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The potential of innovative dry source-separating urban sanitation technologies in Montero, Bolivia

A sustainability assessment

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Abstract

The potential of innovative dry source-separating urban sanitation technologies in Montero, Bolivia
A sustainability assessment

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Montero is one of the cities with the highest population growth in the lowlands of Bolivia. According to Montero's municipal plan for water and sanitation, only 36 % of the population in the urban areas of Montero is connected to the sewage system. Since 2015, approximately 200 urine diverting dry toilets (UDDTs) have been built in Montero, providing safe sanitation to a thousand inhabitants lacking access to the sewage system. However, the treatment of the faeces and urine is inadequate, with loss of valuable nutrients and risk of polluting water bodies. The objective of this study is to assess nutrient recycling innovative dry source-separating sanitation systems, in a context relevant for Montero, using a selection of sustainability criteria. Three innovative dry sanitation systems, collecting and treating the faeces and urine from the UDDTs, were assessed in relation to the existing system. The assessment was performed on the basis of multiple criteria within the following categories: Health, Resource Use, Environmental, Socio-Cultural, Technical-organizational and Financial. From literature research and calculations of nutrient and costs, the indicator for sustainability for each criterion was scored from 1 (worst) to 5 (best).

The first alternative sanitation system, which collects and stores the liquid urine centrally and treats the faeces with vermicompost, was considered more sustainable from the health, resource use and environmental perspectives, but reported a lower value of the produced fertilizers than the other two innovative alternatives. Alternative 2, producing a solid fertilizer from the urine by ion exchange with peat and zeolite and adding urea treatment to the humus from the vermicompost, reported the largest amount and highest total value of the fertilizers and good resource use. However, the system was least sustainable from a technical-organizational point of view and had the highest annualized costs. Lastly, alternative 3, drying the urine on site and treating the humus with urea from the dried urine, reported the highest nutrient recovery rate while the energy consumption was much higher than for the other systems. Despite numerous assumptions for the calculations in this report, the result can indicate which sanitation system is most sustainable from each perspective. Future recommended studies are laboratory tests of the nutrient content from local pilot tests to evaluate the economic value of the produced fertilizers as well as further analyzing the farmers' social acceptance towards using fertilizers produced from UDDTs.

Key words: Montero, UDDT, nutrient recycling, sanitation, sustainability, multiple criteria, health, resource use, environmental, technical, organizational, financial, fertilizer

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REFERAT
Potentialen av innovativa torra källsorterande urbana sanitetstekniker i Montero, Bolivia - en hållbarhetsanalys
Ylva Geber

I låglandet i Bolivia, är Montero bland städerna med snabbast befolkningstillväxt. Enligt Monteros kommunala plan för vatten och sanitet från 2019, är endast 36 % av befolkningen i de urbana delarna av Montero kopplade till avloppsnätet. Sedan 2015 har ungefär 200 torra urinseparerande toaletter (UDDT:s) byggts i Montero, tillhandahållande av säker sanitet till tusentals invånare med avsaknad av tillgång till avloppsnätet. Samtidigt är behandlingen av toalettavfallen otillräcklig med förluster av värdefulla näringsämnen och risk för förorening av vattendrag. Syftet med den här studien är att bedöma olika näringsåtervinnande innovativa sanitetsystem, utifrån ett perspektiv av en stad som Montero och under användandet av ett urval av hållbarhetskriterier. Tre innovativa torra sanitetsystem, med upphämtning och behandling av fekalier och urin från torra urinseparerande toaletter, var analyserade i relation till det nuvarande systemet. Analysen utfördes baserat på multipla kriterier inom kategorierna Hälsa, Resursanvändning, Miljö, Sociokulturellt, Tekniskt-organisatoriskt och Finansiellt. Från litteraturstudier och beräkningar över näringsvärden och kostnader, kunde indikatorerna för hållbarhet hos varje kriterium rankas mellan 1 (sämst) och 5 (bäst).

Det första alternativa sanitetssystemet med upphämtning och central lagring av flytande urin samt behandling av fekalier med vermikompost, bedömdes vara mer hållbart utifrån ett hälso-, resursanvändning- och miljöperspektiv, men rapporterades ha ett lägre ekonomiskt värde hos den producerade gödselprodukten än de två andra innovativa systemen. Alternativ 2, med produktion av ett fast gödsel från urin genom jonutbyte med torv och zeolit, samt tillkommande ureabehandling av humusen från vermikomposten, hade den största mängden och högsta totala värdet på gödselprodukterna, samt en god resursanvändning med avseende på näringsämnen och energi. Däremot var systemet minst hållbart utifrån ett tekniskt-organisatoriskt perspektiv samt hade de högsta årliga kostnaderna. Slutligen hade alternativ 3, med urintorkning vid hushållet samt behandling av humusen med urea från den torkade urinen, den högsta återvinningen av näringsämnen, samtidigt som energikonsumtionen var mycket högre än för de andra systemen. Trots många antaganden för beräkningarna till denna rapport, kan resultatet indikera på vilket sanitetssystem som är mest hållbart utifrån varje perspektiv. Framtida rekommenderade studier är laborativa tester av näringsinnehållet från lokala pilottester för att utvärdera det ekonomiska värdet hos de producerade gödselmedlen, samt vidare utvärdera böndernas sociala acceptans till att använda de olika gödselmedlen från urinsorterande toaletter.

Nyckelord: Montero, UDDT, näringsåtervinning, sanitet, hållbarhet, multipla kriterier, hälsa, resursanvändning, miljö, tekniskt, organisatorisk, finansiellt, gödselmedel

RESUMEN
El potencial de technologías innovadoras de saneamiento seco urbano con separación y reuso en Montero, Bolivia: una evaluación de sostenibilidad
Ylva Geber

En las tierras bajas de Bolivia, Montero es uno de las ciudades con el mayor crecimiento demográfico. Según el plano municipal de agua y saneamiento de Montero, solo el 36 % de la población en las zonas urbanas de Montero, está conectada a la red de alcantarillado. Desde el 2015, aproximadamente 200 baños secos ecológicos (BSE) se han construido en Montero, proporcionando saneamiento seguro a miles de residentes que carecen de acceso al sistema de alcantarillado. Sin embargo, el tratamiento de los residuos de los BSE es insuficiente con perdidas de nutrientes valiosos y riesgo de contaminar cuerpos de agua. El objetivo de este estudio es analizar sistemas innovadores de saneamiento seco que reutilizan los nutrientes, desde una perspectiva de una ciudad como Montero, usando una selección de criterios de sostenibilidad. Tres sistemas innovadores de saneamiento, con recolección y tratamiento de heces y orina de los BSE:s, fueron evaluados en relación del sistema actual. El análisis se realizó en base de criterios múltiples en las categorías de Salud, Uso de recursos, Medio ambiental, Socio cultural, Técnico-organizacional y Financiera. En base de investigación de literatura, cálculos y estimaciones propios, los indicadores de sostenibilidad para cada criterio se puntuó de 1 (peor) a 5 (mejor).

La primera alternativa, el sistema de saneamiento con recolección centralizada y con almacenamiento de orina y tratamiento de heces con lombrices, fue considerado más sostenible en los aspectos de salud, uso de recursos y medio ambiente, pero presentó un valor económico más bajo por el abono producido comparado con los otros dos alternativas innovadoras. La alternativa 2, produciendo un abono solido de la orina por intercambio iónico con turba y zeolita y añadiendo tratamiento de urea del humus producido con lombrices, presentó la mayor cantidad y valor total por el abono y un buen uso de recursos en cuanto a nutrientes y energía. Sin embargo el sistema era el menos sostenible desde el aspecto técnico-organizacional y tenía los costos anualizados más altos. Al fin, la alternativa 3, secando la orina en el hogar y tratando el humus con urea de orina secada, presentó la mayor tasa de recuperación de nutrientes mientras el consumo de energía fue mucho mayor que las otras alternativas. A pesar de numerosas suposiciones para los cálculos y estimaciones, el resultado puede indicar cual de los sistemas de saneamiento es más sostenible de acuerdo a cada aspecto de sostenbilidad. Estudios recomendados en el futuro son análisis de laboratorio del contenido de nutrientes de estudios piloto locales, para evaluar el valor económico de los abonos producidos y evaluar la aceptación social de los agricultores sobre el aprovechamiento de los abonos producidos de los BSE:s.

Palabras claves: Montero, BSE, reuso de nutrientes, saneamiento, sostenibilidad, criterios multiples, salud, uso de recursos, medio ambiental, técnico-organizacional, financiera, abono

PREFACE
Uppsala, January 2020
Ylva Geber

This master thesis covers 30 credits and concludes five years of studies at the Master Programme in Environmental and Water Engineering at Uppsala University and Swedish University of Agricultural Sciences (SLU). The work has been conducted in collaboration with Research Institutes of Sweden (RISE), Stockholm Environment Institute (SEI) and UNICEF Bolivia during the autumn semester 2019. The supervisor was Elisabeth Kvarnström, researcher at RISE and the subject reader Jennifer McConville, researcher at Department of Energy and Technology, SLU. The examiner was Fritjof Fagerlund, senior lecturer at Department of Earth Sciences, Program for Air, Water and Landscape Sciences; Hydrology, Uppsala University.

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POPULÄRVETENSKAPLIG SAMMANFATTNING

I distriktet Santa Cruz i det bolivianska låglandet, är Montero staden med den snabbast växande befolkningen. Detta ställer större krav på tillgången till rent vatten och säker sanitet. Trots detta, var 2019 enbart en dryg tredjedel av invånarna anslutna till avloppsnätet. Hos hushållen med avsaknad av tillgång till avloppsnätet, gör många familjer sina behov i hål där toalettavfallen antingen samlas in och transporteras bort eller täcks över med ny jord. Då bakterier från avföringen enkelt sprids i det tropiska klimatet i Montero, är det viktigt att det tas om hand och behandlas. Även om det fortfarande är en lång väg kvar, började kommunen år 2015 att gå mot en lösning på problemet, i och med att den första urinseparerande toaletten byggdes. Idag finns omkring 200 sådana toaletter i Montero belagda utanför hushållet.

Själva toalettstolen är uppdelad i två delar där urinen leds från den främre delen genom rör ned i marken. Avföringen samlas i en behållare i en kammare under toaletten. Inget vatten krävs till spolning, så för att motverka lukt strös istället en skopa sågspån på ytan. Med detta system tas den mest smittspridande fraktionen om hand och risken för infektion hos familjerna motverkas. Vad som i nuläget saknas, är en lösning på hur avföringen sedan ska behandlas för att producera en produkt som kan användas utan risk för smittspridning. Idag grävs avföringen ned på reningsverket i Montero. I och med att större och större delar av markytan har använts, har man kommit till insikten att lösningen inte är hållbar i framtiden. Bristen hos systemet uppenbarades i samband med kommunens mål att bygga ytterligare några tusentals urinseparerande toaletter i staden. Det är vanligt att urin och avföring betraktas som avfall som ska tas om hand och få inser vilka stora potentialer i form av näringsämnen som finns i dessa fraktioner. Kväve, fosfor och kalium från maten vi äter härstammar till stora delar från jordbruket, som alltmer urlakas på näringsämnen. Under det senaste decenniet har *peak phophorus* blivit en välkänd term. Forskning pekar mot att fosforreserverna kommer att räcka i ytterligare 30-300 år. Under tiden kommer kvaliteten på den utvunna fosforn minska och priset öka. Samtidigt visar svensk forskning på att resurserna för produktion av kvävegödsel är ännu mindre samt har en avsevärt högre inverkan på kostnaden för växtodling vid en framtida prishöjning.

I det här examensarbetet var syftet att hitta en hållbar lösning på hur både avföring och urin kan samlas upp och behandlas med innovativa metoder för att erhålla attraktiva gödselmedel. Utöver att ta bort smittoämnena från toalettavfallet, skapas nämligen en komersiell produkt som sedan kan användas inom jordbruket för att förse odlingarna med näring. En sådan innovativ lösning som redan prövats med gott resultat i staden El Alto i det bolivianska höglandet, är kompostering påskyndad av maskar. I El Alto tas även den flytande urinen om hand och lagras under ett par månader i stora tankar på reningsverket.

Det första alternativet i denna analys var ett motsvarande system till det i El Alto. Forskning visar dock på att mask-komposteringen i sig självt inte kan ta bort parasitiska maskar, utbredda i Bolivia och vanliga infektionsbärare. Ett andra alternativ som utreddes i detta examensarbete är att efterbehandla humusen med urea, vilket bevisats kunna motverka parasitiska maskar, samt att producera ett fast gödsel, genom reaktion med torv och mineralen zeolit. För att motverka de många transporter som krävs för att hämta upp de 2000 liter flytande urin, genererat av ett genomsnittligt hushåll i Montero varje år, är ett tredje alternativ att torka urinen på en bädd av basiskt torkningsmaterial direkt i anslutning till hushållet. Då den torkade urinen har en hög halt av urea, kan denna ersätta den kommersiella urean för att behandla humusen mot parasitiska maskar.

För att uppnå en långsiktig lösning på sanitetsituationen i Bolivia, analyserades de tre innovativa lösningarna för de separerade toalettfraktionerna utifrån olika hållbarhetskriterier. På så sätt utvärderades perspektiven hälsa, resursanvändning, miljö, ekonomi, sociokulturellt, organisation och teknik för samtliga system. Att tillverka en fast produkt av urinen genom reaktion med torv och zeolit och blanda denna med humus varpå blandningen behandlades med urea, visade sig producera gödselmedlet med det högsta totala ekonomiska värdet. Detta på grund av en stor mängd gödselmedel samt att tillsatsen av urea höjde värdet genom det ökade kväveinnehållet. Samtidigt är kostnaden för de tillsatta substanserna större än värdet på gödselmedlet. Genom att torka urinen och använda delar av denna torra produkt till att behandla humusen, varpå båda säljs som separata fasta gödselmedel, uppnås ett större relativt ekonomisk värde mot tillsatserna. Systemet var även det med högst näringsåtervinning, men mindre positivt ur hållbarhetssynpunkt var de stora mängder förbrukad energi som åtgick till torkningsprocessen. Samtliga torra gödselprodukter antogs sälja bättre på marknaden då de bönder som intervjuats hade en mer positiv bild till gödsel i smulig eller pulver-form än som vätska.

En tydlig slutsats var att samtliga tre innovativa alternativa sanitetslösningar bevisades vara mer hållbara med avseende på hälsa, resursanvändning och miljö än dagens system. En utmaning är de något högre kraven på den tekniska kapaciteten hos organisationen i relation till dagens system samt de högre kostnaderna för att samla in och behandla samtliga fraktioner från de torra toaletterna. Resultatet i detta arbete kan fungera som vägledning för nyckelaktörer i Montero och Bolivia för att hitta en metod som behandlar urin och avföring från de torra toaletterna samt återför näring till jordbruket, utifrån deras prioriterade hållbarhetskriterier. För att uppnå ett hållbart system, bör den sociala acceptansen hos bönderna utredas vidare så att en efterfrågan på de producerade gödselmedlen kan säkerställas.

ACRONYMS AND ABBREVIATIONS

ABP - Animal By Product

COSMOL - The Cooperative of Public Services Montero Limited

CRE - The Cooperative of Rural Electrification

FAO - The Food and Agriculture Organization

UDDT - Urine Diverting Dry Toilet

FSH - Foundation Sumaj Huasi

K - Potassium

MMAyA - Ministry of Environment and Water (in Bolivia)

N - Nitrogen

NPK - Nitrogen-Phosphorus-Potassium

O&M - Operation and Maintenance

P - Phosphorus

RISE - Research Institutes of Sweden

SDG - Sustainable Development Goal

SEI - Stockholm Environment Institute

SuSanA - Sustainable Sanitation Alliance

WB - World Bank

WHO - World Health Organization

WWTP - Waste Water Treatment Plant

ZeoPeat - Zeolite + Peat

CONTENTS

1 INTRODUCTION

Inadequate sanitation and hygiene, together with unsafe drinking water, cause 60 % of the disease burden from diarrhea and 100 % of the infections from the soil-transmitted pathogens, *helminths*, globally leading to 870 000 deaths in 2016 (ECOSOC, 2019). The network organization Sustainable Sanitation Alliance (SuSanA) defines sustainable sanitation not only as protecting human health but also as being economically viable, socially acceptable, technically and institutionally appropriate as well as protecting the environment and natural resources. During the last decade, there has been a global progress in the number of people with access to safe sanitation, from 28 % in 2010 to 47 % in 2017, of which Latin America stands for one of the greatest increases. Nevertheless, United Nations (ECOSOC, 2019) reports that the progress rate needs to at least be doubled to reach Sustainable Development Goal (SDG) 6: Ensure availability and sustainable management of water and sanitation for all, till 2030. According SuSanA (2017), sustainable sanitation contributes directly or indirectly to targets in all 17 SDGs. Such an indirect contribution is for example recycling nutrients from wastewater contributing to SDG 2: Zero hunger; and further to SDG 1: End poverty.

Bolivia is one of the poorest countries in South America (Luca, 2019). In 2018, 49 % of the population lacked access to improved sanitation facilities (UN, 2018). Bolivia is strongly affected by climate change, which in recent years has resulted in a higher frequency of droughts and flooding (Sida, 2019). Except from direct damages, flooding also results in dispersion of sewage with the water masses, causing diseases. Montero is the city with the highest population growth, within the Santa Cruz department, in the lowlands of Bolivia. According to Montero's municipal plan for water and sanitation, only 36 % of the population in the urban areas of Montero is connected to the sewage system (GAMM, 2019). The majority of the rest of the population use simple latrines or septic tanks. To overcome the widespread lack of sanitation access among the most vulnerable and poor population, and the degrading impacts of untreated or poorly treated wastewater, the city is in the need of sustainable sanitation, considering economic, social and environmental aspects. Since 2015, approximately 200 urine diverting dry toilets (UDDTs) have been built in Montero, providing safe sanitation to a thousand inhabitants who lack access to the sewage net. However, the treatment of the toilet waste is inadequate with loss of valuable nutrients and risk of polluting water bodies (Jönsson, 2002).

1.1 OBJECTIVE AND RESEARCH QUESTIONS

The objective of this study is to assess nutrient recycling, innovative dry, source-separating sanitation systems, in a context relevant for a city like Montero, using a selection of sustainability criteria co-developed by relevant stakeholders. By analyzing the perspectives health, environmental, resource use, financial, socio-cultural and technical-organizational, the goal is to capture all dimensions of sustainability related to urban sanitation. On a larger scale, the project aims to provide information for the Stockholm Environment Institute led *WATCH program*, contributing with information and capacity for institutions in Bolivia, aiming for safe sanitation and watershed management (SEI, n.d.). The objective is also to contribute to UNICEF Bolivia's work in Montero and influence the Bolivian sanitation sector as well as enhance knowledge to the Bolivian population about sustainable sanitation.

In order to achieve the purpose of this study, the following research questions have to be answered:

- What are the positive and negative aspects of new and innovative sanitation systems appropriate in a Montero context, considering a selection of sustainability criteria related to the interests of different stakeholder groups?
- How sustainable, according to the selected criterion, is each of the innovative systems in a Montero context, in relation to the existing urine diverting system?

1.2 SCOPE AND LIMITATIONS

This project analyses different sanitation systems from user interface to disposal or end use of treated products. Grey water is not assessed in the study since it is assumed to be the same for all analyzed systems. This because they are defined consisting of the UDDT module currently under construction in Montero, which is judged utilizing a sustainable collection method with grey water gardens (Personal Communication, UNICEF, 2019).

