ni fácil ni complicado / complicado / muy complicado
3. ¿Qué le parece los ruidos u olores eventuales del sistema de inodoro de su hogar?
   Muy cómodo / cómodo / ni cómodo ni incómodo / incómodo / muy incómodo
4. En su opinión, ¿qué tan seguro encuentra su sistema de inodoro? ¿Por qué?
   Muy seguro / seguro / ni seguro ni inseguro / inseguro / muy inseguro
5. ¿De qué material es su baño?
   Cemento / azulejo / otro

Preguntas sobre la evaluación de riesgos para la salud:

1. ¿Qué problemas ha encontrado del sistema del inodoro?
   UDDT: el contenedor de heces u orina se llena antes del día de recolección / Asiento de inodoro roto / ducha rota / lavabo roto / filtro de aguas grises roto / recipiente de heces roto / recipiente de orina roto / otro

   CONV: inodoro tapado / asiento del inodoro roto / botón de descarga roto / ducha rota / fregadero roto / otro
2. (Pregunta de seguimiento UDDT ¿Qué tan seguido se llena el recipiente de heces u orina antes del día de recolección?)
   Cada dos semanas / Cada dos meses / algunas veces al año / solo en ocasiones especiales / Nunca

3. (Pregunta de seguimiento UDDT¿Qué hace si el recipiente de heces u orina se llena antes del día de recolección?)
   Llama al proveedor del servicio inmediatamente / Llama al proveedor del servicio dentro de los 48 / Llama al proveedor del servicio después de las 48 h / Espera hasta que el próximo día de recolección

4. (Pregunta de seguimiento CONV:¿Qué tan seguido ocurre que se tapa el alcantarillado principal?)
   Cada dos semanas / Cada dos meses / unas cuantas veces al año / solo cuando el material sólido se ha lavado / Nunca

5. (Pregunta de seguimiento CONV: ¿Qué hace si el alcantarillado se tapa?)
   Llamar al proveedor de servicios inmediatamente / Llamar al proveedor de servicios dentro de los 48 / Llamar al proveedor de servicios después de las 48 h / Esperar a hablar con el proveedor de servicios mientras evita usar el baño o hasta que venga

6. (Pregunta de seguimiento: ¿Qué tan seguido ocurre [. . . alguno de los otros problemas / fallos mencionados ...]?)
   Cada dos semanas / Cada dos meses / Algunas veces al año / Pasan varios años sin ninguna falla / Nunca.

7. (Pregunta de seguimiento: ¿Qué hace si [. . . alguno de estos problemas / fallos de funcionamiento mencionados ...] ocurre?)
   Llame al proveedor de servicios de inmediato / Llame al proveedor de servicios dentro de los 48 / Llame al proveedor de servicios después de los 48 / Arreglarlo yo mismo / nada

8. (Pregunta de seguimiento: ¿Por cuánto tiempo tiene que esperar hasta que llega el proveedor de servicios?)
   Hasta un día / hasta una semana / hasta un mes / más de un mes / No llega

9. (Pregunta de seguimiento: ¿Qué hace mientras espera que el proveedor de servicios venga?)
   Continua usando el inodoro / Deja de usar el inodoro / Usa el inodoro de los vecinos / cambia a otro recipiente de heces u orina / Usa las heces u orina no tratadas como fertilizante / descarga la orina o las heces en algún lugar cercano / otro

(PREGUNTA ADICIONAL: ¿Cuáles cree que son los beneficios y los desafíos de su sistema de inodoro?)

B Sustainability criteria and associated subcriteria: an example

Criteria and subcriteria with suitable indicators for evaluation of sustainability of sanitation systems suggested by Kvarnström et al. (2004).

Criteria and subcriteria	**Indicator**
Health	
Risk of infection of complete use of system	Risk assessment or qualitative
Risk of exposure to hazardous substances: heavy metals, medical residues, organic compounds	Risk assessment or qualitative
Environment	
Use of natural resources, construction and O&M	
Land (investment, constr. and O&M	m^2/pe
Energy (constr. and O&M)	MJ/pe
Construction material (constr.)	Type and volume
Chemicals (constr. and O&M)	Type and volume
Fresh water (O&M)	
Discharge to water bodies	
BOD/COD	g/pe/yr
Impact on eutrophication	g/pe/yr of N and P
Hazardous substances: heavy metals, persistent organic compounds, antibiotics/medical residues, hormones	mg/pe/yr
Air emissions	
Contribution to global warming	kg of CO_2 equivalent/yr
Odour	Qualitative
Resources recovered	
Nutrients	% of incoming to the system
Energy	% of the consumption within the system
Organic material	% of incoming to the system
Water	% of incoming to the system
Quality of recycled product (released to soil)	
Hazardous substances: heavy metals, persistent organic compounds, antibiotics/medical residues, hormones	mg/unit

(continued)

Criteria and subcriteria	Indicator
Technical function	
System robustness: risk of failure, effect of failure, structural stability, robustness against extreme conditions	Qualitative
Robustness of use of system: shock loads, abuse of system	Qualitative
Possibility to use local competence for construction and O&M	Qualitative
Ease of system monitoring	Qualitative
Durability/ Lifetime	Qualitative
Complexity of construction and O&M	Qualitative
Compatibility with existing systems	Qualitative
Flexibility / adaptability (to user needs and existing environmental conditions - high goundwater level, geology etc.)	Qualitative
Socio-culture (institutional and user)	
Willingnes to pay (% of available income)	Reasonable % of income - defined by users
Convenience (comfort, personal security, smell, noise, attractiveness, adaptability to different age, gender, and income groups	Qualitative
Institutional requirements	Qualitative
Responsibility requirements	Qualitative
Current legal acceptability	Qualitative
Approppriateness to current local cultural context (acceptable to use and maintain	Qualitative
System perception (complexity, compatibility, observability - including aspects of reuse)	Qualitative
Ability to address awareness and information needs	Qualitative
Economy	
Annual costs, including capital and maintenance costs	Cost/pe/yr
Capacity to pay - user (% of available income)	Disposable income/pe
Local development	Qualitative

C Health hazards associated with input/output products

	WASTE COMPONENTS									
	POTENTIAL BIOLOGICAL HAZARDS					POTENTIAL CHEMICAL HAZARDS		POTENTIAL PHYSICAL HAZARDS		
	Viruses	Bacteria	Protozoa	Helminths	Vector-related diseases	Toxic chemicals	Heavy metals	Sharp objects	Inorganic material	Malodours
Liquid waste fractions										
Diluted excreta (human or animal)	O	O	O	O						O
Urine (human or animal)	O	O	O	O						O
Domestic waste water	O	O	O	O	O			O	O	O
Stormwater	O	O	O	O	O	O	O	O		
River water	O	O	O	O	O	O	O			
Industrial wastewater (Note 1)						O	O			
Solid waste fractions										
Faecal sludge	O	O	O	O	O			O	O	O
WWTP sludge	O	O	O	O	O	O	O	O	O	O
Organic domestic waste	O	O			O					
Inorganic domestic waste						O	O	O	O	
Agricultural waste (crop residuals)	O	O	O	O	O			O	O	
Gardening waste					O				O	
Animal manure/slurry	O	O	O	O	O				O	O
Medical waste	O	O	O	O		O	O	O	O	O
Industrial waste						O	O	O	O	O
Slaughter house waste	O	O	O	O	O		O			O
Construction and demolition waste								O	O	

Health hazards associated with waste fractions (input/output products) are marked with an O (WHO, 2016).

D Identified hazards in input/output products

	Potential biological hazards					Potential chemical hazards	
	Viruses	Bacteria	Protozoa	Helminths	Vector-related diseases	Toxic chemicals	Heavy metals
CONVENTIONAL SYSTEM							
Liquid waste fractions							
Domestic mixed wastewater	x	x	x	x	x		
Solid waste fractions							
WWTP sludge	x	x	x	x	x	x	x
UDDT SYSTEM							
Liquid waste fractions							
Urine	x	x	x	x			
Greywater	x	x	x	x	x		
Solid waste fractions							
Faeces	x	x	x	x	x		

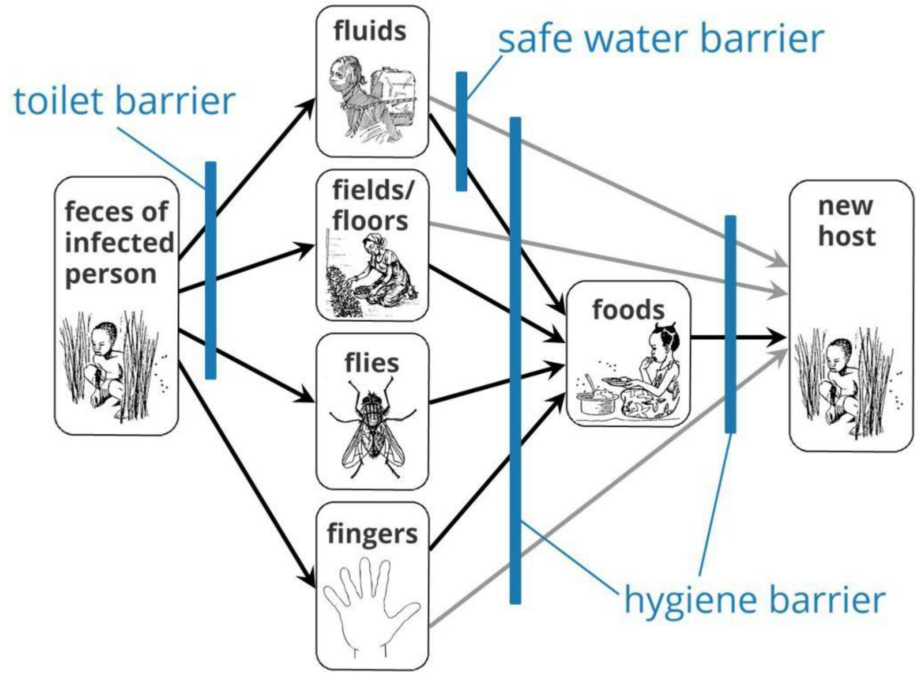
Identified hazards associated with input/output products within the respective system options are marked with crosses. The input/output products are listed in the rows under liquid waste fractions and solid waste fractions.

E Typical operation and maintenance tasks

Typical operation and maintenance tasks within the the conventional and the UDDT systems (Tilley et al, 2014; Mara, 2003; Metcalf & Eddy, 2003; Proyecto NODO, 2014; USEPA, 2002)

Conventional system
Routine inspection and maintenance tasks in man-holes or pumping stations in sewer network
Manual cleaning of bar screens and grit removal from grit chamber in pre-treatment phase
Cutting grass on embankments and removing it so that it does not fall into the pond.
Removal of floating scum and macrophytes from the surface of facultative and maturation ponds
Spraying scum on anaerobic ponds with clean water or pond effluent
Removal of accumulated solids in inlets and outlets
Repairing any damage to the embankments and external fences and gates.
Taking samples for laboratory analyzes
Removing sludge from WSP ponds
Safe handling of WWTP sludge
UDDT system
Manual collection and transportation of urine and faeces from households to treatment station including cleaning of vehicle and tools
Emptying faeces and urine from vecicle and transferring faeces in to drying beds and urine into storage tanks
Manual separation of larger inorganic compounds in faeces/ECO humus and oxygenation with spade
Control of humidity and temperature in faeces/ECO humus
Monitoring of humidity in faeces/ECO humus through addition of water
Taking samples for laboratory analyzes
Safe handling of ECO humus and treated urine

F F diagram



Disease transmission routs from feaces of an infected person are through fluids, fields/floors, flies, fingers and food (Water1st International, n.d.)

G Scale for determination of likelihood and severity of hazardous events

DESCRIPTOR		DESCRIPTION
Likelihood (L)		
1	Very Unlikely	Has not happened in the past and it is **highly improbable** it will happen in the next 12 months (or another reasonable period).
2	Unlikely	Has not happened in the past but **may occur in exceptional circumstances** in the next 12 months (or another reasonable period).
3	Possible	May have happened in the past and/or **may occur under regular circumstances** in the next 12 months (or another reasonable period).
4	Likely	Has been observed in the past and/or is **likely** to occur in the next 12 months (or another reasonable period).
5	Almost Certain	Has often been observed in the past and/or **will almost certainly occur** in most circumstances in the next 12 months (or another reasonable period).
Severity (S)		
1	Insignificant	Hazard or hazardous event resulting in **no or negligible health effects** compared to background levels.
2	Minor	Hazard or hazardous event potentially resulting in **minor health effects** (e.g. temporary symptoms like irritation, nausea, headache).
4	Moderate	Hazard or hazardous event potentially resulting in a **self-limiting health effects or minor illness** (e.g. acute diarrhoea, vomiting, upper respiratory tract infection, minor trauma).
8	Major	Hazard or hazardous event potentially resulting in **illness or injury** (e.g. malaria, schistosomiasis, food-borne trematodiases, chronic diarrhoea, chronic respiratory problems, neurological disorders, bone fracture); and/or may lead to legal complaints and concern; and/or major regulatory non-compliance.
16	Catastrophic	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); and/or will lead to major investigation by regulator with prosecution likely.

The likelihood and severity for risk events were assessed on a scale from very unlikely to almost certain and from insignificant to catastrophic (WHO, 2016)

H Assessment of likelihood of hazardous events

Hazardous events including transmission route, likelihood according to sources and likelihood as reported in this study - assessment for the conventional system.