2 BACKGROUND

2.1 SUSTAINABILITY ASSESSMENT OF SANITATION SYSTEMS

At the 2005 World Summit on Social Development, United Nations defined *economic development*, *social development* and *environmental protection* as the three pillars for sustainable development (United-Nations, 2005). To assess the sustainability of different treatment alternatives for sanitation systems, an extensive and systematic methodology which combines these three pillars is required (Bradley et al., 2002). A commonly used method to define sustainability is by proposing a set of sustainability criteria (Vidal, 2018; Bradley et al., 2002; Hellström et al., 2000).

In a framework for system analysis of sustainable urban water management, Hellström et al. (2000) state five main categories for sustainability; health and hygiene, social-cultural, environmental, economic and functional- technical. For each category one or several prioritized criteria with at least one indicator for validation of the system are defined. Hellström et al. (2000) emphasize that these indicators when applicable should be quantifiable and measurable, for the sustainability analysis to have a practical application. Existing research has studied which criteria and indicators are most relevant for analysing sustainability of wastewater treatment and urban water management (Bradley et al., 2002; Hellström et al., 2000). While a Life Cycle Assessment is a method quantifying the impact of a system in absolute numbers, a multi-criteria assessment of sustainability is useful for a relative comparison of different sanitation solutions.

2.2 SITE DESCRIPTION

The Plurinational State of Bolivia, in this study referred to as Bolivia, is a landlocked country located in the mid-western part of South America, bordering Brazil, Argentina, Peru, Paraguay and Chile (INE, n.d.a). The official capital is Sucre while the government is seated in La Paz, both located in the highland. Nearly a third of the country's area is located above 3000 m.a.s.l. (INE, n.d.a). The lowlands covers approximately 60 % of the area and consists of plains and low plateaus rich in forests.

Montero is the forth biggest municipality of the Santa Cruz department with a population of around 134 000 inhabitants, according to a projection for 2019 by the National Institute of Statistics of Bolivia (INE). The altitudes of the municipality varies between 230-390 m.a.s.l. The yearly precipitation averages above 1000 mm with more humid weather during summer and drier winters (GAMM, 2019). The tropical climate, with yearly average temperature of 23 °C, provides conditions for growing various crops. During the summer, sugar cane represent almost 90 % of the crops (INE n.d.b, Unpublished, CIAT, 2019b). Corn and soy are common crops abundant all year around, while yuca and wheat are alternative crops during the winter. In the area around Saavedra, a small city located 15 km north of Montero, the closest cultivations can be found. The soils in Montero consists mostly of sand and smaller proportions of silt (Personal Communication, CIAT, 2019a). Due to generally acid soils, the pH of the soils is commonly increased by spreading the burned agricultural ashes. The groundwater level are during the normal dry conditions located around 1.8 m below the surface, but can after rainfall be 20 - 30 cm below surface or sometimes reaching up to the surface (Personal Communication, CIAT, 2019a).

2.2.1 Sanitation in Montero

At present, only 36 % of the population in the urban areas of Montero is connected to the conventional sewage system (GAMM, 2019). The wastewater is lead to the Wastewater Treatment Plant (WWTP) in Montero, where it passes through a metal grid which removes larger solids, before ending up in an anaerobic lagoon. Currently, no other barriers exist at the WWTP, but two filters with automatic removal of the solids, electromagnetic treatment and a sedimentation pond are under construction (Personal Communication, COSMOL, 2019c). Around 1 % of the city's population uses urine diverting dry toilets (UDDTs), in which the faeces are collected in containers and transported and treated separately at the WWTP. The remaining 63 % use simple latrines or septic tanks from which the faecal sludge is transported to the WWTP and mixed with the wastewater.

2.2.2 Local organisation

In Bolivia the water supply and sanitation services are regulated by the authority Autoridad de Fiscalización y Control Social de Agua Potable y Saneamiento Básico (WB, 2017). The predecessor of this authority, granted in 1998 the local cooperative COSMOL the responsibility for the public service of drinking water and sewage system in the city of Montero (Personal COSMOL Communication, COSMOL, 2019g). Apart from the centralized sewage net, COSMOL is today responsible for the operation of the UDDTs in Montero. COSMOL provides information to the households with UDDTs about hygiene and health and performs weekly monitoring to each household (Personal Communication, UNICEF, 2019, Unpublished, COSMOL, 2019a).

During the last decade, approximately 200 UDDTs have been constructed in Montero, by three different organisations and foundations: Etta Projects, SNV and Foundation Sumaj Huasi (FSH) (GAMM, 2019). Since 2015, COSMOL has been responsible to the municipal government to perform collection service of the waste from the approximate 150 UDDTs constructed by SNV and FSH (Personal Communication, COSMOL 2019b). Among these, only 59 % agreed to write contract with COSMOL. Since then, some of the households have converted their dry toilets into water toilets, while others decline the services most likely due to economical and social reasons. See locations of COSMOL, WWTP and the UDDTs in Figure 1.

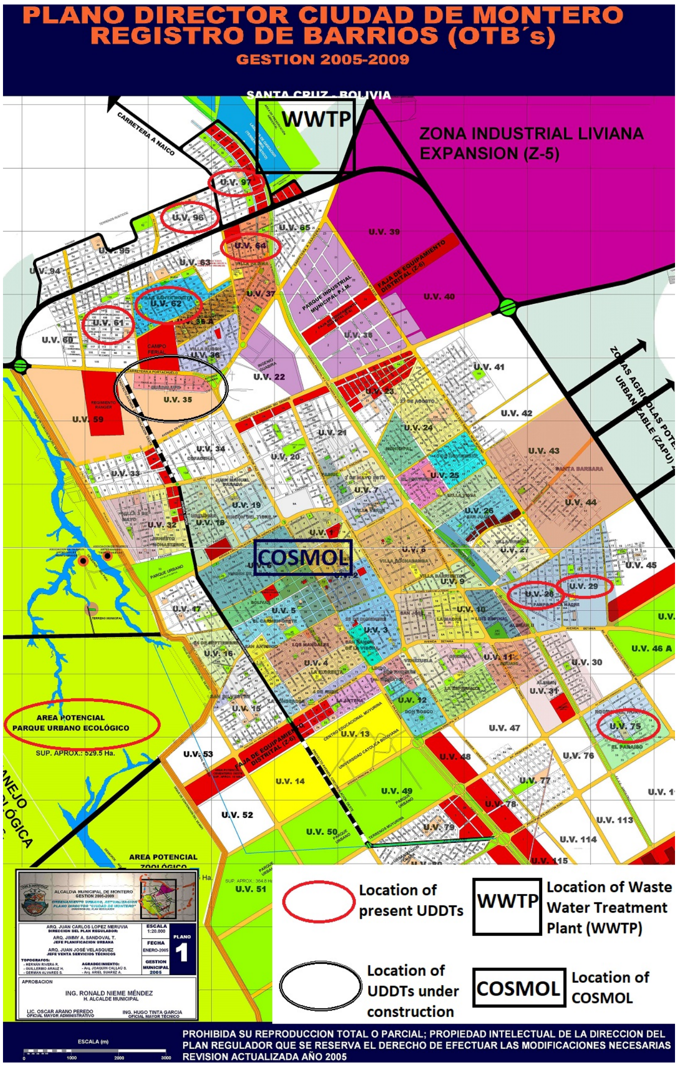

Figure 1. Map over Montero. Red circled areas have UDDT with collection of COSMOL. Area for planned UDDTs is marked with a black circle. The waste water treatment plant and COSMOL are marked with black squares.

2.2.3 Urine diverting dry toilets

The common module of a urine diverting dry toilet (UDDT) separates the faeces and urine in two separate tanks, see Figure 2. In Montero the UDDTs are located outside the house and have mainly three modules, in which the faeces goes into a single chamber, double chambers or in a portable tank in the chamber. Swedish Embassy in Bolivia and Swedish International Development Cooperation Agency (SIDA) have in cooperation with UNICEF, funded the construction of an additional 60 UDDTs in Montero, see location in Figure 1, which are being built by COSMOL during a period of 17 months between 2019 and 2020 (Personal Communication, UNICEF, 2019). These UDDTs are built with COSMOL's own module, see Figure 3, consisting of a room for a raised toilet and an urinal, a second room for a shower and a basin for hand wash and laundry, sheltered with a roof. The grey water from the shower and basin are directed with pipes into a well where sand and gravel can sediment while the water passes a filter and infiltrates in a grey water garden outside the toilet (Personal Communication, UNICEF, 2019b).

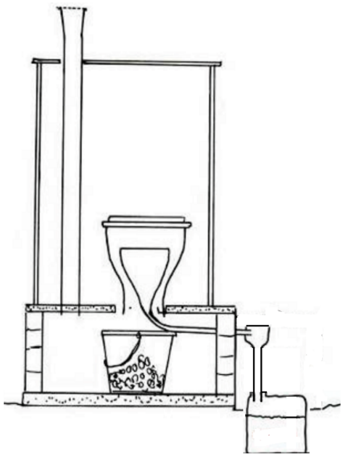

Figure 2. *UDDT with a portable container for faeces in the chamber and a buried tank for urine.*

Figure 3. *UDDT with grey water garden in Montero under construction by COSMOL. Source: (Y. Geber 2019).*

The urine is led from the toilet and urinal with pipes to infiltrate into the soil below. The faeces are collected in a container below the toilet chair, equally with the module in Figure 2. A few of the present UDDT are instead built with a double chamber, where the faeces are stored in the full chamber and collected manually after a year, while the other chamber is being used. A ventilation pipe with a wind-driven turbine, facilitates the drying of the solids and avoid rain water to enter the system. To prevent from smell and insects in the tropical climate, the households are provided with drying material consisting of 14 parts of sawdust and 1 part of lime which is to be spread inside the toilet after use. Used toilet paper is disposed in a separate bin and viewed as household waste (Personal Communication, COSMOL 2019b, Unpublished, UNICEF, 2019).

2.2.4 Burial of dry faeces

At the WWTP, an area of approximately 600 m^2 (18mx35m) is set aside for burial of faeces mixed with the drying material from the UDDTs (Personal Communication, COSMOL 2019a). The area is separated with a simple fence and holes of approximate 1 m^3 are dug where the bottom and walls are covered with a layer of lime (Personal Communication, COSMOL 2019b). Prior to the burial, the containers of dry faeces are stored for some weeks covered with a lid, see far to the left in Figure 4. Solids from the UDDTs that are more humid than usual, are first stored in one of the two chambers within the area, see Figure 5.

Figure 4. *Wastewater Treatment Plant (WWTP) in Montero, with area for burial of dry solids. Storing of covered containers in prior to burial (to the left). Source: (Y. Geber 2019).*

Figure 5. *Two chambers in the burial area of the WWTP, for additional drying of the solids which is noted to be too humid. Source: (Y. Geber 2019).*

The containers are collected from the households every third month, with exception from the UDDTs with double chambers that only are emptied and collected once a year. During the burial process, layers of dry faeces and lime are alternated. The last 20 - 30 cm are filled with the original soil from the site. Except from the layer of lime there are no barriers, such as an impermeable layer, preventing the pathogens and nutrient from the faeces to infiltrate into the soil below (Personal Communication, COSMOL, 2019c).

In 2018, sampling and laboratory tests from the burial site, reported abundance of Escherichia Coli (E Coli) and helminth eggs in the faeces after more than a year of burial, see Appendix A, indicating that there was humidity sufficient for the helminth to survive (Quebracho-S.R.L., 2018). In future, COSMOL plans to construct 16 additional chambers and add an extra yet undefined step of treatment to the dry faeces from the UDDTs.

2.3 PATHOGENS IN HUMAN EXCRETA

Human faeces can potentially contain all the four types of human pathogenic organisms (bacteria, viruses, protozoa and helminths), but the quantity and actual species are strongly dependent on the health status of the people using the toilet (US-EPA, 2013). To reduce the potential for public exposure to pathogens, the European Parliament have defined a regulation stating requirements when using animal byproducts (ABP) for human consumption, including fertilizers produced from human excreta (EUR-Lex, 2002). The ABP regulation states that trade of manure is only permitted if treated in at least 70 °C for an hour or if other standardized processes can ensure minimising of biological risks. These processes are required to validate 5 $\log_{10}$ reduction of Salmonella[1] or Eterococcus faecalis, a 3 $\log_{10}$ reduction of viable eggs from Ascaris sp and a 3 $\log_{10}$ reduction of parovirus if thermo resistant virus are identified as a relevant hazard.

In Bolivia, the quantity of pathogens and specific species differs depending on the geography, shown in a study of children performed in both the high plain and in the tropical zone by the Ministry of Health and Sports (Mollonedo & Prieto, 2006). In the tropical zone the dominating pathogens, found in more than 30 % of the children in the study, were the helminths Uncinaria and Ascaris lumbricoides, the protozoa Blastocystis hominis and Giardia lamblia (G lamblia), and the bacteria E coli. In the high plane, only G lamblia, E

[1]ABP defines Salmonella as Salmonella Seftenberg since they focus on heat hygienizing, while all Salmonella species are generally good indicator organisms

coli and Blastocystis hominis were found in more than 5 % of the children. Among the found pathogens in this study, the United States Environmental Protection Agency (US EPA) consider Ascaris lumbricoides, G lamblia and E coli as principal pathogens of concern in sewage sludge (US-EPA, 2013). Generally the species of helminth and bacteria can be considered a more severe health risk since they can survive outside their host, unlike protozoa and virus which will rapidly be reduced with time outside their host (Rieck et al., 2012). In neither the high plane nor the tropical zone, viruses were detected (Mollonedo & Prieto, 2006).

The eggs from helminths are the pathogens with the longest survival time and can under certain conditions survive up to 7 years in soil (US-EPA, 2013). The human morbidity has a strong correlation with the numbers of worms present. People infected with a low number of worms, usually do not get any symptoms, while a higher number of worms can cause symptoms such as abdominal pain, diarrhea, malnutrition and impaired physical development and growth (WHO, 2019). Eggs from Ascaris sp, here referred to as Ascaris, are the only viable helminth eggs that can be determined with laboratory tests. Since Ascaris is the helminth that is hardest to inactivate, an assumption can be made that no other helminths can survive if Ascaris is proved to be inactivated, i.e. the amount of viable eggs reduced sufficiently (US-EPA, 2013). Ascaris has been estimated to cause 12 million acute illnesses and 10 000 deaths every year (de Silva et al., 1997). The highest morbidity is among children.

2.4 NUTRIENT LEAKAGE TO WATER RECIPIENTS

Release of wastewater effluents containing nutrients, from conventional wastewater systems, is a major cause of eutrophication in surface waters globally (Jönsson, 2002). Since UDDTs are operated without water supply, water effluents are avoided and eutrophication reduced. Nutrients leakage to groundwater is a remaining problem for dry sanitation systems if operation and treatment is inadequate. The most common groundwater pollutant is nitrate, for sanitation system mostly contaminated from the nitrogen-rich urine. Excessive nitrite levels remains in the groundwater for decades and can in babies under 3 month, cause oxygen deficit (WHO, 2011). For a dry system that collects and transports both urine and faeces between closed containers and after treatment reuses them in crop production, where the nutrients can be absorbed, the risk is negligible (Tilley et al., 2008). A dry system burying the faeces, needs to perform this at least 1.5 m above the groundwater table and at least 30 m from drinking water wells to ensure groundwater contamination is prevented (Tilley et al., 2008).

2.5 NUTRIENT RECYCLING IN SANITATION SYSTEMS

The faeces and urine from the UDDTs are at present in Montero viewed as waste that needs to be treated, as in the case with a conventional sewage system. However, the UDDTs, have an exceptional potential to produce valuable products from the faeces and urine where the nutrients are recycled. The nutrients in most of the food we eat originate from the agriculture, which is why producing fertilizers of faeces or urine is a method to recycle the nutrients in a sustainable way. The Planetary Boundaries represent an ecological ceiling, beyond which the risk of generating large scale irreversible changes is increased. These ecological boundaries, represent the outer boundary in *the Doughnut* model, created in 2012, to encompass human well being (Raworth, 2017). The inner boundary makes up a social foundation, below which there is shortfall in well being with increased hunger, health problems and poverty, see Figure 6. The biogeochemical flows of nitrogen (N) and phosphorous (P), represent one of the two Planetary Boundaries already being beyond the ecological boundary, thus making recycling of nutrients in sanitation system particularly important.

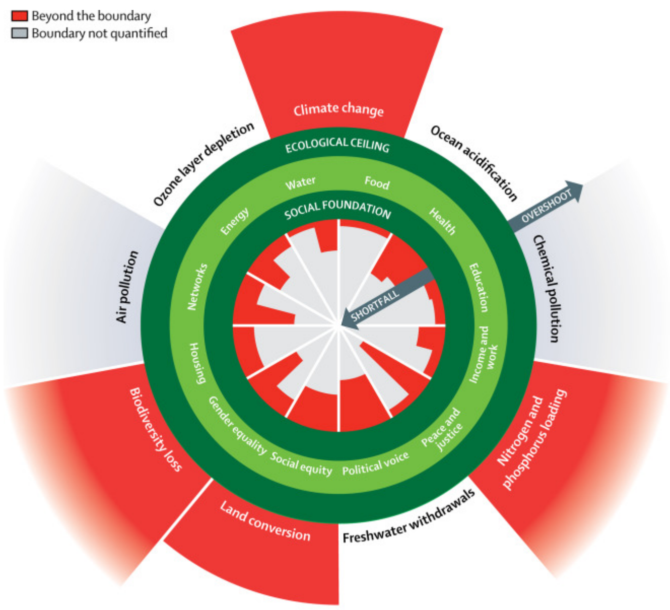

Figure 6. *The Doughnut* of social and ecological planetary boundaries.

During the last decade, *peak phosphorus* has become a well known term. Research indicates that the P reserves will last another 30 - 300 years, while the quality will with high certainty be reduced while the prices increase (Cordell & White, 2011). Jönsson (2019) reports that the reserves for production of mineral N fertilizer are around five times smaller than those for production of P fertilizer. A corresponding increase in price for P versus N fertilizers, would according to Jönsson, in Sweden, increase the price for crop production seven times more for the N fertilizer.

In Sweden an average person produces 290 - 550 L fresh urine and 51 kg faeces every year (Stintzing et al., 2004; Jönsson & Vinnerås, 2004). This is based on a protein rich diet, which agrees with the diet in Bolivia (FAO, 2013), mainly predominant by meat rather than vegetables. A diet predominant by vegetables and fibres generate a higher mass of faeces per year and person (Rieck et al., 2012) as well as a lower N content due to a smaller protein content. According to a study at the Swedish University of Agricultural Sciences the corresponding amount of N extracted from a Swedish person is 4 kg per year as urine and 0.5 kg per year as faeces (Jönsson & Vinnerås, 2004). In the same study, the authors have proposed a set of equations for calculating the content of N and P in urine and faeces in other countries. These are based on data from FAO regarding the protein content in the corresponding diet, see Equation 1 and 2:

$$m_{N,excreta} = 0.13 \cdot m_{protein,tot} \quad (1)$$

$$m_{P,excreta} = 0.011 \cdot (m_{protein,tot} + m_{protein,veg}) \quad (2)$$

According to the same study, 88 % of the N and 67 % of the P from a Swedish person, can be assumed to be secreted in the urine and the remaining parts end up in the faeces. However, the authors have not found a good method of translating this to other countries. In wastewater, urine is the fraction with the biggest nutrient content even though the volume only is one percent (Maurer et al., 2006). At the same time, the pathogen content in urine is minimal in comparison with faeces (Höglund, 2001). With an UDDT, the nutrients in the urine can be recycled as fertilizers without the need of advanced treatment. An UDDT simultaneously reduces the amount of excreta that needs additional treatment as well as saves water and reduces the transports.

2.5.1 Treatment of faeces with vermicomposting

Vermicomposting is an innovative way of treating the faeces from the UDDTs by composting accelerated by worms. The worms fragment the solids mechanically and changes the biochemical properties of the compost while recovering most of the nutrients and maintaining the aerobic conditions (Loehr et al., 1985). When the faeces have been treated under sufficient time, the worms can be separated with a 2 mm rack with fresh food on top, through which the worms migrate and can be moved to another vermicompost chamber. According to a pilot study of urine diverting vermicomposting toilets in Germany, the humidity in the vermicompost for efficient treatment should be in the range 65 - 80 % and the temperature maintained between 20 - 25 °C (Buzie-Fru, 2010). In general, earth worms are relatively resistant to pH changes and the conclusions about the optimal pH range differ in research. However, pH below 4.5 and pH above 8.4 should be avoided with the risk of worm migration versus ammonia losses (Buzie-Fru, 2010).

Foundation Sumaj Huasi (FSH) have used vermicomposting as a central treatment method of the dry solids from the UDDTs in the city El Alto, Bolivia since 2009 (Personal Communication, Suntura, 2019). For the vermicompost, the earthworm *Eisenia foetida* is used, which globally is the dominant worm species for treatment of faeces (Carrillo Miranda, 2014; Buzie-Fru, 2010). FSH has studied the best drying material to add to the faeces in the UDDTs and sawdust, without chemical treatment, was considered most suitable since it is absorbed best by the worms (FSH, 2015) and produces humus with the requested characteristics. For the vermicompost in El Alto, 3 kg of worms are used per m^3 of faeces (Silveti et al., 2011). The risk with too many worms is that they start to migrate to other places in the lack of food. For further design values from El Alto, see Appendix B.

In El Alto, 9 months operation of the vermicompost, without adding more faeces, has been concluded result in optimal properties of the humus. Control of humidity is performed regularly to ensure a adequate environment for the worms. A soil moisture sensor can be used to measure the humidity (%) of the compost. By pressing down a spade at different spot in the chamber, an approximate check if the humidity is even through the chamber can be performed (Personal Communication, Suntura, 2019). An estimation of the water demand for the vermicompost in El Alto, is 0.5 m^3 water per week for a 30 m^3 chamber with capacity for 16 000 kg faeces, applied a few times a week (Personal Communication, Suntura, 2019). The chambers, where the treatment takes place, are covered with lids to protect the worms from other animals and prevent from external contamination. A drainage pipe is constructed for the excessive water. Every second or third week the top 20 cm of each chamber is stirred manually to provide oxygen for the worms. The produced humus from the chambers, is moved to an open chamber after 9 months, for drying with sun heat. In El Alto, one month is sufficient for reducing the volume by evaporation and producing a dry product. Only in case of rainfall the chamber must be covered with a tarpaulin (Personal Communication, Suntura, 2019). No uniform results of the nutrient recovery rate from the vermicompost have been found in literature.

Pilot studies of vermicompost treatment with 2.3 kg earthworms per m^3 in 21°C, have reported 5 log reductions of the indicator bacteria Salmonella sp, with a clearly higher reduction compared to the control value, see Table 1. On the contrary, Hill, G et al. (2013) did not report a 5 log reduction of E Coli during the 90 days of treatment with 6.5 kg earthworms per m^3 in 19°C. None of the studies could prove a sufficient inactivation of viable Ascaris eggs.

2.5.2 Treatment of faeces with urea

Urea contributes globally to more than 50 % of the synthetic N fertilizers (Glibert et al., 2006; Simha et al., 2018). Urea is one of the major components in urine, with concentrations of 20 g/L (Simha et al., 2018). Ammonia has been found to contribute to inactivation of pathogens in source separated faecal matter, when it occurs in its uncharged form NH_3 (Nordin et al., 2009a). A cheap and simple way to add ammonia to the faeces is to add urea, which is degraded to ammonia by the naturally occurring enzyme urease in the faeces. Urea is safe and easily handled and has been considered for treatment of faeces on municipality level (Vinnerås et al., 2009, 2003; Schönning & Stenström, 2004). The pH is increased by the urea and since it remains in the material after the treatment, regrowth of pathogens is minimal. For the treatment, a properly closed container and urea are needed. In a study of treatment of faeces with urea directly in degradable plastic bags (Peepoo) the disinfectant proved to perform as a successful low cost sanitation method (Vinnerås et al., 2009). By adding urea to a fertilizer the value increases with the additional N content.

In a study by Vinnerås et al. (2003) with 3% urea at 20°C, a 5 log reduction of the indicator bacteria E Coli and Salmonella was reported, significantly faster than for the control test without urea, see Table 1. A later study from 2009 indicated a relationship between urea concentration, temperature and the required treatment time for inactivation of pathogens (Nordin et al., 2009b). In a parallel study by Nordin et al. (2009a) of the inactivation effect of Ascaris eggs, 1-2 % urea was tested during 35 days. A 3 log reduction, in agreement with the ABP regulation, was not reached within the study length for temperatures of 24°C or below. Research has proved effective inactivation of Ascaris eggs, when adding sufficient amounts of urea (Fidjeland et al., 2015). In a report by Fidjeland et al., (2015) the relation between the required time for ammonia treatment and the temperature, pH, amount of added ammonia and requested log reduction of viable Ascaris eggs (LRV) was expressed as Equation 3.

$$t = \frac{3.2 + LRV}{10^{-3.7+0.062 \cdot T} \cdot NH_{3,pitzer}^{0.7}} \cdot 1.14 \tag{3}$$

where $NH_{3,pitzer}$ is a measurement of the activity of ammonia. In a web application by the same article author, the treatment time can be calculated from the NH_3 concentration rather than the activity (Fidjeland, n.d.).

Table 1. Time (days) to 5 log reduction of the indicator pathogens E Coli and Salmonella Sp and to 3 log reduction of Ascaris with different treatment methods. / means that the method is not analysed in the study

Method	Time (days) for 5 log reduction				Time (days) for 3 log reduction		Source	Treatment time	Initial conc pathogens	Additional information	Comments
	E Coli		*Salmonella sp*		*Ascaris*						
	test	*control*	*test*	*control*	*test*	*control*					
Vermi-composting	177	0.26 log reduction after 59 days	<59 days	0.59 log reduction after 59 days	/		Buzie-Fru, 2010	59 days	E07-E08 CFU/g	2.30kg worms/m2 T=21°C	5 log red after 177 days if log -trend assumed (R2=0,95)
Vermi-composting	2.14 log reduction after 90 days	2.30 log reduction after 90 days	/		Increase in amount (minor reduce viabilty)		Hill et al, 2013	90 days	E04 CFU/g E Coli 485 viable Ascaris eggs	0.013g worms per g compost T=19°C	Equals 6.5 kg/m2 in the chambers in El Alto
Urea, 3%	5	50	50	<5 log reduction in 50 days	<50 days	2.7 log reduction in 50 days	Vinnerås et al, 2003	50 days	E07 CFU/ ml bacteria E04 viable Ascaris eggs	Viable E Coli measured. T=20°C	Assuming detection limit 2 log
Urea 1%	/		4 days	24 days	/		Nordin et al 2009	N/A	E06-E08 CFU/g	T=24°C	Reporting linear reduction with time
Urea 2%	/		2 days		/						
Urea 1%	/		46 days	132 days	/					T=14°C	
Urea 2%	/		6 days		/						
Urea 1 %	/		/		>3.3 log reduction in 10 days	3.2 log reduction in 35 days	Nordin et al 2009	35 days	2000 Ascaris eggs	T=34°C	
Urea 2 %	/		/		>3.3 log reduction in 4 days					T=34°C	
Urea 1 %	/		/		0.66 log reduction in 35 days	0.3 log reduction in 35 days			808 Ascaris eggs	T=24°C	
Urea 2 %	/		/		2.9 log reduction in 35 days					T=24°C	

2.5.3 Stored urine in crop production

Urine can be used as a well-balanced fertilizer in the agriculture with respect to N, P and K (potassium). It also contains various micro-nutrients and can contribute to crop yields on a level with synthetic and commercial fertilizers (Rieck et al., 2012). Most bacterial pathogens in urine, including E Coli and Salmonella are inactivated within days, due to the increased pH and ammonia content when the urine degrades (Stenström et al., 2011). On the contrary, some pathogens such as rotavirus remains in the urine for longer time, especially in cold temperatures (Schönning & Stenström, 2004). Since cross-contamination in the UDDT, from the faeces, can increase the risk of infection from urine, storage is recommended to secure safe reuse. WHO recommends a storage time of 6 months in 20 °C for commercial use of urine as fertilizer in agriculture (WHO, 2006). Due to the high urea content of concentrated urine, Ascaris eggs can be inactivated by a log 3 reduction at 20 °C within 4 months, which can be proved by the web application of Fidjeland, (n.d.). For safe use of urine in agriculture, an additional month between fertilization and harvest is a recommendation. Since the N in urine is 0.6 % (Jönsson & Vinnerås, 2004), compared with the 46 % N content in synthetic urea fertilizers (SMART-Fertilizer-Management, n.d.), relatively large volumes are required when using urine as fertilizer in agriculture.

2.5.4 Volume reduction of urine with ZeoPeat

To decrease the volume of the urine, a treatment method is to add *ZeoPeat*, a mixture of the mineral zeolite and magnesium charged peat by 7 : 1 (Caspersen & Ganrot, 2017;

Personal Communication, Ganrot, 2019). The technique is to enhance an ion exchange between the urine and the ZeoPeat to concentrate the nutrients in the solid phase, which can be separated from the remaining N rich water, in this report referred to as *N water*. The company Again AB has patented the ZeoPeat mixture. To enhance the ion exchange and to effectively separate the solid phase from the liquid, the company has constructed the devise *Makenutri 200V* (Personal Communication, Olsson, 2019), consisting of an electrical stirrer and a sedimentation container, with the capacity of treating 170 L urine per batch. The stirring process takes around 50 minutes, while 6 hours of sedimentation is recommended for sufficient separation of the different substances. This allows two batches per Makenutri 200V a day, if filling the device at the end of the working day to sediment during the night.

When using 20 % of ZeoPeat, the produced solid, called *Gainutri*^{TM}, has a weight reduction of 60 % against the initial urine and nutrient recovery of approximately 70 % N, 98 % P and 70 % K (Personal Communication, Ganrot, 2019). Since the produced solid consists of approximately 50 % of water, a subsequent drying process is recommended to generate an attractive fertilizer. The resulting N water has a volume of 80 % of the initial urine and consists of 30 % of the N content from the urine. Since the method has yet not proved to reduce Ascaris, the urine need to be stored before the ion exchange, or alternatively the product treated with urea after. If the urine is stored before the separation in Makenutri 200V, the N water can be used as irrigation water, supplying extra N to the plants. To achieve an attractive product for agriculture, Again AB recommends Gainutri^{TM} to be mixed with additional peat or humus followed by drying (Personal Communication, Olsson, 2019).

2.5.5 Urine drying

Another innovative technology to reduce the volume of urine while retaining the nutrients, is alkaline dehydration (Karlsson, 2019). The drying process of urine is performed directly at each UDDT, which decreases the requirement of transports to a high extent. Unstable urea in urine, which contains 85 % of the tot-N content, decomposes to volatile ammonia during hydrolysis which can lead to losses of N during the dehydration process (Kirchmann & Pettersson, 1994). To stabilize the urea, an alkaline drying media that increases the pH>10 can be used (Personal Communication, Simha, 2019, Karlsson 2019). In several studies, wood ash and lime ($Ca(OH)_2$) have been used as alkalising agents in the drying media. Stabilization of urea during the dehydration process has also been reported with mixtures of lime with sandy soil or wood ash. By increasing the air temperature during the dehydration process, the drying time is reduced and the required drying area is minimized (Personal Communication, Simha, 2019, Karlsson 2019).

In a recent study (Personal Communication, Simha, 2019) of the dependence of the drying rate on temperature, an increase of the drying rate from 19 kg to 27 kg per day and m^2 was measured, independently of the drying media, when the temperature was increased from 50 °C to 60 °C. When wood ash was used alone as drying media, pH>10 could not be retained throughout the drying process. A pH>10 was retained when lime was used as drying media either alone or in mixture with sandy soil. There has been research on the urine drying method since 2016 (Dutta & Vinnerås, 2016), but it has still only been tested in practice a few times. In 2019, the technology was tested in large scale for the first time, for UDDTs in Finland (Karlsson, 2019). Due to a colder climate and larger collective UDDT systems, the pilot test included several energy demanding devices. The researchers have however done some additional estimations of applying their technology in Bolivia. For the lowlands in particular, with its warmer climate, suggestions are to use a solar heater to operate the dehydration (Personal Communication, Simha, 2019).

The suggested technology consists of a plastic box with drying media, where the urine is added through pipes. Hot air from the solar heater, attached on the outer wall of the UDDT, are drawn through pipes into the box, pushed by a 80 W fan, operating up to 12 hours a day. A ventilation pipe with wind cap connected to the plastic box, leads out the humid air to facilitate the drying. For a household of 4-5 people, a box with a surface area of 50 x 60cm^2 is estimated to be sufficient for dehydration of the produced urine under 1 month, with margin for visitors, see Appendix C. The researchers have estimated that the temperature will be kept around 30 - 50 °C within the dehydration box, taking the local monthly temperatures averages between 20 - 27 °C into account (Personal Communication, Simha, 2019, Climate-Data.org n.d.). The nutrient recovery from this treatment method is 90 % for N and 100 % P and K (Personal Communication, Simha, 2019). Pathogens including Ascaris are rapidly decreased due to the high urea content in combination with the high pH.

3 METHODOLOGY

3.1 SYSTEM DESCRIPTION AND SYSTEM BOUNDARIES

Each innovative system consists of defined methods for transports and treatments for both urine and faeces. Every assessment was made so that it is possible to get an idea how sustainable the system is separately for handling the urine versus faeces. Even if the grey water was not evaluated in this analysis, the present grey water garden was assumed existing on each UDDT. To reduce the number of visits to the household to once a week, which is the frequency of today (Personal Communication, COSMOL, 2019b), social visits were assumed being performed during each trip for collecting faeces or urine. Additional social visits were thus only needed the weeks when no collection was performed. The assessment includes 1000 UDDTs, since former cost calculations from COSMOL concluded that this is the minimum number of toilets to make the system go around (Personal Communication, COSMOL, 2019a). The average number of people per household was assumed being 4.5, which is the average of the family sizes in the 60 UDDTs under construction (Personal Communication, UNICEF, 2019). This is higher than the average of 4.1 for Montero (INE, 2015), motivated with that the UDDTs are often located less centrally and have more children than the average household in Montero.

3.1.1 Alternative 0

The existing UDDT modules in Montero were defined as the reference system (alternative 0). Only the latest module, with one portable container for faeces, constructed by COSMOL in cooperation with Swedish Embassy in Bolivia and UNICEF, was included in the analysis, since this is the module that is planned to be constructed in future (Personal Communication, UNICEF, 2019). The system includes the UDDT and plastic containers for faeces, on site infiltration of urine and transport and burial of faeces off site, see Figure 7. The required burial time of the faeces has yet not being tested, but two years is assumed, from the laboratory tests of samples from the burial site, see Appendix A, after which the buried material are dug up, transported and deposited at a landfill.

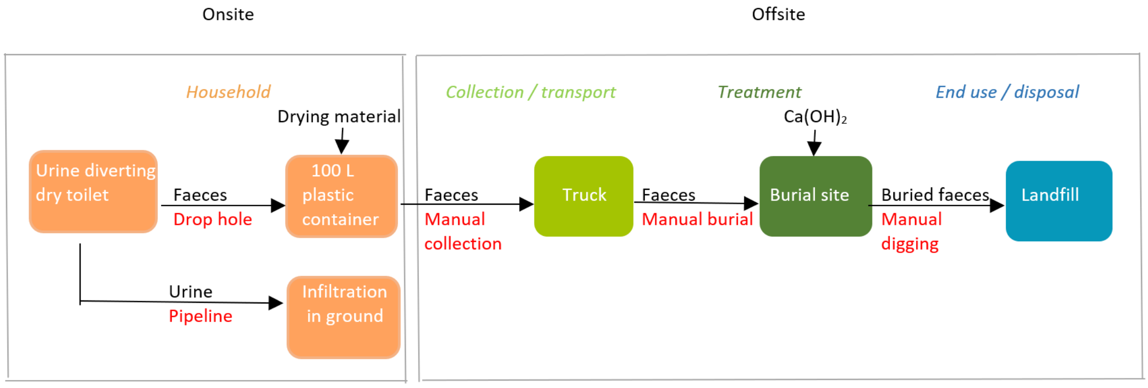

Figure 7. Flow chart for sanitation system for alternative 0 on site and off site. Red texts indicates where the workers potentially are affected.

3.1.2 Alternative 1

The first innovative sanitation method (alternative 1) was vermicomposting of the collected faeces at the WWTP and collection and storing of urine, since such a system already exists in El Alto, initiated by Foundation Sumaj Huasi. Alternative 1 includes the UDDT and portable containers for faeces and plastic tanks for urine on site and transport of faeces and urine separately, vermicomposting of faeces and storing of urine during 4 months. The idea of this alternative is to be simple and similar to an already existing system in Bolivia, which is why this alternative does not include additional treatment of the humus from the vermicompost. Thus alternative 1 is not as innovative as alternative 2 and 3. COSMOL is not considered being responsible for the transport of humus and stored urine to agriculture, see Figure 8.

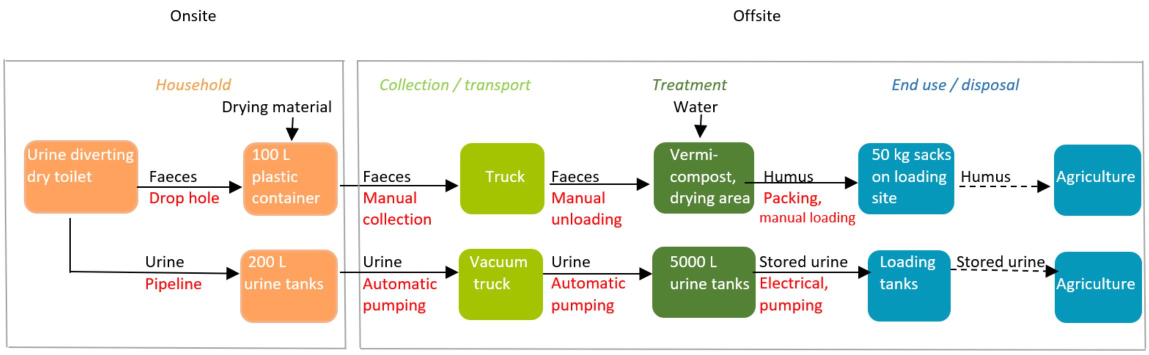

Figure 8. Flow chart for sanitation system for alternative 1 on site and off site. Red texts indicates where the workers potentially are affected. Dashed line shows steps outside COSMOL's area of responsibility.

3.1.3 Alternative 2

The second innovative sanitation method (alternative 2) equals alternative 1 with vermicomposting and collection of liquid urine, but treats the fractions differently. Alternative

2 includes the UDDT and portable containers for faeces and plastic tanks for urine on site and transport of faeces and urine separately. On treatment level it consists of vermicomposting of the faeces, ion exchange between the urine and ZeoPeat, mixing and drying the two resulting products and treating the mixture with urea. The ZeoPeat mixture is in this analysis assumed being purchased from Again AB in Sweden to be able to easier adjust the blend for the conditions in Montero during a future pilot test. The N water, which is also produced from the ion exchange, is added to the wastewater at the WWTP, since no treatment method without long storage times has been found. COSMOL is not considered being responsible for the transport of the humus-Gainutri mixture to agriculture see Figure 9.