Conventional system - WORKER			
No.	**Hazardous event including transmission route**	**Likelihood according to sources**	**Likelihood - reported in this study**
1.	Exposure to high concentration of gases during routine or occasional inspection and maintenance tasks in manholes or pumping stations in sewer network including sewer cleaning	Protective equipment might not be adequate since equipment do not allow breathing fresh air from above the manholes (personal communication Agua Tuya, 29 August 2019). However, explosions in public sewers have not yet been experienced in all large cities in America and Europe (Dowd, 1935). Subacute symptoms from smaller concentrations of the gases are the main danger caused by sewer gases (Tiwari, 2008).	Very unlikely (1) - Since provision of protective equipment might not be adequate, gases can be inhaled. Despite this, from a "per user and year" perspective, it is **highly improbable** that a worker will get exposed to highly accumulated concentrations of sewer gas in the next 12 months.
2.	Ingestion of pathogens or receiving vector-related diseases during routine or occasional inspection and maintenance tasks in manholes or pumping stations in sewer network	A policy for usage of protective equipment exists through an industrial safety and occupational health area at EPSAS (personal communication AAPS, 11 June 2019). However, 40 % of the emergency complaints to EPSAS are about the sewer network (MMAyA, 2014). Eight out of ten interviewees at the household level explained that sewer blockage cause overflows in the streets and that EPSAS has to come frequently during especially rainy season to maintain the sewers. Such overflows in the sewer network is common in many other areas of El Alto as well (personal communication Agua Tuya, 29 August 2019).	Possible (3) - From a "per user and year" perspective, the hazardous event **may occur under regular circumstances** in the next 12 months.

(continued)

No.	Hazardous event including transmission route	Likelihood according to sources	Likelihood - reported in this study
3.	Ingestion of pathogens or receiving vector-related diseases during manual cleaning of coarse bar screens in pre-treatment phase or regular sampling for laboratory analyzes	A policy for usage of protective equipment exists through an industrial safety and occupational health area at EPSAS (personal communication AAPS, 11 June 2019). However, more workers are required for on-site sanitation systems compared to off-site sanitation systems because conveyance phase is handled manually.	Possible (3) - From a "per user and year" perspective, the hazardous event **may occur under regular circumstances** in the next 12 months.
4.	Ingestion of pathogens or receiving vector-related diseases during desludging of anaerobic and facultative pond	A policy for usage of protective equipment exists through an industrial safety and occupational health area at EPSAS (personal communication AAPS, 11 June 2019). However, desludging has never been realized in the Puchukollo WWTP (personal communication AAPS, 11 June 2019)	Very unlikely (1) - The hazardous event has never occur in the past and it is **highly improbable** it will happen in the next 12 months.
	Conventional system - COMMUNITY		
No.	**Hazardous event including transmission route**	**Likelihood according to sources**	**Likelihood - reported in this study**
5.	Ingestion of pathogens or receiving vector-related diseases from spillage of raw sewage in sanitation conveyance area	Eight out of ten interviewees at the household level explained that sewer blockage cause overflows in the streets yearly during rainy season. Such overflows in the sewer network is common in many parts of El Alto (personal communication Agua Tuya, 29 August 2019).	Almost certain (5) - From a "per user and year" perspective, the hazardous event has often been observed in the past and **will almost certainly occur** in most circumstances in the next 12 months
6.	Ingestion of pathogens or receiving vector-related diseases from insufficiently treated output products in area of disposal or discharge.	Annual average measurements of coliforms in effluent from Puchukollo WWTP exceeded national limits during all years of obtained data: 2015-2018. See Appendix I for coliform concentration in effluent and national limit.	Likely (4) - The hazardous event has been observed in the past and is **likely** to occur in the next 12 months.

Hazardous events including transmission route, likelihood according to sources and likelihood as reported in this study - assessment for the UDDT system.

UDDT system - WORKER			
No.	**Hazardous event including transmission route**	**Likelihood according to sources**	**Likelihood - reported in this study**
7.	Ingestion of pathogens or receiving vector-transmitting diseases during manual collection and transportation of urine and faeces from households to treatment station including cleaning of vehicle and tools	There is a strict policy regarding usage of protective equipment at FSH (personal communication FSH, 18 June 2019). However, more workers are required per user for on-site sanitation systems compared to off-site sanitation systems because conveyance phase is handled manually.	Possible (3) - From a "per user and year" perspective, the hazardous event **may occur under regular circumstances** in the next 12 months.
8.	Ingestion of pathogens or receiving vector-transmitting diseases during emptying faeces and urine from vehicle and transferring faeces into compost beds and urine into storage tanks	There is a strict policy regarding usage of protective equipment at FSH (personal communication FSH, 18 June 2019). However, more workers are required per user for on-site sanitation systems compared to off-site sanitation systems because conveyance phase is handled manually.	Possible (3) - From a "per user and year" perspective, the hazardous event **may occur under regular circumstances** in the next 12 months.
9.	Ingestion of pathogens or receiving vector-transmitting diseases during manual separation of larger inorganic compounds in faeces/ECO humus, oxygenation with spade in faeces/ECO humus, addition of water into faeces and sampling for laboratory analyzes	There is a strict policy regarding usage of protective equipment at FSH (personal communication FSH, 18 June 2019). However, more workers are required per user for on-site sanitation systems compared to off-site sanitation systems because conveyance phase is handled manually.	Possible (3) - From a "per user and year" perspective, the hazardous event **may occur under regular circumstances** in the next 12 months.

(continued)

UDDT system - COMMUNITY			
No.	**Hazardous event including transmission route**	**Likelihood according to sources**	**Likelihood - reported in this study**
10.	Ingestion of pathogens or receiving vector-related diseases from spillage of fresh excreta in conveyance phase	There is a risk of leakage in the conveyance phase, but faecal matter do not risk getting mixed with storm water to the same extent as sewage because conveyance is not under ground.	Unlikely (2) - The hazardous event **may occur in exceptional circumstances** in the next 12 months.
11.	Ingestion of pathogens or receiving vector-related diseases from insufficiently treated output products in area of disposal or discharge.	Discharged output products to soil (greywater) is separated from excreta, which implies that the main pathogenic load is removed (Stenström et al., 2011).	Unlikely (2) - The hazardous event **may occur in exceptional circumstances** in the next 12 months.

I Discharge of E.coli from Puchukollo WWTP and national limit

Annual mean values on E.coli in effluent from Puchukollo WWTP exceed the national limit during all years 2015-2018.

	Puchukollo WWTP effluent	**National limit**
2015: E.coli [MPN/100 ml]	$1.75*10^5$	$1*10^3$
2016: E.coli [MPN/100 ml]	$1.28*10^5$	$1*10^3$
2017: E.coli [MPN/100 ml]	$3.88*10^5$	$1*10^3$
2018: E.coli [MPN/100 ml]	$3*10^5$	$1*10^3$

J Calculations for eutrophying emissions

Firstly, the per capita mass flow rates of nitrogen, phosphorous and organic matter in faeces, urine, greywater and mixed domestic wastewater were estimated. A model developed by Jönsson and Vinnerås (2004) was used to make estimations on nitrogen and phosphorous content in urine and faeces in a Bolivian context. The model is based on Swedish data and demonstrate how FAO national statistics on average supply of protein of vegetal and animal origin in a country can be used for country-specific estimations. It shows a linear relation between total protein intake and nitrogen content in excreta, which is described in equation 1. Phosphorous content in excreta is in the model calculated through its relation with total protein intake and the proportion of protein of vegetal origin. The relation is described in Equation 2. National statistics on average protein supplies in 2013 in Bolivia were taken from FAOSTAT (2017).

$$Nitrogen = 0.13 * Total\,food\,protein \tag{1}$$

$$Phosphorous = 0.011 * (Total\,food\,protein + vegetal\,food\,protein) \tag{2}$$

Jönsson and Vinnerås (2004) report that 88% of the nitrogen is excreted in urine (and 12% in the feaces) whilst 67% of the phosphorous is excreted in urine (and 33% in faeces) in a Swedish context. The proportion of nutrients in faeces versus urine differ between investigated countries in the report. Countries from where the composition of urine and faeces in terms of nitrogen and phosphorous are investigated are China, Haiti, India, South Africa and Uganda. To estimate the proportion of nitrogen and phosphorous excreted in urine respectively faeces in a Bolivian context, FAO data on average protein supply from animal and vegetal origin was analyzed for all the mentioned countries above (FAOSTAT, 2017). China and South Africa receive their protein intake to 60 % from a vegetal origin, which was closest to the corresponding 50% in Bolivia. In Sweden, the vegetal protein intake is 30% of total intake and in Haiti, India and Uganda, the proportion is 80%. Mean values of the nitrogen and phosphorous proportions in urine respectively faeces in China and South Africa were used to make estimations for Bolivia: 88% of the nitrogen is excreted in urine (and 12% in faeces) and 63% of the phosphorous is excreted in urine (and 37% in faeces).