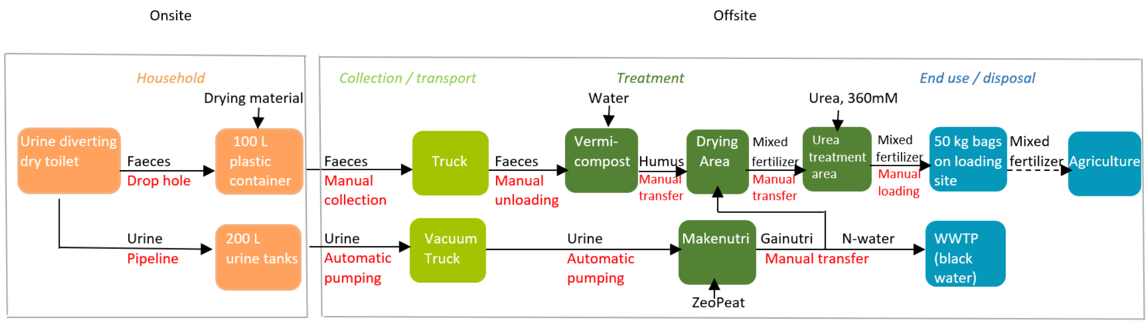

Figure 9. Flow chart for sanitation system for alternative 2 on site and off site. Red texts indicates where the workers potentially are affected. Dashed line shows steps outside COSMOL's area of responsibility.

3.1.4 Alternative 3

The third and last innovative sanitation method (alternative 3) equals alternative 2 with vermicomposting and urea treatment, but exchanges the collection and central treatment of urine with an innovative on site urine drying technology. Alternative 3 includes the UDDT and portable containers for faeces and urine dehydration device on site and transport of faeces and dry urine separately. Centrally the system includes vermicomposting and urea treatment of the faeces with urea from the dried urine to fulfill a 3 log reduction of Ascaris. The dried urine not needed for the urea treatment is stirred, to get an even distribution of nutrients, before packing. COSMOL is not considered being responsible for the transport of humus and dried urine to agriculture, see Figure 10.

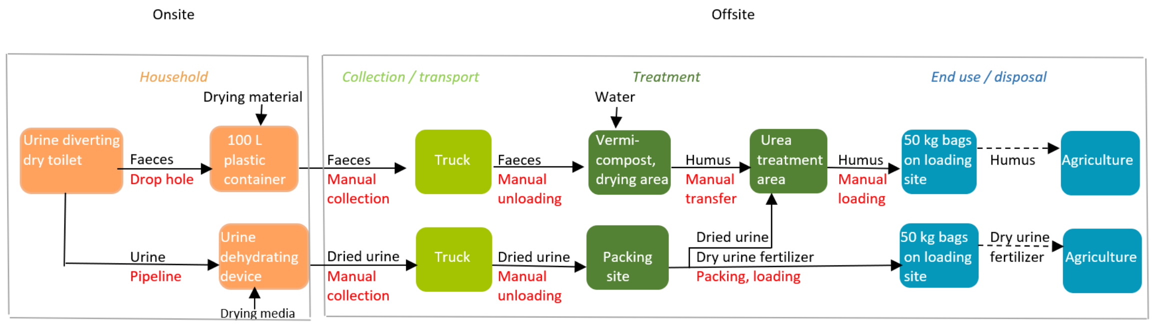

Figure 10. Flow chart for sanitation system for alternative 3 on site and off site. Red texts indicates where the workers potentially are affected. Dashed line shows steps outside COSMOL's area of responsibility.

3.2 SUSTAINABILITY ASSESSMENT USING MULTIPLE CRITERIA

For the sustainability assessment of potential nutrient recycling systems of source separation technologies, multiple criteria were analysed, to contain all perspectives of sustainability. The categories for criteria; *Health*, *Environmental*, *Financial*, *Socio-Cultural* and *Technical-Organizational* was chosen inspired by the framework for system analysis by Hellström et al. (2000). An additional category, *Resource Use*, was added, since the purpose of this analysis is to assess nutrient recycling in the current UDDTs.

3.3 SELECTION OF CRITERIA AND INDICATORS

A selection of a total of ten criteria was made, where each category had at least one criterion. An initial proposition of criteria was made under dialogue with Research Institutes of Sweden (RISE) and Stockholm Environment Institute (SEI), partly inspired by the criteria in Hellström's framework that were considered relevant for dry source separated systems. In a latter step, small modifications of the criteria were made after consulting with UNICEF and COSMOL and corresponding indicators and analytical methods were defined. The chosen criteria were validated with the opinions of key persons within the sanitation sector. These opinions were displayed during a workshop about sustainability criteria for sanitation systems, taking place in Montero a few weeks into project, see D.1 in Appendix D. The final set of sustainable criteria are summarized in Table 2.

Table 2. Chosen criteria for the sustainability assessment with corresponding indicators and assessment methods

Category	Criteria	Criteria identified by	Indicator	Method for assessment
Health	Health risk: workers	In cooperation with RISE and SEI	*Likelihood and severity of contact with faeces and associated risks for workers [score] (1)	Literature research, field observations, semiquantitative risk assessment matrix [a]
	Risk of infection: at reuse of treated feces and urine	In cooperation with RISE and SEI	*Reduction of indicator bacteria [log reduction] (2) *Reduction of viable Ascaris eggs after treatment [log reduction] (2)	Literature research, comparison with ABP requirements
Resource Use	Potential of reuse of nutrients	UNICEF Bolivia. Stake holder group 1 workshop in Montero, see Appendix E	*Amount of N and P recycled [%](2) *Mass of N and P recycled [kg/capita, year] (2)	Literature research, calculations from Bolivia FAO data
	Energy consumption	In cooperation with RISE and SEI	*Total energy consumption on site [% of yearly energy consumption at household level] (2) *Total energy consumption off site [% of yearly energy consumption at household level] (2)	Literature research, calculations
Environmental	Potential environmental risks	In cooperation with RISE and SEI. Stake holder group 1, 2 and 3, workshop in Montero, see Appendix E	*Likelihood and severity of potential environmental risks [score] (1)	Literature research, field observations, semiquantitative risk assessment matrix
Financial	Operation, maintenance and investment costs	In cooperation with RISE and SEI. Stake holder group 2, 3 and 4, workshop in Montero	*OM costs [USD/capita, year] (2) *Capital cost [USD/capita, year] (2)	Literature research, calculations, system cost tool [b] from the World Bank Group
	Economical value of recycled products	In cooperation with RISE and SEI.	*Value of recycled products [USD/capita,year] (2)	Literature research, calculations
Socio-Cultural	Social acceptance: farmers	In cooperation with RISE and SEI. Stake holder group 3 workshop in Montero	*Farmers attitude towards using treated urine and faeces in agriculture [ ] (1)	Interviews
	Affordability	Stake holder group 1, workshop in Montero, see Appendix E	*Cost for collection and treatment service in relation to salary [USD/household, year] (2)	Literature research, calculations
Technical-Organizational	Required technical-organizational capacity	In cooperation with RISE and SEI. COSMOL. Stake holder group 2 and 4, workshop in Montero, see Appendix E	*Complicity of what is needed on organizational level in relation to existing capacity [colours] (1)	Literature research, field observations, capacity profile [c]

(1) Qualitative analysis (2) Quantitative analysis
a. WHO guidelines, 2016 b. World Bank Group, n.d. c. Söderberg, 2003

3.4 SCORING CRITERIA

In the sustainability assessment, each criterion was provided a score in a certain scale. All criteria were translated into a numerical score 1-5, where 1 indicates the poorest result and 5 the best. For all criteria the score was also translated into a color, further clarifying if the result is positive or negative:

red = 1: very poor result
orange = 2: poor result
yellow = 3: neither good nor bad result
light green = 4: good result
green = 5: very good result

3.5 ASSESSMENT METHODS

Depending on if the indicators were quantitative or qualitative, different approaches were used to obtain the necessary information, see Table 2. A large part of the study was a literature analysis, for estimating pathogen reductions, health risks, nutrient recovery and leakage, energy consumption, technical components and financial costs. Relevant articles from journals within waste management, water technology and microbiology were generated from Google scholar or directly from the data bases *Research Gate*, *Elsevier*, *Springer Link* or *SuSanA*. For qualitative information to gain a quantitative score, semi-quantitative assessment matrices were used for health- and environmental criteria evaluating risks, which could convert big amounts of data into a clear result. Some costs and product specific data were taken from web pages specialised in the area such as Bominox (2014), distributor of pumps. Information about the actual sanitation system in Montero, Bolivia or about certain sanitation technologies was mostly acquired directly from researchers through personal communication. Additionally, field investigations and interviews were performed. The calculations were generally performed in Excel to handle the large amount of data. For the more complex cost calculations on system scale, annualized costs taking a 5 % discount rate into account, was calculated using a tool from World Bank Group, (n.d.).

3.5.1 Health

Health risk: workers

To estimate the health risk for workers during collection, transport and treatment of faeces and urine, a semi-quantitative risk assessment matrix was produced, evaluating the likelihood and severity of each detected risk. In the semi-quantitative matrix, all hazard events and exposure routes were listed and evaluated. Every hazard was scored between 1 - 5 for likelihood and between 1 - 16 for severity for each alternative sanitation system, inspired by tool 3.3 from WHO (2016), see Table 3.

Table 3. Suggested risk definitions for semi-quantitative risk assessment, Tool 3.3 WHO Guidelines (WHO, 2016)

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.

Chemical, biological and physical risks were considered, including pathogens from faeces and urine, traffic accidents and back injuries. A total score was calculated from the product of the likelihood and the severity and translated to one of the ranks *low* (L), *medium* (M), *high* (H) or *very high* (VH), similarly as in tool 3.4 from WHO, see Table 4.

Table 4. Semi-quantitative risk assessment, tool 3.4 in WHO Guidelines (WHO, 2016)

		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) x (S)		<6	7–12		13–32	>32
Risk level		Low Risk	Medium Risk		High Risk	Very High Risk

Literature research was the main method to evaluate the severity and likelihood. The main search terms used in the databases were: ammonia, nitrate, nitrite, health risks, safety and WHO. In the assessment, the existence of *Control measures* for each risk and corresponding *Validation of control* was included. If a control measure was detected and validated to be followed, for example proper safety equipment being used, a lower likelihood of the risk was assumed. In WHO's guidelines (2016), only the highest rank of a risk in the assessment was used to score the entire system. Since all alternatives in this analysis include risks of severe traffic accidents, another scale was define to show difference between them. The scale was instead defined after seeing the result of the assessment and scored according to the total risk score for risks rated *medium* or higher as well as the number of high risks. To relate to the total risk score, 5 medium and 5 high risks, each with an average score of a medium versus high risk in Table 4, correspond to a total score of 160. The scale for the final scores was set to the following, where all criteria in the lower level needed to be fulfilled to be awarded that particular final score:

1 - Very high : if >0 risks rated *very high*

2 - High : if >4 risks rated *high*, no risks rated *very high*, Total risk score $\geq$175

3 - Medium : if $\leq$4 risks rated *high*, no risks rated *very high*. Total risk score <175

4 - Low : if $\leq$3 risks rated *high*. No risks rated *very high*. Total risk score <150

5 - Very low : if 0 risks rated *high* or *very high*. Total risk score <125

Risk of infection from products after treatment

The risk of infection from the produced products from treated faeces and urine was estimated by comparing with the ABP logarithmic regulations of 5 log reduction for the indicator bacteria Salmonella Sp and 3 log reduction for Ascaris. To evaluate the log reduction of Salmonella for the alternative treatment methods observations from research reports were studied. Due to studies detecting Ascaris above the regulations in vermicomposts, alternative 2 and 3 were designed including urea treatment to ensure no risks for Ascaris. The sufficient urea amount was found using Fidjeland's equation, see Equation 3. The main research terms in the data bases were: *vermicompost, worms, earth worms, log reductions, logarithmic reductions, pathogens, indicator bacteria, Salmonella, E Coli, Ascaris, helminths, urea, storage* and *ammonia treatment*. The final ranks were defined in the following scale:

1 - *no* if the system failed to fulfill any of the log reductions of Salmonella Sp and Ascaris in the ABP regulation for faeces and urine
3 - *partly* if the produced products partly fulfilled the log reductions of Salmonella Sp and Ascaris in the ABP regulation
5 - *yes* if all the produced products fulfilled the defined log regulations of Salmonella Sp and Ascaris in the ABP regulation

3.5.2 Resource Use

Potential of reuse of nutrients

The nutrient reuse analysis was limited to include N and P in human excreta in Bolivia. These contents were calculated with national FAO data (FAO, 2013), for protein content in national food, and Equation 1 and 2 suggested in the study by Jönsson & Vinnerås (2004). Approximate national data of production of faeces and urine was provided from the Ministry of Environment and Water in Bolivia MMAyA (2010). Calculations were made to compare them with the Swedish design values, see Appendix E, and a conclusion drawn that the Swedish design data also can represent the Bolivian case, due to their similarities. The Swedish design values of the proportion of the N and P that are excreted in the urine versus in the faeces were used for the analysis of Bolivia as well, due to lack of national data. Since this proportion depends on the sources of the protein in the diet, the relative amount of vegetable protein were compared between the countries to analyse if this method was appropriate. The main search terms in the literature research were: *nitrogen, phosphorus, nutrients, content, faeces, urine, Bolivia, FAO, design values, toilet waste, UDDT, source separating toilets* and *kg/capita,year*.

For the humus and stored urine, no agreeing results for the recovery rate was found. Therefore it was calculated from samples of the nutrient content in vermicompost versus stored urine in El Alto, see Equation 4 and 5. The median of the samples was used, seen as more accurate than the mean value, due to differing result for N in one of the urine samples, see Table B.1 and B.2 in Appendix B.

$$N_{recovery} = 100 \cdot \frac{mass_{product} \cdot N_{\%,product}}{mass_{waste} \cdot N_{\%,waste}} \tag{4}$$

$$P_{recovery} = 100 \cdot \frac{mass_{product} \cdot P_{\%,product}}{mass_{waste} \cdot P_{\%,waste}} \tag{5}$$

,where $\%, product$ is found in Appendix B, $product$ = humus or stored urine and $waste$ = fresh urine or faeces.

Added nutrients from for example urea was not included in the calculations for the recovery. To visualize the nutrient flows, losses and recoveries in each sanitation alternative, flow chart diagrams, inspired by the multi criteria analysis in El Alto by Smith (2020), were made. The nutrient recovery of N and P in Gainutri and dried urine was defined from research results and laboratory measures (Personal Communication, Ganrot, 2019, Unpublished, Simha, 2019). The total amount of N and P recycled per person and year was calculated from the initial nutrient content in faeces and urine per person and year in Bolivia and from the nutrient recovery, by Equations 6 and 7.

$$N_{recycled} = N_{in,faeces} \cdot \frac{N_{recovery,faeces}}{100} + N_{in,urine} \cdot \frac{N_{recovery,faeces}}{100} \tag{6}$$

$$P_{recycled} = P_{in,faeces} \cdot \frac{P_{recovery,faeces}}{100} + P_{in,urine} \cdot \frac{P_{recovery,faeces}}{100} \tag{7}$$

The total amount of recycled N versus P for the system was calculated by adding the amount from the products generated from the faeces versus the urine. A total recycling rate was calculated by comparing the total recycled amount of each nutrient with the initial amount produced by one person during one year, see Equation 8 and 9.

$$N_{recovery,total} = \frac{N_{recycled}}{N_{faeces} + N_{urine}} \tag{8}$$

$$P_{recovery,total} = \frac{P_{recycled}}{P_{faeces} + P_{urine}} \tag{9}$$

Since the recovery rate in percentage is directly correlated with the amount produced nutrients per person and year, a score was awarded each system for N and P only for the recovery rate. The final score was gained from the average of the score for N and P. If the average landed between two scores, it was rounded of to the lower score. The motivation to this was that the calculated recovery rates assume all urine and faeces produced by the families can be collected. In reality, most people go to work or school, with the outcome that not all the nutrients will be recovered and thus, rounding down is more realistic. Each recovery rate for N versus P was scored according to the following scale:

1 if <20 % of nutrient recycled
2 if 20-39 % of nutrient recycled
3 if 40-59 % of nutrient recycled
4 if 60-79 % of nutrient recycled
5 if $\geq$ 80 % of nutrient recycled

Energy consumption

The total energy consumption for each component was calculated in kWh/year for each sanitation system. Data was received through personal communication with experts within the different systems (Personal Communication, COSMOL, 2019a, Unpublished, Suntura, 2019 Unpublished, Olsson, 2019, Unpublished, Simha, 2019) and from literature research. The main search terms, to find additional literature, were: *electricity, consumption, MJ/L, kWh, Watt/L, fuel* and *gasoline*. A total yearly consumption per UDDT was calculated on site versus off site including transports and treatment processes. For the fuel consumption calculations were made for the required number of vehicles from the amount of produced faeces and the driving distance. Since the social visits were assumed being included in the urine collection twice a week for alternative 1 and 2 and the collection of dried urine once a month for alternative 3, less extra social visits were required than for alternative 0, resulting in the demand of less motorcycles. Some of the energy consumption for driving to the social visits is therefore a part of the energy consumption for the truck.

To set the score for the energy consumption, on site versus off site, it was related to the average yearly energy consumption at household level. An important note is that the off site energy consumption, from transport and treatments, is not affecting the families' electricity bill. The average monthly consumption of 209 kWh was calculated from statistical data of the total energy consumption at household levels over the number of households connected to the electricity grid by Cooperativa Rural de Electrificación Ltda (AETN, 2018). Since this cooperative is operating in the lowlands of Bolivia and provides service to all households in Montero, it gives an indication of the actual energy consumption in Montero. The scores were set separately for on site and off site consumption with the following scale, based on the result:

1 if >10 % of yearly average energy consumption at household level
2 if >5 % and ≤10 % of yearly average energy consumption at household level
3 if >2 % and ≤5 % of yearly average energy consumption at household level
4 if >0.5 % and ≤2 % of yearly average energy consumption at household level
5 if ≤0.5 % of yearly average energy consumption at household level
Finally, the final score was the average of the on site and off site scores.

3.5.3 Environmental

Potential environmental risks

The potential environmental risks were evaluated with a semi-quantitative risk assessment matrix, similarly as for the criterion *Health risk for workers*. Each potential risk was evaluated with the same framework used by Coastal and Environmental Services Ltd (CES), expert of creating *Environmental and Social Impact Assessments* (ESIAs) (CES, 2016). According to this framework, the severity of each risk was evaluated due to the temporal and spatial scale of the system being affected by the environmental risk, as well as the impact. All potential relevant environmental risks caused by each sanitation system were listed and scored. Both atmospheric emissions and groundwater pollution were analyzed. Literature research was the main method to find and evaluate the likelihood and severity of potential risks. The main search terms used in the databases were: *ammonia, nitrate, nitrite, ground water, pollution, emission, losses, urea, safety, environmental risk, animals, toxic, climate change, carbon dioxide* and *methane*. Since all dry systems need collection with truck, a certain risk for emissions of greenhouse gases rated *very high* is included in any system with UDDTs, since more environmentally friendly options such as electric cars are rare or non existent in Bolivia. For this reason, the limits for the different final ranks were set less strict than for *Health risks: workers*, where one or more risks rated very high immediately would have resulted in the lowest score, 1. In similar with the semi-quantitative assessment for health risks, the scale for the final scores was based on the result. The alternatives were assigned one of the following ranks, where the lower rank was only awarded if all listed requirements were fulfilled:

1 - Very high : if >2 risks rated *very high*. ≥ 13 risks rated *medium*, *high* or *very high*. Total score ≥ 145
2 - High : if 2 risks rated *very high*. <13 risks rated *medium*, *high* or *very high*. Total score <145
3 - Medium : if 1 risks rated *very high*. <11 risks rated *medium*, *high* or *very high*. Total score <130
4 - Low : if 1 risks rated *very high*. <9 risks rated *medium*, *high* or *very high*. Total score <115
5 - Very low : if 0 risks rated *very high*. <7 risks rated *medium*, *high* or *very high*. Total score <100
, where Total risk score is the sum of the risk score for all risks rated *medium* or higher.

3.5.4 Financial

Operation, maintenance and capital costs

For the cost calculations for each alternative system, all capital costs and Operation and Maintenance (O&M) costs on site, for transport and treatment was included, as well as the income of the produced fertilizers. The annualized capital and O&M costs were generated with CWIS Costing and Planning tool World Bank Group, (n.d.), taking the life span and the discount rate into account. Since no data of a regular discount rate was found for Bolivia, a common value of 5 % discount was assumed. For the calculations all the systems were designed for 1000 UDDT with the average of 4.5 people per UDDT and the costs were calculated per capita. In the cases when information was lacking, assumptions were made, see Table F.1- F.5 in Appendix F. For each system, the number of each item was calculated separately, seen in the equations in the same appendix. Since the social visits were performed during the collection services, less motorcycles were for example needed for the alternatives with higher frequency in the collection of urine or faeces. In the same way, the amount of staff and therefore also the amount of clothes and safety protection varied depending on the transport frequency and amount of treatment steps. Since the tool from World Bank Group separated the transport and treatment, the percentage of the time the staff spent on transport versus treatment was calculated.

For the final scores the construction and maintenance of the UDDTs were included, in contrary to the affordability assessment. This because not only the families are affected by the annualized yearly costs of the sanitation systems, but also the municipality and/or embassy subsidizing the costs. In lack of capital and O&M costs for sanitation per capita and year from literature, the scale for the final scores were defined after calculating the cost of each alternative system in this analysis, to get a distribution of the scores. The final score for the capital cost was defined after the following scale:

1 if capital cost was >55 USD/capita,year
2 if capital cost was 51-55 USD/capita,year
3 if capital cost was 46-50 USD/capita,year
4 if capital cost was 41-45 USD/capita,year
5 if capital cost was $\leq$ 40 USD/capita,year

The final score for the O&M cost was defined after the following scale:

1 if O&M cost was >50 USD/capita,year
2 if O&M cost was 41-50 USD/capita,year
3 if O&M cost was 31-40 USD/capita,year
4 if O&M cost was 21-30 USD/capita,year
5 if O&M cost was $\leq$ 20 USD/capita,year

The final score for the criterion *Capital and O&M costs* for each alternative was received from the average of the two individual scores. When the average was in the middle of two scores, the O&M score was viewed as the most important, and therefore determining if the score was rounded up or down.

Economical value of recycled products

The criterion *Economical value of recycled products* was defined from the soil improvement characteristics and the nutrient content. The main search terms used in the data bases were: *value, humus, soil improvement properties, fertilizer, mineral fertilizer, vermicompost, UDDT, organic, cost, price, nutrient, nitrogen, phosphorus, potassium, NPK* and *urea*. Since FSH in El Alto has so far not received a demand of the stored urine and instead donated it for free to an agricultural organization (Personal Communication, Suntura, 2019), the stored urine for this analysis is also assumed being donated and thus not having a value. For the humus from the vermicompost without additional treatment, an economical value of the humus per kg was set to the same value as for the vermicompost in El Alto. For the mixture of humus, Gainutri and urea, the humus was assumed having the same value per weight as in El Alto while the Gainutri contributed with soil improvement properties, directly correlated to the input amount of zeolite (Personal Communication, Olsson, 2019), and the value of the extra added nutrients. Similarly the urea addition contributed with extra N and provided the product with a higher economical value due to the increased nutrient content.

The value for each nutrient N, P and K was calculated in USD/ton from the local price of mineral fertilizers in relation to the proportion of the specific nutrient (Personal Communication, CIAT, 2019a). The nutrient content for each of the humus and the stored urine, were calculated from data from local laboratory tests from El Alto, see Appendix B. For Gainutri and dried urine the nutrient content was calculated from the recovery rate from research. While N and P were calculated for faeces and urine in Bolivia from the research proved Equation 6 and 7, no clear mathematical relation could be found for K. The amount was instead calculated as a fourth of the N content, assuming that the relative proportions of N and K is the same in Bolivia as in Sweden (Personal Communication, Simha, 2019, Jönsson & Vinnerås 2004). The values of the nutrients were assumed being the only contribution to the economical value of dried urine (Personal Communication, Simha, 2019) . Each local value of the nutrients N, P and K and of humus as well as the global value of zeolite, is summarized in Table 5.

Table 5. Local price and value of mineral and organic fertilizers and corresponding value to each of the containing nutrients

Product	Price [USD/ton]	Value N [USD/ton]	Value P [USD/ton]	Value K [USD/ton]
Urea (46-0-0)	435*	946	/	/
Diammonium phosphate (18-46-0)	667*	946	1080	/
Muriate of Potash (0-0-62)	667*	/	/	1076
Humus from vermicompost, FSH	145**	/	/	/
Zeolite	200***	/	/	/

* (Personal Communication, CIAT, 2019a)

** (Personal Communication, Suntura, 2019)

*** Global price, (Personal Communication, Olsson, 2019)

The price per ton for each of the produced products for the alternative systems and the value for all the produced products in each system per year was calculated with Equations 10 - 19 where V=value [USD/ton], V_{tot}=total value for produced fertilizer [USD/year], PA= produced amount [ton], $\%N$/ $\%P$/ $\%K$ / $\%Z$ = percentage of mass as nitrogen/phosphorus/potassium/zeolite, h=humus, h, FSH = humus produced in vermicompost by Foundation Sumaj Huasi (El Alto), $s.u$ = stored urine, h, G_{mix} = humus-Gainutri mixture, Nh=nitrogen enriched humus and du=dried urine.

$$V_h = V_{h,FSH} \tag{10}$$

$$V_{tot,h} = PA_h \cdot V_h \tag{11}$$

$$V_{s.u} = 0 \tag{12}$$

$$V_{tot,s.u} = 0 \tag{13}$$

$$V_{h.Gmix} = \frac{(PA_h \cdot V_h + PA_G \cdot (\frac{\%N_G}{100} \cdot V_N + \frac{\%P_G}{100} \cdot V_P + \frac{\%K_G}{100} \cdot V_K + \frac{\%Z_G}{100} \cdot V_Z) + PA_u \cdot \frac{\%N}{100} \cdot V_N)}{PA_{h.Gmix}} \tag{14}$$

$$V_{tot,h.Gmix} = PA_{h.Gmix} \cdot V_{h.Gmix} \tag{15}$$

$$V_{Nh} = \frac{PA_h \cdot V_h + PA_{du,h} \cdot (\frac{\%N_{du}}{100} \cdot V_N + \frac{\%P_{du}}{100} \cdot V_P + \frac{\%K_{du}}{100} \cdot V_K)}{PA_{Nh}} \tag{16}$$

$$V_{tot,Nh} = PA_{Nh} \cdot V_{Nh} \tag{17}$$

$$V_{du} = \frac{\%N_{du}}{100} \cdot V_N + \frac{\%P_{du}}{100} \cdot V_P + \frac{\%K_{du}}{100} \cdot V_K \tag{18}$$

$$V_{tot,du} = (PA_{du,tot} - PA_{du,h}) \cdot V_{du} \tag{19}$$

The total values for each system per capita and year were calculated by adding the values of the different fertilizers produced from the alternative system. To translate the values into final scores, the calculated values of the fertilizers were related to global prices for stored urine found in the literature. In a study by Richert et al. (2010), the prices, which did not consider the social acceptance, varied between 4 - 7 euros, equalling 4.4 - 7.6 USD. In this assessment a scale was set up, where 7.6 USD answered to the highest score 5, 4.4 USD to the average score 3. The full scale of final scores was the following:

1 if value of fertilizers is <1 USD/capita,year
2 if value of fertilizers is 1 - 2.9 USD/capita,year
3 if value of fertilizers is 3 - 4.9 USD/capita,year
4 if value of fertilizers is 5 - 6.9 USD/capita,year
5 if value of fertilizers $\geq$ 7 USD/capita,year

For the systems with more than one product, an average was taken of each score. If the final score for any of the systems fell between two scores, the final score was chosen by qualitative analysis taking into account how close the score was to the levels below or above. The relative value compared to the cost of the additives, needed for the treatment and production of the fertilizer, calculated for the criteria *Capital and O&M costs*, was also estimated.

3.5.5 Socio-Cultural

Social acceptance: farmers

To analyse the criterion *Social acceptance: farmers*, interview questions were formulated in Spanish to farmers in the farmlands in the surroundings of Montero. The purpose of the interviews was to get a picture of the general attitude of the farmer of recycling nutrients originating from treated source separated urine and faeces to their cultivation. The idea was also to get an understanding whether the farmers preferred some of the generated products from the UDDTs before the others and underlying reasons for this. The formula of the interview were mostly semi structured, allowing the interviewee to come up with new aspects and ideas, while some questions provided the interviewee with alternative answers. The interview included description about the idea of this project and explanation about the produced products in the alternative treatment processes. Questions were formulated regarding the opinion of the requirements of a fertilizer. The interview questions translated into English can be found in Appendix G.

Due to the limited time on site in Bolivia in relation the scope of the project, the aim was to interview 10 local farmers. However, only 3 interviews were performed in the end, because of an unstable situation throughout the country following the presidential election. Closed workplaces and big parts of the population being involved in propaganda on the roads before the election and protests and road blockades afterwards, made it difficult to find interviewees. The score for each product was awarded specifically from the interview question ”Which of the three mentioned products (...) can you imagine using as a fertilizer for your agriculture?” assuming that the farmers had a social acceptance to the fertilizer they could consider buying. Each product thus got a score from the percentage of the interviewed farmers having a social acceptance according to the following scale:

1 if 0-20 % social acceptance among interviewed farmers
2 if 21-40 % social acceptance among interviewed farmers
3 if 41-60 % social acceptance among interviewed farmers
4 if 61-80 % social acceptance among interviewed farmers
5 if > 80 % social acceptance among interviewed farmers

The final score for each alternative system was awarded according to the average score of each of the produced products by the alternative. Due to limited data, potential correlation with gender, age or properties of farmland could not be analyzed. The result could however be discussed in relation to the open questions. An additional literature research was performed to relate the interview result to in the discussion. The main search terms in the data bases were: *social acceptance, farmers, UDDT, fertilizer, Bolivia* and *attitude*.

Affordability

The affordability was reviewed on household basis, by adding all yearly costs on site and off site, including capital and O&M costs and splitting these over the 1000 households with UDDTs. To decide whether or not each alternative system was considered affordable an *affordability index*, stating the maximum percentage of the individual household salary that was considered affordable, was used. In lack of an affordability index specifically for sanitation in Bolivia, an index of 3 % of the household income was defined by viewing index for the bordering countries Chile and Argentina. For Chile a maximum 5 % of individual household income can go to water and sanitation services and in Argentina maximum 3 % can go to water services (Smets, 2009). In the literature research to find information about affordability index for sanitation the main search terms in the data bases were: *affordability, affordability index, sanitation, salary, income, afford, household, Bolivia* and *South America*.

The evaluation of the affordability was performed as a comparison of the maximum affordable cost for sanitation services for a household calculated from the affordability index and the mean salary of the household in each income quintile. A quintile is defined as any of five equally sized groups that a set of things can be divided into (Cambridge Dictionary, n.d.). Since the income holders in a household can vary from being two adults (or in some cases more), to being just the man or even just the woman, some different scenarios were reviewed. Data from 2018 for people aged 18 or over, living in the urban areas of the Santa Cruz district, was used. The data was generated from questionnaires (INE, 2018), where 33 % had filled in their salary. This represented for the urban parts of Santa Cruz just over 1000 people over 18 years. Since the salaries were defined for different periods of time, all data was converted into income per month to be able to order the data and split it into quintiles and calculate the mean for each quintile. The income quintiles are seen in the results in Table 36. For the scoring, only the income for 1 man per household was included, since in many cases in Bolivia the woman does not work. Also the construction cost of the UDDT was not included when setting the score for the affordability. This because the UDDTs in Montero have generally been highly subsidized by the Swedish Embassy and in some cases by the municipality (Personal Communication, COSMOL, 2019a). Another reason for this exclusion, is that the initial investment cost of the UDDT is the same for all alternatives. The final scores were defined as the number of quintiles which the cost for the sanitation services was considered affordable:

1 if the sanitation cost is considered affordable for $\leq$1 quintile (none/only the highest)
2 if the sanitation cost is considered affordable for the 2 highest quintiles
3 if the sanitation cost is considered affordable for the 3 highest quintiles
4 if the sanitation cost is considered affordable for the 4 highest quintiles
5 if the sanitation cost is considered affordable for 5 quintiles (all)

3.5.6 Technical-Organisational

Required technical-organizational capacity

In the initial literature research about institutional capacity, the main search terms used in the data bases were: *institutional capacity, MCA, organisational capacity, complexity, operation and maintenance, infrastructure, requirements* and *capacity profile*. A capacity profile inspired by Söderberg (2003) was made to analyze the required technical- organizational capacity for each alternative system. Söderberg defines five critical factors for a well-functioning organization which were included in the capacity profile. These are:

Arena - the capacity of the organization to involve stakeholders and handle conflicts
Distribution of responsibilities - clear distribution of responsibilities in the organization
Communication - the capacity of the organization to control and give feedback to the users

Implementation - the capacity of the organization to implement the system
System in operation - the capacity to perform regularly operation and good maintenance

In Montero, COSMOL is responsible all the way from collecting the faeces at the UDDT to finishing the treatment. For this reason the factor *Distribution of responsibilities* did not differ between the alternatives and was therefore excluded from the analysis. Since the communication between COSMOL and the UDDT users is closely linked to the arena, in form of weekly visits to the UDDTs, the two factors were combined to one single factor called *Arena and communication*.

For each of the three remaining critical factors, a score was awarded for every alternative system according to either quantitative or qualitative measurements, see Table 6.

Table 6. Requirements for each score for the three critical factors for the evaluation of the criteria *Required technical-organizational capacity*

Critical factors	**Arena and communication**	**Implementation**	**System in operation**
Score	Requirements	Infrastructural components needed*	Work load**: number of O&M tasks daily or weekly
1	No arena for handling potential conflicts. No reviewing of usage or information	>5	>12
2	No arena for handling potential conflicts. Reviewing of usage and information occurs occasionally	4-5	9-12
3	Arena for handling potential conflicts. No regularly reviewing of usage and information and/or problems with communication identified	2-3	5-8
4	Arena for handling potential conflicts, reviewing usage regularly and providing with information about changes/news problem with service identified Problems with communication identified	1	1-4
5	Arena for handling potential conflicts, reviewing usage regularly and providing with information about changes/news No problem with communication	<1	O&M tasks a few times a year or more rarely

*In the analysis, the *infrastructure components* were defined as components requiring connection to electricity or being of corresponding complexity. Infrastructure of bricks and cements which are regularly built by COSMOL is excluded. Scale based on results.

Finally, one final score was generated for each alternative system. In the cases where the same score occurred twice for different factors, the final score was set to the score corresponding to the majority of the three scores. In the cases where all three factors were scored differently the final scored was calculated as the average of the three factor scores.

4 RESULTS AND DISCUSSION

The scores to assess the sustainability of the alternative systems are listed and discussed for one criterion at a time. The advantages and disadvantages for each alternative are discussed in the end of this section.

4.1 PERFORMANCE ASSESSMENT OF SUSTAINABILITY CRITERIA

4.1.1 Health

Health risk: workers

In the semi-quantitative risk assessment matrix over *Health risks: workers* for alternative 0, 15 potential health risks were identified whereof three rated *High*, see Table 7. The assessment basis for the likelihood and severity of each evaluated hazard can be found in appendix H.

Table 7. Semi-quantitative risk assessment matrix over potential health risks for **alternative 0** for each sanitation step from collection at UDDTs to deposit. For assessment bases, see Table H.1

Sanitation step	No.	Hazard identification			Existing control		Risk assessment: L=Likelihood; S=Severity; R= Risk level			
		Hazard event	Hazard	Exposure route	Control measure	Validation of control	L	S	Score	R
Collection of faeces and transport	1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	2.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	3.	Back injuries when carrying heavy tanks	Back injuries	Congested	n/a	n/a	3	8	24	H
	4.	Traffic accident	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	2	8	16	H
Maintenance	5.	Exposure to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	4	2	8	M
	6.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	1	2	L
	7.	Back injuries when maintaining burial area	Back injuries	Congested	n/a	n/a	1	8	8	M
Burial	8.	Exposure to untreated feces during burial	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	9.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	10.	Back injuries when caring heavy tanks	Back injuries	Congested	n/a	n/a	3	8	24	H
	11.	Falling into burial holes	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	4	8	M
	12		Body injuries	Falling	n/a	n/a	2	4	8	M
	13.	Dropping heavy tanks	Body injuries	Dropping items	Boots	Boots always used	3	4	12	M
	14.	Contact with Calcium hydroxide	Reduced breathing	Ingestion	Protective clothing	Mouth protection might not always be used	3	2	6	M
	15.		Skin irritation	Contact with skin	Protective clothing	Face and wrists uncovered	3	4	12	M

In the semi-quantitative risk assessment matrix over *Health risks: workers* for alternative 1, 19 potential health risks were identified whereof four rated *High*, see Table 8.

Table 8. Semi-quantitative risk assessment matrix over potential health risks for **alternative 1** for each sanitation step from collection at UDDTs to end use of products. For assessment bases, see Table H.2

Sanitation step	No.	Hazard identification			Existing control		Risk assessment: L=Likelihood; S=Severity; R= Risk level			
		Hazard event	**Hazard**	**Exposure route**	**Control measure**	**Validation of control**	**L**	**S**	**Score**	**R**
Collection of faeces and transport	1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	2.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	3.	Back injuries when carrying heavy tanks	Back injuries	Congested	n/a	n/a	3	8	24	H
	4.	Traffic accident when collecting faeces	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	2	8	16	H
Collection of urine and transport	5.	Exposure to untreated urine during pumping	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	2	4	L
	6.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	1	1	1	L
	7.	Traffic accident when collecting urine	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	3	8	24	H
Maintenance	8.	Exposure to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	4	2	8	M
	9.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	1	2	L
Treatment	10.	Exposure to untreated feces when operating vermicompost	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	11.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	12.	Falling into treatment chambers	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	4	8	M
	13.		Body injuries	Falling	n/a	n/a	2	2	4	L
	14.	Dropping heavy tanks	Body injuries	Dropping items	Boots	Boots always used	3	4	12	M
	15.	Back injuries when shovelling humus and moving with wheel barrow	Back injuries	Congested	n/a	n/a	2	8	16	H
	16.	Contact with Calcium hydroxide	Reduced breathing	Ingestion	Protective clothing	Mouth protection might not always be used	2	2	4	L
	17.		Skin irritation	Contact with skin	Protective clothing	Face and wrists uncovered	2	4	8	M
	18.	Exposure to untreated urine when storing	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	1	2	2	L
	19.	Exposure to untreated urine if storage tank leaks	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	1	4	4	L

In the semi-quantitative risk assessment matrix over *Health risks: workers* for alternative 2, 22 potential health risks were identified whereof four rated *High*, see Table 9.