MMAyA has together with VAPSB developed a guide for technical design and execution of water and sanitation projects with alternative technologies in Bolivia (MMAyA, 2010). The per capita and year generation of BOD_5 in excreta used is in this guide is taken from a report by Hienss et al. (1998) about treatment of faecal sludge in the tropics. The value was adopted to this study.

The per capita mass flow rates of nitrogen and phosphorous in greywater were calculated from the relation between mass flow, concentration and flow rate (see Equation 3).

$$\dot{m} = c * Q \tag{3}$$

where $\dot{m}$ is the per capita mass flow rate of the nutrients [g/p,d], c is concentration of nutrients in greywater [mg/l] and Q is the per capita flow rate of greywater [l/p,d]. The per capita flow rate of greywater was estimated from a study about greywater characteristics and generation rates in a peri-urban municipality of a developing country (Oteng-Peprah et al., 2016). An average value for greywater generation, where in-house access to drinking water exists, was chosen. Concentration of phosphorous and BOD_5 in greywater was determined from the same study. Nitrogen concentration in greywater was estimated from literature values given for comparison motives in a report about greywater characteristics in urban India (Edwin et al., 2014). A value in the middle of the given range was chosen.

The per capita and year generations of eutrophying agents in mixed domestic wastewater were calculated as the sum of the agents in excreta and greywater. Potential contribution via toilet paper was excluded from the calculations.

Secondly, removal efficiency of nitrogen, phosphorous and BOD_5 were calculated. Accessed information from the Puchukollo treatment plant were annual mean values from 2015-2018 of the total nitrogen (tot-N) and total phosphorous (tot-P) concentration in influent and effluent of the treatment plant. The removal efficiency were calculated using this received data and median values were used in subsequent calculations. Concerning the UDDT system, the only source of eutrophication was considered to be greywater discharge. It is a reasonable assumption if the faeces and urine are used for agricultural purposes and are not discharged downstream or recharged to groundwater (Lennartsson et al., 2009). It was assumed no leakage of nutrients or organic matter from the agricultural activities and the greywater garden was estimated to have the same removal efficiency as a subsurface wetland (MMAyA, 2010).

Thirdly, the per capita mass flow rates of nitrogen, phosphorous and BOD_5 in output products getting discharged into a river or infiltrated into soil were calculated. The obtained removal efficiency of nitrogen, phosphorous and BOD_5 were used for the calculations. All calculations are demonstrated in the followong subsections.

J.1 N, P and BOD_5 in faeces, urine, greywater and mixed domestic wastewater in Bolivia

Nitrogen, phosphorous and BOD_5 in excreta:

Equations used for calculations are:

$Nitrogen = 0.13 * (Total\, food\, protein)$

and

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

Relevant parameters for calculations are shown in Table 22 together with the estimation for BOD_5 in excreta.

Table 22: *Parameters for calculation of nitrogen and phosphorous content in Bolivian urine and faeces and estimation of BOD_5 in Bolivian excreta.*

Parameter	Explanation	Unit	Value	Data source
$Protein_{tot}$	Average total protein supply in Bolivia in 2013	[g/p,d]	66.01	FAOSTAT, 2017
$Protein_{veg}$	Average protein supply of vegetal origin in Bolivia in 2013	[g/p,d]	36.25	FAOSTAT, 2017
$N_{excreta}$	Per capita mass flow rate of nitrogen in excreta	[kg/p,y]	3.13	This study
$P_{excreta}$	Per capita mass flow rate of phosphorous in excreta	[kg/p,y]	0.41	This study
N_{urine}	Per capita mass flow rate of nitrogen in urine	[kg/p,y]	2.76	This study
N_{faeces}	Per capita mass flow rate of nitrogen in faeces	[kg/p,y]	0.38	This study
P_{urine}	Per capita mass flow rate of phosphorous in urine	[kg/p,y]	0.26	This study
P_{faeces}	Per capita mass flow rate of phosphorous in faeces	[kg/p,y]	0.15	This study
$BOD_{5,excreta}$	Per capita mass flow rate of BOD_5 in excreta.	[kg/p,y]	16.43	Heinss et al., 1998

Calculations:

$N_{excreta}[kg/p,y] = 0.13 * Protein_{tot}[g/p,d] * 365[d/y] * 0.001[kg/g] = 3.13$ kg/p,y

$P_{excreta}[kg/p,y] = 0.011 * (Protein_{tot}[g/p,d] + Protein_{veg}[g/p,d]) * 365[d/y] * 0.001[kg/g] = 0.41$ kg/p,y

Nitrogen and phosphorous proportion in faeces respectively urine:

88% of the nitrogen is excreted in urine and 12 % in faeces as according to earlier motivations:

$N_{urine}[kg/p,y] = 0.88 * N_{excreta}[kg/p,y] =$ 2.76 kg/p,y

$N_{faeces}[kg/p,y] = 0.12 * N_{excreta}[kg/p,y] =$ 0.38 kg/p,y

63 % of the phosphorous is excreted in urine and 37% in faeces as assording to earlier motivations:

$P_{urine}[kg/p,y] = 0.63 * P_{excreta}[kg/p,y] =$ 0.26 kg/p,y

$P_{faeces}[kg/p,y] = 0.37 * P_{excreta}[kg/p,y] =$ 0.15 kg/p,y

Nitrogen, phosphorous and BOD_5 in greywater:

Equation used for calculation:

$\dot{m} = c * Q$

$\dot{m}$: per capita mass flow rate [mg/p,d]
c: concentration [mg/l]
Q: flow rate [l/p,d]

Parameters relevant for the calculations are shown in Table 23.