Table 9. Semi-quantitative risk assessment matrix over potential health risks for **alternative 2** for each sanitation step from collection at UDDTs to end use of products. For assessment bases, see Table H.3

Sanitation step	No.	Hazard identification			Existing control		Risk assessment: L=Likelihood; S=Severity; R= Risk level			
		Hazard event	Hazard	Exposure route	Control measure	Validation of control	L	S	Score	R
Collection of faeces and transport	1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	2.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	3.	Back injuries when carrying heavy tanks	Back injuries	Congested	n/a	n/a	3	8	24	H
	4.	Traffic accident when collecting faeces	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	2	8	16	H
Collection of urine and transport	5.	Exposure to untreated urine during pumping	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	2	4	L
	6.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	1	1	1	L
	7.	Traffic accident when collecting urine	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	3	8	24	H
Maintenance	8.	Exposure to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	4	2	8	M
	9.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	1	2	L
Treatment	10.	Exposure to untreated feces when operating vermicompost	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	11.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	12.	Falling into treatment chambers	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	4	8	M
	13.		Body injuries	Falling	n/a	n/a	2	2	4	L
	14.	Dropping heavy tanks	Body injuries	Dropping items	Boots	Boots always used	3	4	12	M
	15.	Back injuries when shovelling humus and moving with wheel barrow	Back injuries	Congested	n/a	n/a	2	8	16	H
	16.	Contact with Calcium hydroxide	Reduced breathing	Ingestion	Protective clothing	Mouth protection might not always be used	2	2	4	L
	17.		Skin irritation	Contact with skin	Protective clothing	Face and wrists uncovered	2	4	8	M
	18.	Inappropriate operation of Makenutri 200V	Body injuries	Injuries from the stirrer	n/a	n/a	2	2	4	L
	19.	Exposure of untreated urine to pathogens in form of Gainutri	All microbial pathogens	Ingestion	Protective clothing	Gloves, full clothing and boots used	3	2	6	M
	20.		Hookworms	Skin penetration	Protective clothing	Mouth protection might not always be used	2	1	2	L
	21.	Contact with urea	Reduced breathing	Ingestion	Protective clothing	Mouth protection might not always be used	1	2	2	L
	22.		Skin irritation	Contact with skin	Protective clothing	Face and wrists uncovered	1	4	4	L

In the semi-quantitative risk assessment matrix over *Health risks: workers* for alternative 3, 19 potential health risks were identified whereof four rated *High*, see Table 10.

Table 10. Semi-quantitative risk assessment matrix over potential health risks for **alternative 3** for each sanitation step from collection at UDDTs to end use of products. For assessment bases, see Table H.4

Sanitation step	No.	Hazard identification			Existing control		Risk assessment: L=Likelihood; S=Severity; R= Risk level			
		Hazard event	**Hazard**	**Exposure route**	**Control measure**	**Validation of control**	**L**	**S**	**Score**	**R**
Collection of faeces and transport	1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	2.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	3.	Back injuries when carrying heavy tanks	Back injuries	Congested	n/a	n/a	3	8	24	H
	4.	Traffic accident when collecting faeces	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	2	8	16	H
Collection of dried urine and transport	5.	Exposure to dried urine during collection	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	1	2	L
	6.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	1	1	1	L
	7.	Traffic accident when collecting dried urine	Body injuries	Fracture, neck injury	Seat belt	Generally not used in Montero. Lacks on some seats	2	8	16	H
Maintenance	8.	Exposure to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	4	2	8	M
	9.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	1	2	L
Treatment	10.	Exposure to untreated feces when operating vermicompost	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	3	4	12	M
	11.		Hookworms	Skin penetration	Protective clothing	Gloves, full clothing and boots used	2	2	4	L
	12.	Falling into treatment chambers	All microbial pathogens	Ingestion	Protective clothing	Mouth protection might not always be used	2	4	8	M
	13.		Body injuries	Falling	n/a	n/a	2	2	4	L
	14.	Dropping heavy tanks	Body injuries	Dropping items	Boots	Boots always used	3	4	12	M
	15.	Back injuries when shovelling humus and moving with wheel barrow	Back injuries	Congested	n/a	n/a	2	8	16	H
	16.	Contact with Calcium hydroxide	Reduced breathing	Ingestion	Protective clothing	Mouth protection might not always be used	3	2	6	M
	17.		Skin irritation	Contact with skin	Protective clothing	Face and wrists uncovered	3	4	12	M
	18.	Contact with dried urine when mixing with humus	Reduced breathing	Ingestion	Protective clothing	Mouth protection might not always be used	2	1	2	L
	19.		Skin irritation	Contact with skin	Protective clothing	Face and wrists uncovered	2	1	2	L

The overall result of the semi-quantitative risk assessment showed that all alternatives had relatively small variation in the number of high and medium risks, see Table 11.

Table 11. Summary of semi-quantitative risk assessment for potential health risks for workers for each alternative system. Total risks score is a summary of the risks rated M or above

Alternative	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 3**
Number of risks rated high or very high	3	4	4	4
Total risk score	150	140	154	152
Final score	**3**	**3**	**3**	**3**

The result from the semi-quantitative risk assessment, indicated similar risk for workers for all alternatives, which can be related to the similarities of the systems. The traffic accidents and back injuries representing the largest risk, exists in all UDDT systems. Since the analysis is built on a framework from WHO's tool for setting up a semi-quantitative risk assessment for health risks, the scores for the severity and likelihood for the different alternatives are strengthened. If alternatively the final score would have been defined as the highest identified risk, which is the suggested evaluation scale of WHO, (2016), all alternatives would have been awarded with the final score 2: *high*. This indicates that the differences between the alternative systems in this analysis only varies within a smaller interval. A conventional sanitation solution, would for example probably differ more from all the dry solutions.

Worth to note is that the risk for workers to be infected by pathogens from the faeces is relatively small for all alternative sanitation system. Instead the most severe risk for all alternatives is the traffic accidents, due to the high number of transports with truck and motorbike and lack of seat belts. Relating this to reports from the Embassy of Sweden (2019) of traffic accidents being one of greatest dangers for humans in Bolivia, with higher death rates than for the larger bordering countries, this is expected. However the risk of traffic accidents at work, when driving in 30 - 40 km/h, is probably relatively lower than driving in Bolivia outside working hours.

Risk of infection from products after treatment

Stored urine fulfilled the ABP regulation after 4 months and therefore should this defined storage time ensure a hygienic product (Fidjeland, n.d.). Since dried urine is produced under high pH, the high urea levels treat the urine from bacteria and Ascaris without additional treatment.

For the vermicompost, literature reported correlation with log reduction and time and temperature. In the study of Buzie-Fru (2010) the reduction of E Coli and Salmonella indicated a logarithmic trend with time (R^2= 0.95). Generally the studies did not measure for more than 2 - 3 months (Buzie-Fru, 2010; Hill et al., 2013), why they generally reported worse results than for a vermicompost operated in 9 months, defined for the systems in this project. A higher temperature also results in faster reduction of the bacteria, indicating that a vermicompost operated in Montero with yearly mean temperature of 23 °C would reduce bacteria faster than the research results performed under 19 - 21 °C. Also, the laboratory tests performed by FSH on the vermicompost in El Alto proves that bacteria is sufficiently reduced, even though the much lower temperatures in the high lands (Personal Communication, Suntura, 2019). However the vermicompost was not considered safe from Ascaris, since none of the research results from vermicomposts of source separated faeces, could prove a reduction of Ascaris (Buzie-Fru, 2010; Hill et al., 2013).

For alternative 2 and 3 where additional urea was added to treat the humus against Ascaris, the products were assumed to be free also from activated Ascaris eggs when operating the system for 2 months as calculated with Fidjeland's equation, see Table 12. For the sufficient storage time depending on urea content, see Appendix I.

Table 12. Urea treatment of each produced product and report if required ABP logarithmic reduction for Ascaris (3 log red) was fulfilled or not

Alternative	**Alt 0**		**Alt 1**		**Alt 2**		**Alt 3**	
product	urine	buried faeces	stored urine	humus	Gainutri	humus	dried urine	humus
treatment	none	none	natural urea	none	added urea		natural urea, pH and temp increase	added urea from dried urine
treatment time	/	/	4 months	/	2 months		2 weeks	2 months
3 log red of Ascaris	no	no	yes	no	yes		yes	yes

The overall result of the analysis for the criterion *Risk of infection from products after treatment* showed that alternative 0 did not fulfill any of the ABP regulations, alternative 1 did partly fulfill the regulation, while alternative 2 and 3, designed based on research findings, fulfilled both the regulations for the indicator bacteria and Ascaris, see Table 13.

Table 13. Summary of analysis for risk of infection from products after treatment for each alternative system. The striped color for alternative 0, indicates that no reuse as fertilizers exist

Alternative	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 3**
5 log reduction of indicator bacteria	no	yes	yes	yes
3 log reduction of viable Ascaris eggs	no	no	yes	yes
ABP regulations fulfilled	no	partly	yes	yes
Final score	**1**	**3**	**5**	**5**

When considering the logarithmic reduction of indicator bacteria and viable Ascaris eggs, in relation to the ABP regulations, the actual system, alternative 0, did not fulfil any of the required reductions. This is in agreement with Ascaris being found in the buried faeces after several years, see Table A.1. On the other hand, despite the storage time at the burial site, lime is added to the holes to reduce pathogens. The result of this analysis that alternative 0 does not have sufficient reduction of Ascaris is however strengthened with reports from US-EPA (2013) stating that lime stabilization can reduce virus and bacteria but not helminths effectively. Similarly the result that alternative 2 and 3 have fulfilled both of the logarithmic regulations due to the urea treatment, was expected since the idea was to add urea to inactivate the Ascaris that have been reported not being sufficiently reduced in several tests with pure vermicomposts. Worth to note is that the systems in alternative 2 and 3 are yet not tested in Bolivia. Thus a possible source of error is the estimated amount of urea required to secure sufficient inactivation of viable Ascaris eggs. To make sure that the ABP requirements can be fulfilled without purchasing unnecessarily large amounts of urea, the exact amount is suggested to be tested in pilots tests.

An important note with the assessment of this criteria is that the systems were designed so that alternative 2 and 3 could fulfill the required reductions, automatically being scored 5, while alternative 1 was chosen in the system boundaries not to be improved further to be able to analyze the effect of this difference also from other perspectives. Also, at reuse of products, alternative 0 has no risk of infection, since no fertilizers are produced. It is however still evaluated since risk of infection after treatment remains. A source of error with the result is the somewhat conflicting reports about the performance of inactivating pathogens in vermicomposts and with urea. In some research, the study period was no longer than a month, why further reduction could have been assumed if the treatment would have continued for longer, which the logarithmic trend for E Coli indicates. Also, a theory is that a potential vermicompost in Montero would reduce pathogens faster due to the higher temperature in relation to El Alto and possibly inactivate viable Ascaris eggs sufficiently, (Nordin et al., 2009a). It is therefore important to test the performance of a vermicompost to reduce Ascaris in Montero, to evaluate if the final scores in this analysis are correct. If such a result would prove that the vermicompost itself can inactivate Ascaris to a 3 log reduction, alternative 1 has been scored too low in this analysis. In this theoretical case, the urea treatment step should be considered to be excluded for alternative 2 and 3.

4.1.2 Resource Use

Potential of reuse of nutrients

The relative amount of vegetable protein of the total protein intake in the diet was relatively similar for Bolivia and Sweden, see Table E.2 in Appendix E, indicating that the same proportion of total nutrients was excreted in the urine versus faeces for the two countries. The nutrient recovery for each system was illustrated with flow charts, excluding the additives with potential contributions of N and P to the end product. For this reason the mass nutrient of the recycled products to the right in the figure only shows the amount of the nutrient that are recycled from faeces or urine. For the total nutrient content in products see Section 4.1.4 Financial. Since alternative 0 did not recover any nutrients from the faeces and urine, no flow chart was made.

For alternative 1 the N input from urine decreased from 2.76 kg to 1.79 kg, corresponding a recovery of 65 %, partly due to ammonia losses during the transport and storage, see Figure 11. During the vermicompost the N from faeces was decreased from 0.38 kg to 0.14 kg, a recovery of 36 %.

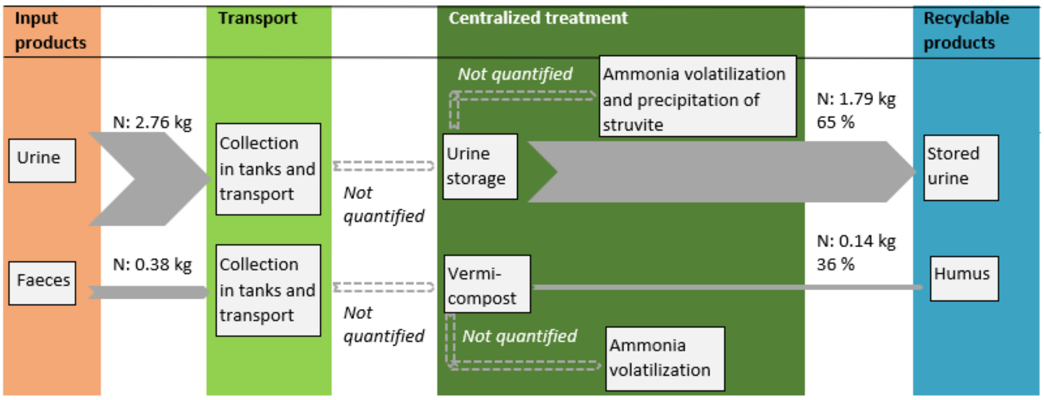

Figure 11. Flow chart for nitrogen (N) from urine versus faeces to recyclable products for **alternative 1**. The N flows are measured in kg/capita,year and the values in % represent the total N recovery.

While the N recovery from faeces was the same for alternative 1 and 2, due to an identical treatment process, the N recovery from the urine was higher for alternative 2, with 1.93

kg recycled in the product, corresponding to a recovery of 70 %, see Figure 11 and 12.

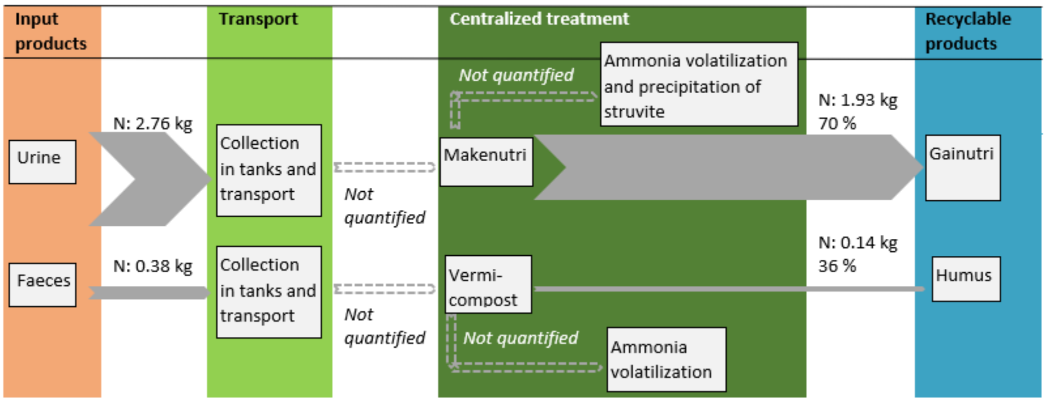

Figure 12. Flow chart for nitrogen (N) from urine versus faeces to recyclable products for **alternative 2**. The N flows are measured in kg/capita,year and the values in % represent the total N recovery.

Alternative 3 also had an identical recovery of N from faeces as the other alternatives operating vermicomposts, but the recovery of N from urine was higher than the other alternatives, 90 %, recycling 2.48 kg N, see Figure 13.

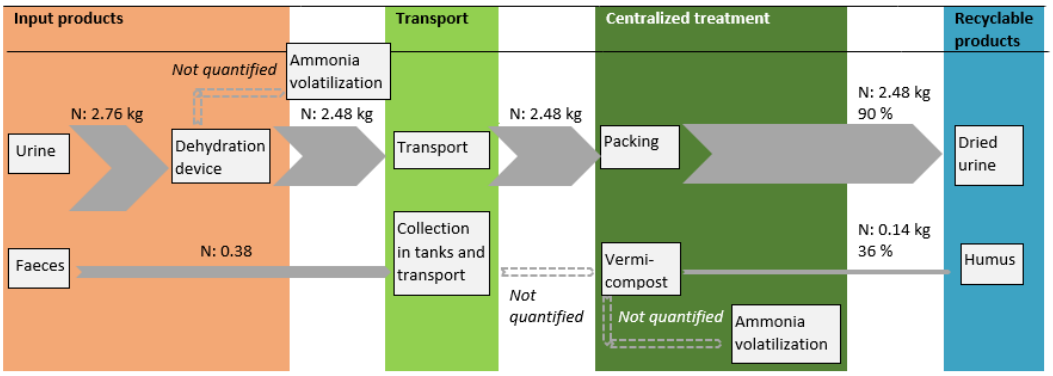

Figure 13. Flow chart for nitrogen (N) from urine versus faeces to recyclable products for **alternative 3**. The N flows are measured in kg/capita,year and the values in % represent the total N recovery.

Alternative 1 could recover around 50 % of the P in urine, recycling 0.14 kg P from the 0.28 kg P in urine, while 0.05 kg of 0.14 kg of the P from the faeces was recycled, corresponding a recovery rate of 39 %, see Figure 14.

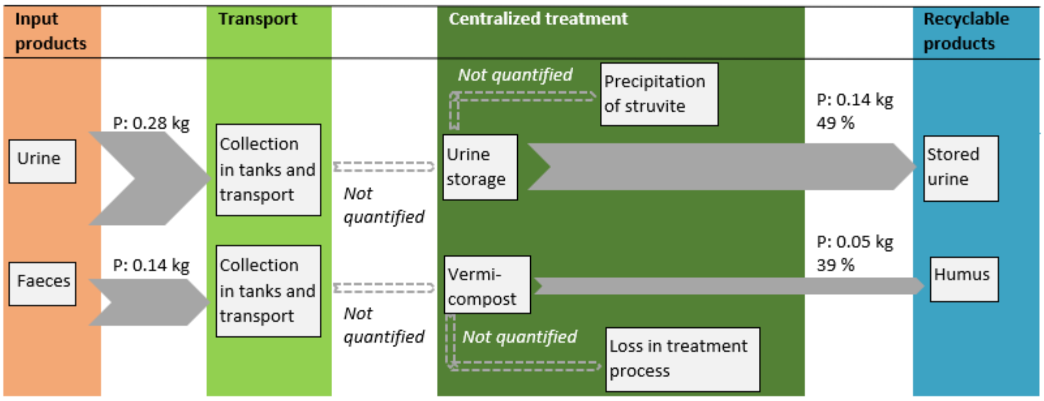

Figure 14. Flow chart for phosphorus (P) from urine versus faeces to recyclable products for **alternative 1**. The P flows are measured in kg/capita,year and the values in % represent the total P recovery.

Also for P, the recovery rate for alternative 2 for the faeces was identical with alternative 1, while almost all the P from the urine, 27 kg out of 28 kg was recycled, a recovery of 98 %, see Figure 15.