Table 23: *Parameters for calculations of nitrogen, phosphorous and BOD_5 content in greywater in Bolivia.*

Parameter	Explanation	Unit	Value	Data source
$C_{N,greywater}$	Concentration of nitrogen in greywater	[mg/l]	8.73	Edwin et al., 2014
$C_{P,greywater}$	Concentration of pohosphorous in greywater	[mg/l]	2.3	Oteng-Peprah, 2016
$C_{BOD_5 greywater}$	Concentration of BOD_5 in greywater	[mg/l]	204	Oteng-Peprah, 2016
$Q_{greywater}$	Per capita greywater flow	[l/p,d]	73	Oteng-Peprah, 2016
$N_{greywater}$	Per capita mass flow rate of nitrogen in greywater	[kg/p,y]	0.23	This study
$P_{greywater}$	Per capita mass flow rate of phosphorous in greywater	[kg/p,y]	0.06	This study
$BOD_{5,greywater}$	Per capita mass flow rate of BOD_5 in greywater	[kg/p,y]	5.44	This study

Nitrogen, phosphorous and BOD_5 in mixed domestic wastewater:

are calculated as the sum of the the agents, respectively, in excreta and greywater. Parameters relevant for the calculations are shown in Table 24.

Table 24: *Parameters for calculation of nitrogen, phosphorous and BOD_5 in mixed domestic wastewater.*

Parameter	Explanation	Unit	Value	Data source
$N_{domestic}$	Per capita mass flow rate of nitrogen in mixed domestic wastewater	[kg/p,y]	3.36	This study
$P_{domestic}$	Per capita mass flow rate of phosphorous in mixed domestic wastewater	[kg/p,y]	0.47	This study
$BOD_{5domestic}$	Per capita mass flow rate of BOD_5 in mixed domestic wastewater	[kg/p,y]	21.86	This study

Calculations:

$N_{domestic}[kg/p,y] = N_{excreta}[kg/p,y] + N_{greywater}[kg/p,y] = 3.36$ kg/p,y

$P_{domestic}[kg/p,y] = P_{excreta}[kg/p,y] + P_{greywater}[kg/p,y] = 0.47$ kg/p,y

$BOD_{5,domestic}[kg/p,y] = BOD_{excreta}[kg/p,y] + BOD_{5,greywater}[kg/p,y] = 21.86$ kg/p,y

J.2 Removal efficiency of N, P and BOD_5 in the treatment stage of the system options and the per capita mass flow rates of the agents discharging downstream or into groundwater

Conventional system:

Removal efficiency is calculated using the equation

$R = \frac{C_{in} - C_{eff}}{C_{in}}$

R: removal efficiency [-]
C_{in}: concentration in influent [mg/l]
C_{eff}: concentration in effluent [mg/l]

The concentrations refer to annual mean values from 2015-2018.

Parameters relevant for the calculations are shown in Table 25.

Table 25: *Parameters relevant for the calculations on the per capita mass flow rates of nutrients in output products from the system options. Concentrations refer to annual mean values from 2015-2018.*

Parameter	Explanation	Unit	Value	Data source
$C_{N,in,conv}$	Concentration of nitrogen in influent to Puchukollo WWTP	[mg/l]	79.3; 56.7; 64.9; 107	Unpublished AAPS, 2019
$C_{P,in,conv}$	Concentration of phosphorous in influent to Puchukollo WWTP	[mg/l]	14.5; 14.4; 17.1; 15	Unpublished AAPS, 2019
$C_{BOD_5,in,conv}$	Concentration of BOD_5 in influent to Puchukollo WWTP	[mg/l]	524.6; 469.4; 528.6; 365	Unpublished AAPS, 2019
$C_{N,eff,conv}$	Concentration of BOD_5 in effluent of Puchukollo WWTP	[mg/l]	48.8; 40.8; 43.6; 88	Unpublished AAPS, 2019
$C_{P,eff,conv}$	Concentration of BOD_5 in effluent of Puchukollo WWTP	[mg/l]	8.5; 8.7; 13.5; 11	Unpublished AAPS, 2019
$C_{BOD_5,eff,conv}$	Concentration of BOD_5 in effluent of Puchukollo WWTP	[mg/l]	98.2; 75.1; 91.5; 61	Unpublished AAPS, 2019
$R_{N,conv}$	Removal efficiency of total nitrogen in conventional system	[-]	0.3	This study
$R_{P,conv}$	Removal efficiency of total phosphorous in conventional system	[-]	0.33	This study
$R_{BOD_5,conv}$	Removal efficiency of BOD_5 in conventional system	[-]	0.83	This study
$N_{eff,conv}$	Per capita mass flow rate of N in receiving waters from effluent of Puchukollo WWTP	[kg/p,y]	2.34	This study
$P_{eff,conv}$	Per capita mass flow rate of P in receiving waters from effluent of Puchukollo WWTP	[kg/p,y]	0.32	This study
$BOD_{5,eff,conv}$	Per capita mass flow rate of BOD_5 in receiving waters from effluent of Puchukollo WWTP	[kg/p,y]	3.72	This study

Calculations:

Removal efficiency are:

$R_{N,conv} = \frac{C_{N,eff,conv} - C_{N,in,conv}}{C_{N,eff,conv}}$ = {Median value} = 0.30

$R_{P,conv} = \frac{C_{P,eff,conv} - C_{P,in,conv}}{C_{P,eff,conv}} = 0.33$

$R_{BOD_5,conv} = \frac{C_{BOD_5,eff,conv} - C_{BOD_5,in,conv}}{C_{BOD_5,eff,conv}} = 0.83$

The per capita mass flow rates of N, P and BOD_5 in effluent of Puchukollo WWTP are:

$N_{eff,conv} = (1 - R_{N,conv}) * N_{domestic} = 2.34$ kg/p,y

$P_{eff,conv} = (1 - R_{P,conv}) * P_{domestic} = 0.32$ kg/p,y

$BOD_{5,eff,conv} = (1 - R_{BOD_5,conv}) * BOD_{5,domestic} = 3.72$ kg/p,y

UDDT system:

Removal efficiency of N, P and BOD_5 are at a first stage equal to the proportion of N, P and BOD_5 in greywater compared to in greywater and excreta in total (mixed domestic wastewater). To obtain the total removal efficiency, these were multiplied with the removal efficiency of N, P and BOD_5 in a subsurface wetland.

Table 26: .

Parameter	Explanation	Unit	Value	Data source
$R_{N,wetland}$	Removal efficiency of N in a subsurface wetland	[-]	0.3	MMAyA, 2010
$R_{P,wetland}$	Removal efficiency of P in a subsurface wetland	[-]	0.2	MMAyA, 2010
$R_{BOD_5,wetland}$	Removal efficiency of BOD_5 in a subsurface wetland	[-]	0.85	MMAyA, 2010
$N_{eff,uddt}$	Per capita mass flow rate of N into soil to groundwater recharge from the UDDT system	[kg/p,y]	0.16	This study
$P_{eff,uddt}$	Per capita mass flow rate of P into soil to groundwater recharge from the UDDT system	[kg/p,y]	0.05	This study
$BOD_{5,eff,uddt}$	Per capita mass flow rate of BOD_5 into soil to groundwater recharge from the UDDT system	[kg/p,y]	0.82	This study

Calculations:

$N_{eff,uddt} = N_{domestic} * \frac{N_{greywater}}{N_{domestic}} * (1 - R_{N,wetland}) =$ 0.16 kg/p,y

$P_{eff,uddt} = P_{domestic} * \frac{P_{greywater}}{P_{domestic}} * (1 - R_{P,wetland}) =$ 0.05 kg/p,y

$BOD_{5,eff,uddt} = BOD_{5,domestic} * \frac{BOD_{5,greywater}}{BOD_{5,domestic}} * (1 - R_{BOD_5,wetland}) =$ 0.82kg/p,y

K Calculations for potential for nutrient recycling

Conventional system:

Nitrogen recovery from WWTP sludge:

The dynamics of removal mechanisms in stabilization ponds are assumed to be similar as the relative size of the arrows representing ”loss to atmosphere” (ammonia volatilization), ”plant and animals” (bioaccumulation) and ”bottom deposits” (sedimentation to bottom sediments) in Figure 13. The proportion of nitrogen escaping with the effluent is as according to calculations for eturophying emissions.