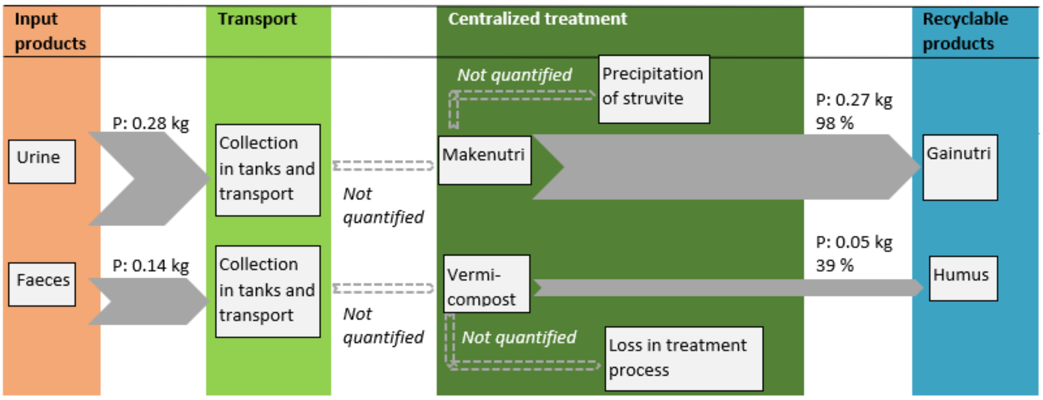

Figure 15. Flow chart for phosphorus (P) from urine versus faeces to recyclable products for **alternative 2**. The P flows are measured in kg/capita,year and the values in % represent the total P recovery.

Similarly with alternative 2, all P (100%) was recovered from the urine for alternative 3 while the same larger loss of P was shown for the vermicompost of the faeces, Figure 16.

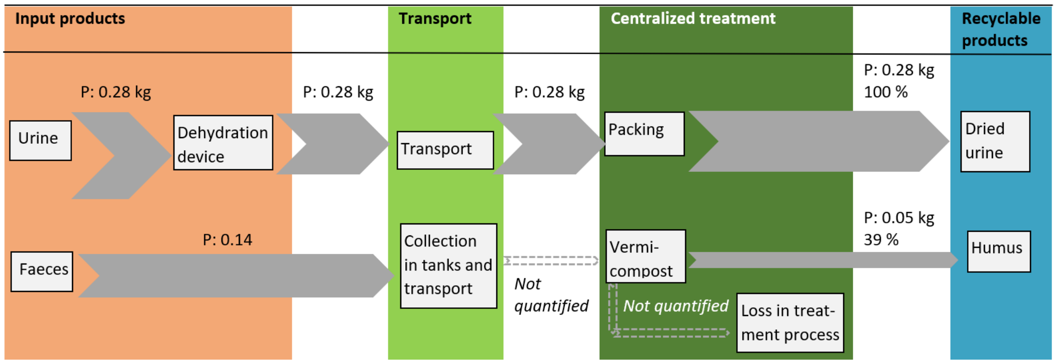

Figure 16. Flow chart for phosphorus (P) from urine versus faeces to recyclable products for **alternative 3**. The P flows are measured in kg/capita,year and the values in % represent the total P recovery.

Alternative 0 had no nutrient recycling and was awarded with the lowest score 1. Alternative 1 recycled 61 % of the N from the faeces and urine and 45 % of the P. Due to the lower recovery of P and a N recycling close to a lower limit the final score was 3. For alternative 2, with recovery of both N and P in the interval between 60 - 79 %, was scored 4. Since both of the total recovery rates for N and P were more than 80 % for alternative 3, it was scored with the highest score 5, see Table 14.

Table 14. Total recovery [%] of N and P from urine and faeces and total amount recycled of each nutrients from the input products for each alternative

Alternative	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 3**
Amount of N recycled [%]	-	61	66	84
Mass of N recycled [kg/capita,year]	-	1.92	2.07	2.62
Amount of P recycled [%]	-	45	79	80
Mass of P recycled [kg/capita,year]	-	0.19	0.33	0.33
Final score	**1**	**3**	**4**	**5**

A source of error with the calculations of the nutrient contents of the produced fertilizers was the uncertainty in the amount of produced fresh faeces in Bolivia as well as the nutrient contents. On the other hand, the use of research of how to calculate the content of N and P from national FAO data over vegetable and animal protein in diet, strengthens these nutrient contents. However, the protein intake could possible differ within Bolivia between the lowland and highland, where a higher meat consumption is likely in the lowlands with more resources. On the other hand the conclusion that the Bolivian produced amount of faeces equals the Swedish one, agrees with the MMAyA data when assuming a content of 45 % drying material in the mixture, stated in documents from El Alto's vermicompost (Silveti et al., 2011).

The reported 45 % drying material mixed with faeces did not clarify if it was referring to volume or weight. As a result, the calculated amount of produced fresh faeces in Bolivia could potentially be estimated too high if the document was concerning the weight rather than volume assumed in this analysis. This would affect the total nutrient recycling potential per person and year, but not the recovery rates and thus not the final scores.

These potential errors can explain that the N recovery for the humus, see Figure 11, 12 and 13, was lower than expected. Yadev et al (2010) and (2011) reported N recovery between 68 - 79 % in vermicomposts. According to these studies, certain amounts of N are expected to be lost from the vermicompost through ammonia volatilization. In comparison, the lab results from the vermicompost in El Alto, Bolivia, used in this analysis, had a calculated recovery of only half the literature value. However, this higher loss of N can be the result of a low C/N ratio in the vermicompost causing ammonia emissions (Yadav et al., 2010). On the other hand, since the vermicompost in El Alto consists of both carbon-rich drying material of mainly sawdust as well as toilet paper, the C/N should not be too low. In a research of biogas production in the Bolivian altiplano, Alvarez et al., (2006) reported low ammonia (N) recovery in cow manure, possibly correlated to the windy and dry conditions in the high altitudes. If the weather conditions in the high land equally are the reason for the low N recovery in the vermicompost in El Alto, a possible theory is that a vermicompost in Montero, located in the lowlands of Bolivia with milder climte, would achieve a higher N recovery. Due to limited data for the humus from the vermicompost in El Alto, with only two sets of sampling, see Table B.1 in Appendix B, the recovery rate is also highly uncertain. The potential of more N being recovered from the faeces than shown in this analysis, would affect all the alternative 1, 2 and 3 similarly since all consists of vermicomposts. Since a relatively small proportion of the N is extracted in the faeces, the final score would not be changed to a large extent.

When estimating the nutrient recovery in stored urine from the samples in El Alto, one of the samples only had 10 % of the N content of the other samples, indicating a clear loss of N, see Table B.2 in Appendix B. This can be explained by possible leakage from the storage tank at some point, which result in a more uncertain recovery rate. Wohlsager et al., (2010) reported N losses of up to 90 % for urine storage in open tanks during 9 months, in contrast with 7 % N losses for closed storage tanks. This motivates that appropriate storage of urine can potentially recover higher levels of N, than indicated in the results in this report. Considering this, the final score for alternative 1 could possible have been set too low in this analysis.

For production of Gainutri and urine drying, the nutrient recovery can only be seen as approximate since none of the systems are yet tested in Bolivia. Another scenario would be if the urine was stored prior to the ion exchange, allowing the produced N water to be reused in agriculture instead of being released in the wastewater. In that case, alternative 2 could achieve a N recovery of up to 30 percentage units higher, corresponding to a total N recovery of up to 92 %. Unless the P recovery from the humus would not increase, this would still not change the final score since it is rounded off to the lower score which is just under the limit to score 5, see Table 14. However, the effect on the increased costs and required technical capacity for this, is not calculated in this analysis. Despite the uncertainties, the relative order of the final score for the alternatives could be assumed being correct, since the alternatives had recovery rates differing with 10 - 20 percentage units from each other. Nevertheless, the recovery rate should not be viewed as the absolute value.

Energy consumption

For the energy consumption, in many cases, the same assumptions as for the cost calculations are being made, see Table F.1 - F.5 in Appendix F. The collection of faeces with truck and the social visits by motorbike made up equal parts of the total energy consumption for 1000 UDDTs, for operating the actual system (alternative 0), see Table 15. The energy consumption for the clearing of the burial site once a year with a brush cutter was of negligible size.

Table 15. Energy consumption for operation of **alternative 0**. The energy consumption for fuel is calculated for gasoline

Fuel	**Amount**	**Total driven distance [km/year]**	**Fuel consumption [km/L]**	**Fuel consumed [L/year]**	**Energy density [MJ/L]**	**Energy density [kWh/L]**	**References**	**Energy consumption [kWh/year]**
Truck for faeces	1	9 412	9	1046	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	9 935
Motorbikes	6	34 320	33	1030	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Taal, 2016) (Kaneko & Rodríguez, 2019)	9 781
Truck for burial material	6	1 000	9	111	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	1 056
Others	**Amount**	**Area cut per year [m2/year]**	**Time cutting [h/year]**	**Fuel consumption [L/h]**	**Fuel consumed [L/year]**	**Energy density [kWh/L]**	**References**	**Energy consumption [kWh/year]**
Brush cutter	1	1200	3	0.4	1.3	9.5	(Personal Communication, COSMOL, 2019a) (Blom, 2019) (Kaneko & Rodríguez, 2019)	13
				Total on site				**0**
				Total off site				**20 785**
				Total				**20 785**

The energy consumption for alternative 1 is dominated by the vacuum trucks by fuel for driving and pumping, see Table 16. The energy consumption for the electrical pump used for pumping the liquid urine was almost negligible in comparison.

Table 16. Energy consumption for operation of **alternative 1**. The energy consumption for fuel is calculated for gasoline

Fuel	**Amount**	**Total driven distance [km/year]**	**Fuel consumption [km/L]**	**Fuel consumed [L/year]**	**Energy density [MJ/L]**	**Energy density [kWh/L]**	**References**	**Energy consumption [kWh/year]**
Truck for faeces	1	9 412	9	1 046	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	9 935
Vacuum trucks	5	39 506	9	4 390	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	41 701
Motorbikes	4	22 880	33	686	34.2	9.5	(Personal Communication, COSMOL, 2019d)) (Taal, 2016) (Kaneko & Rodríguez, 2019)	6 521
Vehicle components	**Amount**	**Pumping [h/year]**	**Fuel consumption [L/h]**	**Fuel consumed [L/year]**	**Energy density [MJ/L]**	**Energy density [kWh/L]**	**References**	**Energy consumption [kWh/year]**
Vacuum pump	5	351	6	2108	34.2	9.5	(Kennedy-Walker, 2015) (Kaneko & Rodríguez, 2019)	20 024
Others	**Amount**	**Volume pumped [m3/year]**	**Pumping capacity [m3/h]**	**Effect pump [kW]**	**Energy consumption [kWh/m3]**		**References**	**Energy consumption [kWh/year]**
Electrical pump	1	2025	50	4	0.08		(Bominox, 2014)	162
				Total on site				**0**
				Total off site				**78 259**
				Total				**78 259**

Alternative 2, consists of more energy consuming components than alternative 1, due to the ion exchange with urine and ZeoPeat. However the dominating sources of energy consumption are equally the vacuum trucks, see Table 17. The electrical pumping of liquid urine and N-water, consumes more electricity than for alternative 1, but the consumption is still relatively negligible.

Table 17. Energy consumption for operation of **alternative 2**. The energy consumption for fuel is calculated for gasoline

Fuel	Amount	Total driven distance [km/year]	Fuel consumption [km/L]	Fuel consumed [L/year]	Energy density [MJ/L]	Energy density [kWh/L]	References	Energy consumption [kWh/year]
Truck for faeces	1	9 412	9	1 046	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	9 935
Vacuum trucks	5	39 506	9	4 390	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	41 701
Motorbikes	4	22 880	33	686	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Taal, 2016) (Kaneko & Rodríguez, 2019)	6 521
Vehicle components	**Amount**	**Pumping [h/year]**	**Fuel consumption [L/h]**	**Fuel consumed [L/year]**	**Energy density [MJ/L]**	**Energy density [kWh/L]**	**References**	**Energy consumption [kWh/year]**
Vacuum pump	5	351	6	2108	34.2	9.5	(Kennedy-Walker, 2015) (Kaneko & Rodríguez, 2019)	20 024
Others	**Amount**	**Volume pumped [m3/year]**	**Pumping capacity [m3/h]**	**Effect pump [kW]**	**Energy consumption [kWh/batch]***	**Energy consumption [kWh/m3]**	**References**	**Energy consumption [kWh/year]**
Electrical pump	1	3645**	50	4	/	0.08	(Bominox, 2014)	292
Makenutri 200V	23	2025	/	/	0.5	2.9	(Personal Communication, Olsson, 2019)	5956
					Total on site			**0**
					Total off site			**84 428**
					Total			**84 428**

For alternative 3 the operation of the fan at household level for the urine drying process consumes almost ten times more energy than the remaining components, see Table 18.

Table 18. Energy consumption for operation of **alternative 3**. The energy consumption for fuel is calculated for gasoline

Fuel	Amount	Total driven distance [km/year]	Fuel consumption [km/L]	Fuel consumed [L/year]	Energy density [MJ/L]	Energy density [kWh/L]	References	Energy consumption [kWh/year]
Truck for faeces	1	9 412	9	1 046	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	9 935
Truck for dried urine	2	18 824	9	2092	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Personal Communication, COSMOL, 2019c) (Kaneko & Rodríguez, 2019)	19 870
Motorbikes	5	25 749	33	772	34.2	9.5	(Personal Communication, COSMOL, 2019d) (Taal, 2016) (Kaneko & Rodríguez, 2019)	7 336
Others	**Amount**	**Effect [W]**	**Operating time [h/year, UDDT]**	**Total operating time [h/year]**	**Energy consumption [kWh/year,UDDT]**		**References**	**Energy consumption [kWh/year]**
Fan for urine drying	1 000	80	4 383	4 383 000	351		(Personal Communication, Simha, 2019)	350 640
				Total on site				**350 640**
				Total off site				**37 141**
				Total				**387 781**

The average monthly energy consumption on household level, were calculated from the CRE data to 209 kWh corresponding to 2509 kWh/year. Off site, the energy consumption for the operation of alternative 0 and 3, corresponded around 1 % of the average yearly energy consumption. This generated a slightly higher score than for alternative 1 and 2 with contributed to 3% of the average yearly consumption, see Table 19. On site, alternative 0, 1 and 2 had no energy consumption, while alternative 3 consumed energy corresponding to 14 % of the yearly average and was therefore scored lower.

Table 19. Final scores for energy consumption on site and off site in relation to average energy consumption per household for the alternative systems. 1000 households (UDDTs) are being assumed

Alternative system	Alt 0	Alt 1	Alt 2	Alt 3
Total energy on-site [kWh/year, UDDT]	0	0	0	351
% of monthly mean consumption	0	0	0	14
Score (on-site)	**5**	**5**	**5**	**1**
Total energy off-site [kWh/year, UDDT]	20.8	78.3	84.4	37.1
% of monthly mean consumption	0.8	3.1	3.4	1.5
Score (off-site)	**4**	**3**	**3**	**4**
Score (majority)	**5**	**4**	**4**	**2**

The result showed that the energy consumption off site was almost directly related to the number of transports, see Table 15 - 18. This was expected since the UDDTs, located outside the city centre for Montero, see map in Figure 1, need collection with trucks of both the faeces and urine, while the treatment processes for source separated waste are generally simple compared to conventional sanitation solutions. On the other hand the energy consumption of the fans driving the urine drying on household level for alternative 3, of more than five times more than the total consumption of the five vacuum trucks used in alternative 1 and 2, was higher than expected. When testing the urine drying process in Montero, the electricity consumption could possibly be reduced due to more efficient drying in the warmer climate or if optimizing the dehydration after further ongoing research.

Alternative 0 was rounded up to 5, since the off site energy consumption of 0.8 % of the average total energy consumption at household level, scored 4, was approximately half of the one for alternative 3, also awarded with score 4. For alternative 3, the high production of the dehydration fan on site would alone have awarded the system with a score of 1, but due to the higher off site score the system was awarded with the final score 2. That a rounding down of the on site and off site score, is performed in this case, is assumed appropriate considering the very large on site consumption for alternative 3, of around four times more than any other alternative's on site or off site consumption. Even if the limit between score 3 and 4 would be decreased the final score for alternative 3 would be the same, strengthening the result.

The relatively large difference of energy consumption of alternative 0 (lower) and alternative 3 (higher) compared to the other two alternatives, proves that despite many assumptions for each unit, the relative score for the alternatives can be considered true.

4.1.3 Environmental

Potential environmental risks

In the semi-quantitative risk assessment matrix over *Potential environmental risks* for alternative 0, 7 potential environmental risks rated *medium* or above were identified whereof 2 rated *very high*, see Table 20. The assessment basis for the likelihood and severity of each evaluated hazard can be found in appendix J.

Table 20. Semi-quantitative risk assessment matrix over potential environmental risks for **alternative 0** for each sanitation step from collection at UDDTs to disposal. For assessment bases, see Table J.1

Sanitation step	No.	Hazard identification		Existing control		Risk assessment: L=Likelihood; S=Severity ; R= Risk level			
		Hazard event	**Hazard**	**Control Measure**	**Validation of control**	**L**	**S**	**Score**	**Risk**
Usage of UDDT on site	1.	Groundwater pollution by infiltration of urine after usage	All microbial pathogens	n/a	n/a	5	2	10	M
	2.		Nitrate/ Nitrite	n/a	n/a	5	8	40	VH
	3.	Pollution to air from urine after usage	Ammonia	Pipes designed so they are not directly ventilated	n/a	3	2	6	M
Maintenance	4.	Pollution to air during maintenance of pipes	Ammonia	n/a	n/a	3	2	6	M
Collection of faeces and transport	5.	Groundwater pollution if dropping tanks with faeces	All microbial pathogens	n/a	n/a	1	4	4	L
	6.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
	7.	Greenhouse gas emissions	Greenhouse gases	n/a	n/a	5	8	40	VH
Burial of faeces	8.	Groundwater pollution from faeces at burial site	Al microbial pathogens	n/a	n/a	5	4	20	H

In the semi-quantitative risk assessment matrix over *Potential environmental risks* for alternative 1, 8 potential environmental risks rated *medium* or above were identified whereof 1 rated *very high*, see Table 21.

Table 21. Semi-quantitative risk assessment matrix over potential environmental risks for **alternative 1** for each sanitation step from collection at UDDTs to end use of products. For assessment bases, see Table J.2

Sanitation step	No.	Hazard identification		Existing control		Risk assessment: L=Likelihood; S=Severity; R= Risk level			
		Hazard event	**Hazard**	**Control measure**	**Validation of control**	**L**	**S**	**Score**	**Risk**
Usage of UDDT at site	1.	Pollution to air from urine after usage	Ammonia	Design pipelines	Pipelines designed so they are not directly ventilated	2	2	4	L
	2.	Groundwater infiltration if leakage from urine tank	All microbial pathogens	Guaranteed life	Tanks not used after guarantied life span	1	2	4	L
	3.		Nitrate/ nitrate	Guaranteed life	Tanks not used after guarantied life span	1	8	8	M
Maintenance	4.	Pollution to air during maintenance of pipes	Ammonia	n/a	n/a	3	2	6	M
Collection of faeces and transport	5.	Groundwater pollution if dropping tanks with faeces	All microbial pathogens	n/a	n/a	1	4	4	L
	6.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
Collection of urine and transport	7.	Groundwater pollution if leakage during pumping	All microbial pathogens	Well-instructed staff	n/a	1	2	2	L
	8.		Nitrate/ nitrite	Well-instructed staff	n/a	1	8	8	M
	9.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
	10.		All microbial pathogens	Driving speed limitations	20-40 km/h speed	1	2	2	L
	11.		Nitrate/ nitrite	Driving speed limitations	20-40 km/h speed	1	8	8	M
Transport	12.	Greenhouse gas emissions	Greenhouse gases	n/a	n/a	5	8	40	VH
Treatment	13.	Groundwater pollution of leakage from treatment chamber	All microbial pathogens	n/a	n/a	1	4	4	L
	14.	Groundwater pollution if dropping untreated faeces during manual transfer	All microbial pathogens	n/a	n/a	1	4	4	L
	15.	Groundwater pollution if leakage from urine storage tanks	All microbial pathogens	Guaranteed life	Tanks not used after guarantied life span	1	2	2	L
	16.		Nitrate/ nitrite	Guaranteed life	Tanks not used after guarantied life span	1	8	8	M
	17.	Pollution to air if damage on urine storage tanks	Ammonia	Guaranteed life	Tanks not used after guarantied life span	1	2	2	L

In the semi-quantitative risk assessment matrix over *Potential environmental risks* for alternative 2, 10 potential environmental risks rated *medium* or above were identified whereof 1 rated *very high*, see Table 22.