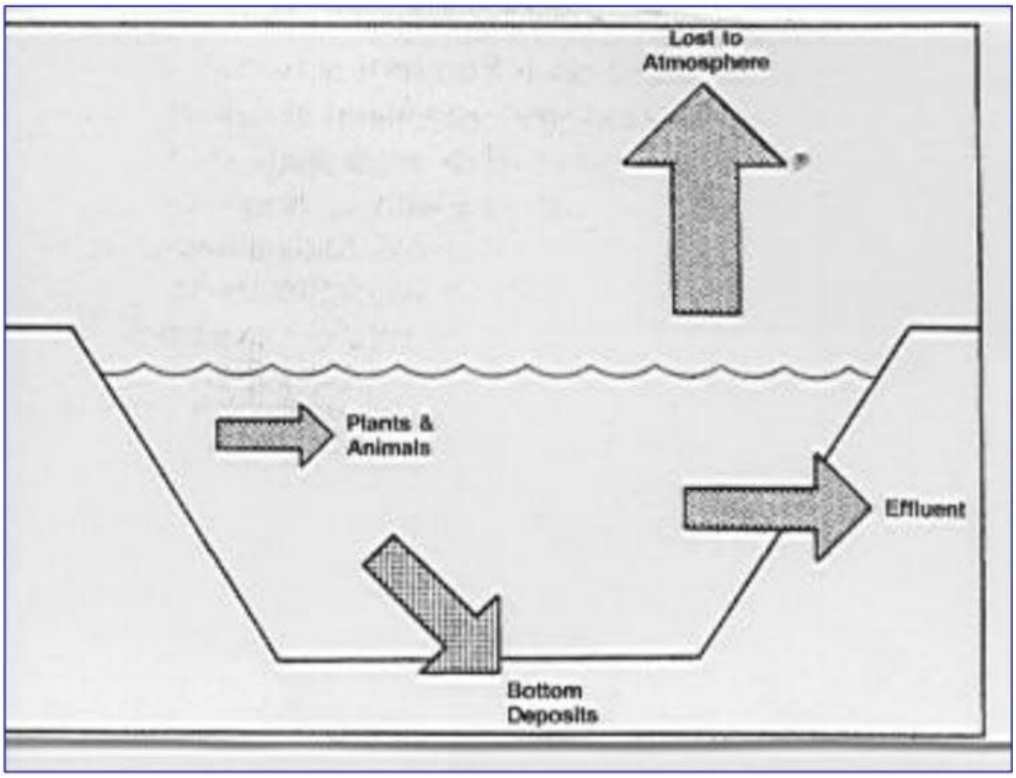


Figure 13: *Nitrogen dynamics in WSPs according to Middlebrooks et al (1999).*

The three arrows representing nitrogen removal have a total size of 22.5 mm on printed paper. The arrow representing sedimentation to bottom sediment have a size of 7 mm on printed paper. The proportion of removed nitrogen that accumulate in WWTP sludge can thereby be calculated. Relevant parameters used in calculations are shown in Table 27.

Calculations:

$K_N = \frac{7}{22.5} = 0.31$

The per capita mass flow rate of N in WWTP sludge can be calculated:

$N_{sludge,wwtp} = N_{domestic}[kg/p,y] * R_{N,conv}[-] * K_N[-] =$ 0.31 kg/p,y

Table 27: *Parameters relevant for the calculations on the per capita nitrogen recovery from WWTP sludge.*

Parameter	Explanation	Unit	Value	Data source
K_N	Proportion of removed N from stabilization ponds that accumulate in WWTP sludge	[-]	0.31	This study
$N_{sludge,wwtp}$	Per capita mass flow rate of N in WWTP sludge	[kg/p,y]	0.31	This study

UDDT system:

The nutrient recovery from urine and faeces were calculated from laboratory analyzes received from the FSH on nutrient concentration in the stored urine and ECO humus (see Table 28) (Unpublished FSH, 2011). Median values were selected for subsequent calculation. Mass flow rates of stored urine and ECO humus produced from excreta collected from a specified number of households were also used (Proyecto NODO, 2014). The average number of persons per households was received from national statistics for Bolivia (INE, 2015).

Table 28: *The amount of test analyzes accessed showing weight percentages on nitrogen and phosphorous in stored urine (a-e) were several more than from the ECO humus (f-g).*

	Stored urine	
Test	**Nitrogen [mg/kg]**	**Phosphorous [mg/kg]**
a	3968	297
b	440	311
c	4606	303
d	4026	322
e	3418	285
Median value	3968	303
	ECO humus	
Test	**Nitrogen [mg/kg]**	**Phosphorous [mg/kg]**
f	12000	9858
g	21000	2930
Median value	16500	6394

Equation used for the calculations:

$$\dot{m}_{nutrient} = \frac{w_{nutrient} * \dot{m}_{product,output}}{f * h}$$

$\dot{m}_{nutrient}$: Per capita mass flow rate of nutrient (N or P) in output product [g/p,d]
$w_{nutrient}$: Weight percent of nutrient (N or P) in output product [g/kg]

$\dot{m}_{output\,product}$: mass flow rate of output product [kg/y]
f: persons per household [p/h]
h: households [h]

Parameters relevant for the calculations are shown in Table 29.

Table 29: *Parameters relevant for the calculations about nutrient recycling from the UDDT system.*

Parameter	Explanation	Unit	Value	Data source
f	Persons per household (Bolivia)	[p/h]	3.5	INE, 2015
h	Households	[h]	650	Proyecto NODO, 2014
$w_{N,stored\,urine}$	Weight percent of N in stored urine	[g/kg]	4	This study
$\dot{m}_{stored\,urine}$	Per capita mass flow rate of stored urine	[kg/d]	2925	Proyecto NODO, 2014
$w_{P,stored\,urine}$	Weight percent of P in stored urine	[g/kg]	0.3	This study
$w_{N,ECO\,humus}$	Weight percent of N in ECO humus	[g/kg]	16.5	This study
$\dot{m}_{ECO\,humus}$	Per capita mass flow rate of ECO humus	[kg/y]	28080	Proyecto NODO, 2014
$w_{P,ECO\,humus}$	Weight percent of P in ECO humus	[g/kg]	6.4	This study
$N_{stored\,urine}$	Nitrogen recovery from urine in the stored urine	[kg/p,y]	1.88	This study
$P_{stored\,urine}$	Phosphorous recovery from urine in the stored urine	[kg/p,y]	0.14	This study
$N_{ECO\,humus}$	Nitrogen recovery from faeces in the ECO humus	[kg/p,y]	0.20	This study
$P_{ECO\,humus}$	Phosphorous recovery from faeces in the ECO humus	[kg/p,y]	0.08	This study
$N_{plant\,uptake}$	Nitrogen recovery from greywater in the plant uptake	[kg/p,y]	0.07	This study
$P_{plant\,uptake}$	Phosphorous recovery from faeces in the ECO humus	[kg/p,y]	0.01	This study

Nitrogen recovery from urine in the stored urine:

$$N_{stored\,urine} = \frac{w_{N,stored\,urine} * \dot{m}_{stored\,urine}}{f * h} = \frac{4[g/kg] * 0.001[kg/g] * 2925[kg/d] * 365[d/y]}{3.5[p/h] * 650[h]} = 1.88 \text{ kg/p,y}$$

Phosphorous recovery from urine in the stored urine:

$$P_{stored\,urine} = \frac{w_{P,stored\,urine} * \dot{m}_{stored\,urine}}{f * h} = \frac{0.3[g/kg] * 0.001[kg/g] * 2925[kg/d] * 365[d/y]}{3.5[p/h] * 650[h]} = 0.14 \text{ kg/p,y}$$

Nitrogen recovery from faeces in the ECO humus:

$$N_{ECO\,humus} = \frac{w_{N,ECO\,humus} * \dot{m}_{ECO\,humus}}{f * h} = \frac{16.5[g/kg] * 0.001[kg/g] * 28080[kg/y]}{3.5[p/h] * 650[h]} = 0.20 \text{ kg/p,y}$$

Phosphorous recovery from faeces in the ECO humus:

$$P_{ECO\,humus} = \frac{w_{P,ECO\,humus} * \dot{m}_{ECO\,humus}}{f * h} = \frac{6.4[g/kg] * 0.001[kg/g] * 28080[kg/y]}{3.5[p/h] * 650[h]} = 0.08 \text{ kg/p,d}$$

Nitrogen recovery from greywater in the plant uptake:

Nutrient recovery from greywater in form of plant uptake is based on the calculations and approximations on the per capita mass flow rates of nutrients in greywater as made in Appendix J.2 (about eutrophying emissions):

$$N_{plant\,uptake} = N_{greywater} * R_{N,wetland} = 0.23[kg/p,y] * 0.3[-] = 0.07 \text{ kg/p,y}$$

Phosphorous recovery from greywater in the plant uptake:

$$P_{plant\,uptake} = P_{greywater} * R_{P,wetland} = 0.06[kg/p,y] * 0.2[-] = 0.01 \text{ kg/p,y}$$

L Assessment of robustness

Investigation and evaluation of robustness of the conventional system. Motivations without sources origin from observations during a study visit to the treatment station of FSH.

Conventional system		
	Impact on system operation according to sources	**Impact on system operation - reported in this study**
Capacity to endure shock loads - quality of input products	Stabilization ponds are resistant to organic shock loads and are suitable for treating industrial wastewater but chemical waste may cause inhibition of the treatment mechanisms. Sewers are suitable for receiving industrial wastewater but would in many cases need pre-treatment for highly polluted wastewater. There is a risk of clogging in the sewers if polluted wastewater is discharged (Tilley et al., 2014). There is a risk of clogging in the sewers if grease or oil is discharged (USEPA, 2002).	System operates but temporary failures might occur and treatment efficiency is negatively affected (3)
Capacity to endure shock loads - quantity of input products	Waste stabilization ponds can handle large quantities of flow (Tilley et al., 2014) as well as sewers, but a minimum velocity needs to be maintained in the sewers to avoid clogging (Sasse, 1998). A too low velocity was not considered a problem in El Alto.	System is not affected (5)
Capacity to endure a cold climate	Stabilization ponds have less efficiency in a colder climate compared to in a warmer one (Tilley et al., 2014). Sewers are robust in a cold climate since sewers are constructed underground and are not exposed to freezing temperatures (Tilley et al., 2014).	System operates but temporary operating errors might occur and treatment efficiency is negatively affected (3)
Resilience against climate change impact - flooding	Heavy rainfall events regularly cause overflow in both sewer network and by the Puchukollo treatment plant as described in section 4.1.1 and ????.	Entire system does not have capacity to treat the incoming waste (1)
Resilience against climate change impact - drought	The conventional system is water dependent.	Entire system is out of service or does not have capacity to treat the incoming waste (1)

Investigation and evaluation of robustness of the UDDT system. Motivations without sources origin from observations during a study visit to the treatment station of FSH.

UDDT system		
	Impact on system operation according to literature and/or motivation	**Impact on system operation - reported in this study**
Capacity to endure shock loads - quality of input products	Vermicomposting is sensitive towards high pH fluctuations since the earthworms do not act by high pH. A high pH follows if for example ash has been used as a drying material instead of sawdust in the households (Proyecto NODO, 2014). Risk for clogging in the conveyance phase of the UDDT system is seen as lower than for the other systems since transportation is human-powered and material risking to clogg the system is visible and be detected in advance.	System operates but temporary operating errors might occur and treatment efficiency is negatively affected (3)
Capacity to endure shock loads - quantity of input products	Jerrycans for urine and containers for faeces can be filled up. Vehicles for transportation can be filled up. Urine storage tanks might be filled up. Treatment efficiency might be affected if there is no place for the urine and faeces to be stored.	Parts of the system are out of service or can not be used (2)
Capacity to endure a cold climate	Vermicomposting requires specific temperature conditions for its treatment mechanisms to function but by adjusting the quantity of water added to the ECO humus beds efficiency can be kept the same in a colder climate as/compared to in a warmer (personal communication FSH, 25 October 2019). It is possible to use a UDDT unit in cold climate (EAWAG, 2019a).	System operates but temporary operating errors might occur and treatment efficiency is negatively affected (3)
Resilience against climate change impact - flooding	Faeces and urine during collection phase are covered in the vehicle, preventing seepage of water from rainfall events. However, because of limited mobility in the roads and for water not to seep into the vehicles, the vehicle might not be able to operate. Vermicompost beds and urine storage tanks can be sealed with covers in order to prevent seepage of water and reduced treatment capacity.	Parts of the system are out of service or do not have capacity to treat the incoming waste (2)
Resilience against climate change impact - drought	User interface and transportation phase operate without any need of water. However, water is required during the treatment of faeces keep the eartworms alive (personal communication FSH, 25 October 2019).	Parts of the system are out of service or do not have capacity to treat the incoming waste (2)

M Indicators for assessment of institutional developed by NORAD (2000)

1. Purpose and strategy

- Purpose and strategies for the institution are clear.
- Purpose and strategies are relevant to country needs.

2. Management

- Leadership has a proven capability to direct and manage the institution.
- Systems and procedures are operative.
- Organisational structures support effective implementation.

3. Financial resources

- Resources are available to cover major recurrent and capital expenditures.
- The institution is to a lare extent self-sustained.

4. Infrastructure

- Buildings and equipment are adequate.
- Infrastructure is well-maintained.

5. Performance

- The institution meets its short-term targets.
- The institution delivers its ”products” with reasonable costs.

6. Institutional competence

- The institution has the required skills to carry out its operations without external assistance.
- The institution has the required competence to suport new projects.

7. Personnel

- The supply of qualified personnel is adequate.
- The personnel are considered competent.
- Personnel policy established/adequate.

8. Culture and Communication

- Shared values and beliefs guide staff/members.
- Motivation is strong.

9. Linkages/Networks

- The institution is linked to relevant national/international partners.
- Doners/financing institutions provide predictible support.

10. Legal and Political Framework

- The institution has a proper and secure legal framework supported by national authorities.

11. External Cultural Framework

- Bureaucratic rules and norms are conductive for performance.
- Corruption, lack of dicipline etc. pose no threat to efficiency.

12. Participation and Legitimacy

- Strong ownership and participation characterize the institution.
- External stakeholders respect and have confidence in the institution.

(NORAD, 2000)

N Calculations for financial value of recycled products

The key Equation 4 was used to calculate the total nitrogen and phosphorous compounds in the two locally available fertilizers Urea 46% and DAP 18-46-0.

$$m = M * n \tag{4}$$

where m is mass [g], M is molar mass [g/mol] and n is amount of substance [mole]. The per capita mass flow rates of nitrogen and phosphorous in kilogram per person and year in each recycled product were retrieved from the results in Section 4.1.3. These per capita mass flow rates were multiplied with the financial value of one kilogram of nitrogen and one kilogram of phosphorous, respectively. A total financial value for each recycled product was received. The calculations are outlined below:

<u>Financial value of 1 kg nitrogen:</u>

Definition of parameters:

m_{urea46}: mass of urea 46% [kg]
$m_{nitrogen}$: mass of total nitrogen [kg]

$FV_{nitrogen}$: financial value of nitrogen [Bs/kg]

Calculations were made per kilogram of urea 46%:

m_{urea46} = 1 kg
$m_{nitrogen}$ = 0.46 * m_{urea46} = 0.46 * 1 = 0.46 kg

1 kg of Urea 46% cost between 4 and 6 bolivianos. It means that 0.46 kg nitrogen value between 4 and 6 bolivianos. 1 kg of nitrogen then has a value between:

$FV_{nitrogen} = \frac{4}{0.46} = 8.696$ bolivianos and

$FV_{nitrogen} = \frac{6}{0.46} = 13.043$ bolivianos.

<u>Financial value of 1 kg of phosphorous:</u>

Definition of parameters:

m_{DAP}: mass of DAP 18-46-0 [g]
$m_{phosphate,Av.}$: mass of available phosphate [g]
$m_{phosphate,WS.}$: mass of water soluble phosphate [g]
$m_{phosphate}$: mass of available and water soluble phosphate [g]
$m_{phosphorous}$: mass of total phosphorous [g]
$m_{nitrogen}$: mass of total nitrogen [g]

$n_{phosphate}$: amount of substance of phosphate [mol]
$n_{phosphorous}$: amount of substance of phosphorous [mol]

$M_{phosphate}$: molar mass of phosphate [g/mol]
$M_{phosphorous}$: molar mass of phosphorous [g/mol]

$FV_{phosphorous}$: financial value of phosphorous [Bs/kg]

$M_{phosphate}$ = 142 g/mol
$M_{phosphorous}$ = 31 g/mol

DAP 18-46-0 contains 46 % available phosphate, 42 % water soluble phosphate and 18% nitrogen. Calculations were made per kilogram of DAP 18-46-0:

m_{DAP} = 1000 g
$m_{phosphate,Av.} = 0.46 * m_{DAP} = 0.46 * 1000$ g = 460 g
$m_{phosphate,WS.} = 0.42 * m_{DAP} = 0.42 * 1000$ g = 420 g
$m_{phosphate} = m_{phosphate,Av.} + m_{phosphate,WS.} = 460 + 420 = 880$ g
$m_{nitrogen} = 0.18 * m_{DAP} = 0.18 * 1000 = 180$ g

Relation between mass, molar and amount of substance is:

$m = M * n$

Amount of substance of phosphate is:

$n_{phosphate} = \frac{m_{phosphate}}{M_{phosphate}} = \frac{880}{142} = 6.197$ mol

In one mole of phosphate (P_2O_5), there are two moles of phosphorous:

$n_{phosphorous} = 2 * M_{phosphate} = 2 * 6.197 = 12.394$ mol

The mass of phosphorous is:

$m_{phosphorous} = M_{phosphorous} * n_{phosphorous} = 31 * 12.394 = 384.225$ g

50 kg of DAP 18-46-0 have an average cost of 400-410 bolivianos. It means that 1 kg of DAP 18-46-0 cost about 8 bolivianos. 1 kg of DAP 18-46-0 contain 0.38 kg phosphorous and 0.18 kg nitrogen. The value of 0.18 kg nitrogen is:

$0.18 * FV_{nitrogen}$

which is between

$0.18 * 8.696 = 1.565$ bolivianos and

$0.18 * 13.043 = 2.348$ bolivianos.

Hence, the value of 0.38 kg phosphorous is between:

$8 - 2.348 = 5.652$ bolivianos

and

$8 - 1.565 = 6.435$ bolivianos.

It means that 1 kg of phosphorous value between:

$FV_{phosphorous} = \frac{5.652}{0.38} = 14.874$ bolivianos and

$FV_{phosphorous} = \frac{6.435}{0.38} = 16.934$ bolivianos.

Financial value of recycled products from one person during one year:

The following parameters are retrieved from Section 4.1.3.

Parameter	**Explanation**	**Unit**	**Value**	**Data source**
$N_{stored\,urine}$	Per capita mass flow rate of nitrogen in stored urine	[kg/p,y]	1.88	This study
$P_{stored\,urine}$	Per capita mass flow rate of phosphorous in stored urine	[kg/p,y]	0.14	This study
$N_{ECO\,humus}$	Per capita mass flow rate of nitrogen in ECO humus	[kg/p,y]	0.20	This study
$P_{ECO\,humus}$	Per capita mass flow rate of phosphorous in ECO humus	[kg/p,y]	0.08	This study
$N_{sludge,WWTP}$	Per capita mass flow rate of nitrogen in WWTP sludge	[kg/p,y]	0.31	This study

The financial value of stored urine from one person during one year is given by:

$FV_{nitrogen}[Bs/kg] * N_{stored/:urine}[kg/p, y] + FV_{phosphorous}[Bs/kg] * P_{stored/:urine}[kg/p, y]$

and vary between

$8.696 * 1.88 + 6.435 * 0.14 = 17.249$ Bs/p,y and

$13.043 * 1.88 + 5.652 * 0.14 = 25.312$ Bs/p,y.

The financial value of ECO humus produced by one person during one year is:

$$FV_{nitrogen} * N_{ECO\,humus} + FV_{phosphorous} * P_{ECO\,humus}$$

and vary between

$8.696 * 0.20 + 6.435 * 0.080 = 2.254$ Bs/p,y and

$13.043 * 0.20 + 5.652 * 0.080 = 3.061$ Bs/p,y.

The financial value of WWTP sludge produced by one person during one year was calculated in the same way.

The financial value of nutrients generated from the UDDT system equals the sum of nutrients generated in stored urine and ECO humus from one person during one year. The financial value of nutrients generated in sewage sludge account for the financial value of recycled products from the conventional system.