Table 22. Semi-quantitative risk assessment matrix over potential environmental risks for **alternative 2** for each sanitation step from collection at UDDTs to end use of products. For assessment bases, see Table J.3

Sanitation step	**No.**	**Hazard identification**		**Existing control**		**Risk assessment: L=Likelihood; S=Severity ; R= Risk level**			
		Hazard event	**Hazard**	**Control measure**	**Validation of control**	**L**	**S**	**Score**	**Risk**
Usage of UDDT at site	1.	Pollution to air from urine after usage	Ammonia	Design pipelines	Pipelines designed so they are not directly ventilated	2	2	4	L
	2.	Groundwater infiltration if leakage from urine tank	All microbial pathogens	Guaranteed life	Tanks not used after guarantied life span	1	2	4	L
	3.		Nitrate/ nitrate	Guaranteed life	Tanks not used after guarantied life span	1	8	8	M
Maintenance	4.	Pollution to air during maintenance of pipes	Ammonia	n/a	n/a	3	2	6	M
Collection of faeces and transport	5.	Groundwater pollution if dropping tanks with faeces	All microbial pathogens	n/a	n/a	1	4	4	L
	6.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
Collection of urine and transport	7.	Groundwater pollution if leakage during pumping	All microbial pathogens	Well-instructed staff	n/a	1	2	2	L
	8.		Nitrate/ nitrite	Well-instructed staff	n/a	1	8	8	M
	9.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
	10.		All microbial pathogens	Driving speed limitations	20-40 km/h speed	1	2	2	L
	11.		Nitrate/ nitrite	Driving speed limitations	20-40 km/h speed	1	8	8	M
Transport	12.	Greenhouse gas emissions from fuel	Greenhouse gases	n/a	n/a	5	8	40	VH
Treatment	13.	Groundwater pollution of leakage from treatment chamber	All microbial pathogens	n/a	n/a	1	4	4	L
	14.	Groundwater pollution if dropping untreated faeces during manual transfer	All microbial pathogens	n/a	n/a	1	4	4	L
	15.	Greenhouse gas emissions for electricity	Greenhouse gases	n/a	n/a	3	8	24	H
	16.	Groundwater pollution if leaking from Makenutri	All microbial pathogens	Guaranteed life	Tanks not used after guarantied life span	1	2	2	L
	17.		Nitrate/ nitrite	Guaranteed life	Tanks not used after guarantied life span	1	8	8	M
	18.	Pollution to air from urine in Makenutri	Ammonia	Temperature	Relatively low temperatures (20-30 C)	2	2	4	L
	19.	Pollution to air from urea	Ammonia	Packing	Air-tight bags	3	2	6	M

In the semi-quantitative risk assessment matrix over *Potential environmental risks* for alternative 3, 6 potential environmental risks rated *medium* or above were identified whereof 1 rated *very high*, see Table 23.

Table 23. Semi-quantitative risk assessment matrix over potential environmental risks for **alternative 3** for each sanitation step from collection at UDDTs to end use of products. For assessment bases, see Table J.4

Sanitation step	No.	Hazard identification		Existing control		Risk assessment: L=Likelihood; S=Severity ; R= Risk level			
		Hazard event	Hazard	Control measure	Validation of control	L	S	Score	Risk
Usage of UDDT at site	1.	Pollution to air from urine after usage	Ammonia	Design pipelines	Pipelines designed so they are not directly ventilated	2	2	4	L
	2.	Groundwater infiltration of urine if leakage from pipes	All microbial pathogens	Guaranteed life	Tanks not used after guarantied life span	1	2	4	L
	3.		Nitrate/ nitrate	Guaranteed life	Tanks not used after guarantied life span	1	8	8	M
Maintenance	4.	Pollution to air during maintenance of pipes	Ammonia	n/a	n/a	3	2	6	M
Collection of faeces and transport	5.	Groundwater pollution if dropping tanks with faeces	All microbial pathogens	n/a	n/a	1	4	4	L
	6.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
Collection and transport of dried urine	7.	Groundwater pollution if car accident	Gasoline	Driving speed limitations	20-40 km/h speed	1	8	8	M
Transport	8.	Greenhouse gas emissions from fuel	Greenhouse gases	n/a	n/a	5	8	40	VH
Treatment	9.	Groundwater pollution of leakage from treatment chamber	All microbial pathogens	n/a	n/a	1	4	4	L
	10.	Groundwater pollution if dropping untreated faeces during manual transfer	All microbial pathogens	n/a	n/a	1	4	4	L
	11.	Greenhouse gas emissions from electricity	Greenhouse gases	n/a	n/a	4	8	32	H

The overall result of the semi-quantitative risk assessment for environmental risks, showed that alternative 0 had the highest number of *very high* risks and also the highest total risk score and was ranked with the final risk score *H* (high risk), see Table 24. Alternative 1 and 3 had low potential risks both when viewing the number of risk and the total risks score and were rated with *L* (low risk)

Table 24. Summary of semi-quantitative risk assessment for potential environmental risks for each alternative system

Alternative	Alt 0	Alt 1	Alt 2	Alt 3
Number of risks rated very high	2	1	1	1
Number of risks rated medium, high or very high	7	8	10	6
Total risk score	130	94	124	102
Final score	**2**	**4**	**3**	**4**

As assumed, greenhouse gas emissions due to transports with truck accounted for one of the largest environmental risks, see Table 20 - 23. In relation to the travels by car many workers do every day to work, sometimes even for commuting between cities, these emissions are relatively small. This can motivate the choice of scale with lower requirements for the final score compared with the scale for *Health risk: workers*. Worth to note is when considering carbon dioxide emissions as environmental risks, time perspective comes in. The consequence of carbon dioxide emissions from burnt fuel is mainly climate change. Climate change is an effect that probably will not be seen in the nearest in months or years, but could instead contribute to irreversible loss of biodiversity on Earth in future. This has not been evaluated in the severity of the environmental risks here and as a result the risks related to climate change is possibly set to high. However, since these risks are similar for all four alternative the relative final scores should not be affected.

That the semi-quantitative risk matrix for environmental risks indicated the highest number of high or very high risks for alternative 0, was expected since it does not collect the urine or treat the faeces. Alternative 2 had a higher number of risks rated *medium* or above than alternative 0, due to several treatment steps, but a lower total risk score and number of very high risks indicating that each risk is less likely and/or severe. The choice of scale is a big uncertainty in the result. If the final score instead of setting limits for amounts of high risks, amounts of risks rated *medium* or above and total risk score to be under certain limits to get a certain score, rather would have corresponded to a mean of the scores for the number of risks rated *medium* or above and the total risk score, alternative 0 would have been awarded with a final score of 3 instead of 2. However the worst environmental score for alternative 0 is motivated with the direct potential hazards (WHO, 2011), especially for small children as a consequence of the groundwater contamination. This risk is further amplified with the shallow groundwater surface in Montero, with the ground water surface clearly above the limit of 1.5 m from the buried faeces. The likelihood of groundwater contamination in Montero is further increased due to the domination of sand in the soils. Since sand consists of relatively large grains, the hydraulic conductivity of the soil is high which favor infiltration of water and contaminants, (Reyes-López et al., 2008).

Even if the environmental risk assessment was based on the framework from Environmental and Social Impact Assessments, some degree of uncertainty comes in with the qualitative judgement of the score for each severity and likelihood. If each environmental risk rather would have been scored according to the environmental impact in relation to the total national impact on the environment (Hellström et al., 2000), the result would potentially be more trustful.

4.1.4 Financial

Operation, maintenance and capital costs

Today the families with the UDDTs are provided with one 15 kg bag of drying material every third month, when the containers with faeces are collected. For large families, finishing their drying material before three months, they need to pay for additional ones. COSMOL estimates that 30 % of the families buy one more bag every third month, assumed to contribute with an income to COSMOL for all systems in this analysis.

Among the yearly capital and O&M costs for alternative 0, the UDDT and the costs for staff are the highest, see Table 25. The costs for the infrastructure of the burial per year and the fuel costs are relatively low.

Table 25. Capital cost per item, lifespan, number of units and yearly costs and O&M costs for alternative 0. All sanitation steps are included

Capital costs							O&M costs		
#	**Item**	**Cost [USD]**	**Lifespan [years]**	**Amount**	**Total cost [USD]**	**Yearly cost [USD/year]**	**#**	**Item**	**Cost [USD/year]**
		On site				*109 736*		*On site*	*2 473*
1	UDDT	2 195	20	1000	2 194 720	109 736	15	Painting/ structure maintenance UDDT	25
							16	Drying material	3 318
							17	Selling extra drying material	-870
		Transport				*5 024*		*Transport*	*48 002*
2	Small truck	1 3675	5	1	13 675	2 735	18	Staff costs	42 085
3	Motorbikes (social visits)	2 030	10	6	12 180	1 218	19	Fuel truck	567
							20	Fuel motorbikes	558
4	Clothes/safety protection	1 071	1	1	1 071	1 071	21	Maintanence truck	116
							22	Maintanence motorbikes	174
							23	Disinfection of containers and trucks	418
							24	Disinfection, clothes	314
							25	Extra containers for faeces	3 770
		Treatment				*1 722*		*Treatment*	*9 060*
5	Burial area	3 742	10	2	7 484	748	26	Staff costs	3 896
6	Disinfection area	202	10	1	202	20	27	Fuel for cutting machine	0.71
7	Improvement lab	2 146	10	2	4 292	429			
8	Solar panel	777	10	2	1 554	155	28	Lime for burial	1 357
9	Toilet	1 097	20	2	2 195	110	29	Changing fences and painting	624
10	Access door	218	10	1	218	22	30	Disinfection, clothes	63
11	Brush cutter	508	10	1	508	51	31	Burial material to landfill	2 812
12	Drying chambers	606	20	5	3 028	51	32	Transport burial material	60
13	Clothes/safety protection	136	1	1	136	136	33	General equipment	145
							34	Soil quailty test	102
		End use				*0*		*End use*	*0*
14	Value products	/	/	/	/	/		/	/

For alternative 1 the staff costs are in the same order as the yearly costs of constructing the UDDTs for all 1000 households, see Table 26. The costs for the infrastructure is generally higher than for alternative 0 with the investment from the vacuum trucks, vermicompost chambers and urine storage tanks.

Table 26. Capital cost per item, lifespan, number of units and yearly costs and O&M costs for alternative 1. All sanitation steps are included

Capital costs							*O&M costs*		
#	**Item**	**Cost [USD]**	**Lifespan [years]**	**Amount**	**Total cost [USD]**	**Yearly cost [USD/year]**	**#**	**Item**	**Cost [USD/year]**
		On site				*114 014*		*On site*	*2 473*
1	UDDT	2 195	20	1000	2 194 720	109 736	20	Painting/structure maintanence UDDT	25
2	Urine collection tanks	43	10	1000	42 775	4 278	21	Drying material (faeces)	3 318
							22	Selling extra drying material	-870
		Transport				*27 389*		*Transport*	*98 391*
3	Small truck	1 3675	5	1	13 675	2 735	23	Staff costs	87 466
4	Vacuum truck	21 000	5	5	105 000	21 000	24	Fuel truck	567
							25	Fuel vacuum truck	2 380
							26	Fuel motorbikes	372
5	Motorbikes (social visits)	2030	10	4	8 120	812			
							27	Maintanence trucks	696
6	Clothes/safety protection	2 842	1	1	2 842	2 842	28	Maintanence motorbikes	116
							29	Fuel vacuum pump	1 143
							30	Disinfection of containers and trucks	501
							31	Disinfection, clothes	1 380
							32	Extra containers for faeces	3 770
		Treatment				*14 472*		*Treatment*	*33 757*
7	Disinfection area	202	10	2	202	20	33	Staff costs	27 955
8	Improvement lab	2 146	10	3	6 438	644	34	Electricity for pump	18
9	Solar panel	777	10	3	2 332	233			
10	Toilet	1097	20	2	2 195	110	35	Worms	3512
11	Access door	218	10	1	218	22	36	Water vermicompost	0
12	Vermicompost chambers	3632	20	14	50 854	2 543	37	Fertilizer bags	377
13	Drying chamber	2 494	20	1	2 494	125	38	Maintenance treatment area	624
14	Wheel barrow	35	2	4	139	70	39	Disinfection, clothes	1 024
15	Electric pump	363	2	1	363	181	40	General equipment	145
16	Hose for pump	30	5	1	30	6	41	Soil quailty test	102
17	Urine storage tanks	703	10	135	94 939	9 494			
18	Clothes/safety protection	1024	1	1	1024	1024			
		End use				*- 5 351*		*End use*	*0*
19	Value humus	- 5 351	1	1	- 5 351	- 5 351		/	/

For alternative 2, the transport costs are the same as for alternative 1, since both systems include collection of urine with vacuum truck. For the alternative some additional high costs for treatment of urine with ZeoPeat in Makenutri devices, increases the total costs for staff conntected to treatment, see Table 27.

Table 27. Capital cost per item, lifespan, number of units and yearly costs and O&M costs for alternative 2. All sanitation steps are included

		Capital costs						*O&M costs*	
#	**Item**	**Cost [USD]**	**Lifespan [years]**	**Amount**	**Total cost [USD]**	**Yearly cost [USD/year]**	**#**	**Item**	**Cost [USD/year]**
		On site				*114 014*		*On site*	*2 473*
1	UDDT	2 195	20	1000	2 194 720	109 736	22	Painting/structure maintanence UDDT	25
2	Urine collection tanks	43	10	1000	42 775	4 278	23	Drying material (faeces)	3 318
							24	Selling extra drying material	- 870
		Transport				*27 389*		*Transport*	*99 377*
3	Small truck	1 3675	5	1	13 675	2 735	25	Staff costs	87 466
4	Vacuum truck	21 000	5	5	105 000	21 000	26	Fuel truck	567
							27	Fuel vacuum truck	2 380
							28	Fuel motorbikes	372
5	Motorbikes (social visits)	2030	10	4	8 120	812	29	Maintanence trucks	696
6	Clothes/safety protection	2 842	1	1	2 842	2 842	30	Maintanence motorbikes	116
							31	Fuel vacuum pump	2 129
							32	Disinfection of containers and trucks	501
							33	Disinfection, clothes	1 380
							34	Extra containers for faeces	3 770
		Treatment				*22 093*		*Treatment*	*124 367*
7	Disinfection area	202	10	2	202	20	35	Staff costs	57 744
8	Improvement lab	2 146	10	8	17 168	1 717			
9	Solar panel	777	10	8	6 218	622	36	Electricity for pump	33
10	Toilet	1097	20	2	2 195	110	37	Worms	3512
11	Access door	218	10	1	218	22	38	Water vermicompost	0
12	Vermicompost chambers	3632	20	14	50 854	2 543	39	Fertilizer bags	4 614
13	Drying chamber	2 494	20	6	14 964	748	40	Zeopeat	50 058
14	Wheel barrow	35	2	8	278	139	41	Electricity for Makenutri 200V	655
15	Electric pump	363	2	1	363	181	42	Urea	5 889
16	Hose for pump	30	5	1	30	6	43	Maintenance treatment area	624
17	Makenutri 200V	5 000	10	23	115 000	11 500	44	Disinfection, clothes	976
18	Shipping cost Makenutri 200V	2 500	10	2	5 000	500	45	General equipment	160
19	Stirrer Makenutri	608	7	23	13 975	1 996	46	Soil quailty test	102
20	Clothes/safety protection	1 988	1	1	1 988	1 988			
		End use				*- 45 081*		*End use*	*0*
21	Value humus-Gainutri mix	- 45 081	1	1	- 45 081	- 45 081		/	/

For alternative 3, the transport costs and investment in infrastructure for the treatment processes are lower than for alternative 1 and 2. On the other hand, more capital and O&M costs are added on site for the urine dehydration process, see Table 28.

Table 28. Capital cost per item, lifespan, number of units and yearly costs and O&M costs for alternative 3. All sanitation steps are included

Capital costs							*O&M costs*		
#	**Item**	**Cost [USD]**	**Lifespan [years]**	**Amount**	**Total cost [USD]**	**Yearly cost [USD/year]**	**#**	**Item**	**Cost [USD/year]**
	On site					*123 563*		*On site*	*55 141*
1	UDDT	2 195	20	1000	2 194 720	109 736	24	Painting/structure maintenance UDDT	25
2	Urine drying box	10	10	1000	10 000	1000			
3	Passive solar heater	33	10	1000	32 877	3 288	25	Drying material (faeces)	3318
4	Electricity connection	10	10	1000	10 000	1000	26	Maintenance drying device	9 000
5	Pipes to urine drying	4	10	1000	4 000	400	27	Drying media urine	4 519
6	Fan in drying box	25	5	1000	25 000	5 000	28	Electricity for fan	39 149
7	Rain cover box	21	10	1000	21 935	2 139	29	Selling extra drying material	- 870
8	Timer for fan	5	10	1000	5 000	500			
9	Installation costs	5	10	1000	5 000	500			
	Transport					*10 693*		*Transport*	*61 783*
10	Small truck	1 3675	5	3	41 024	8 205	30	Staff costs	54 231
11	Motorbikes (social vists)	2 030	10	5	9 135	914	31	Fuel truck	1 701
							32	Fuel motorbikes	419
							33	Maintenance trucks	348
12	Clothes/safety protection	1 574	1	1	1 574	1 574	34	Maintanence motorbikes	131
							35	Disinfection of containers and trucks	445
							36	Disinfection, clothes	738
							37	Extra containers for faeces	3 770
	Treatment					*5 596*		*Treatment*	*42 832*
13	Disinfection area	202	10	1	202	20	38	Staff costs	35 930
14	Improvement lab	2 146	10	5	10 730	1 073	39	Worms	3 512
15	Solar panel	777	10	5	3 886	389			
16	Toilet	1097	20	2	2 195	110	40	Water vermicompost	0
17	Access door	218	10	1	218	22	41	Fertilizer bags	1 796
18	Vermicompost chambers	3632	20	14	50 854	2 543	42	Maintenance treatment area	624
19	Drying chamber	2 494	20	1	2 494	125	43	Disinfection, clothes	723
20	Wheel barrow	35	2	4	139	70	44	General equipment	145
21	Clothes/safety protection	1 244	1	1	1 244	1 244	45	Soil quailty test	102
	End use					*- 24 946*		*End use*	*0*
22	Value N-enriched humus	- 6 085	1	1	- 6 085	- 6 085		/	/
23	Value dried urine	- 18 861	1	1	- 18 861	- 18 861			

After converting all the costs in each table to annualized costs, with the use of the tool from World Bank Group (n.d.), alternative 0 had the lowest annualized costs for both the capital and O&M. For the capital costs, the construction of the UDDT corresponded to almost the whole cost, see Figure 17. For the O&M costs, the transport corresponded to the highest costs for alternative 0 and 1. On the other hand for alternative 2, which was the most expensive alternative, the treatment had higher O&M costs than the transport and, see Figure 18. While alternative 3 had relatively low transport costs to alternative 1 and 2, it had the highest on site costs.

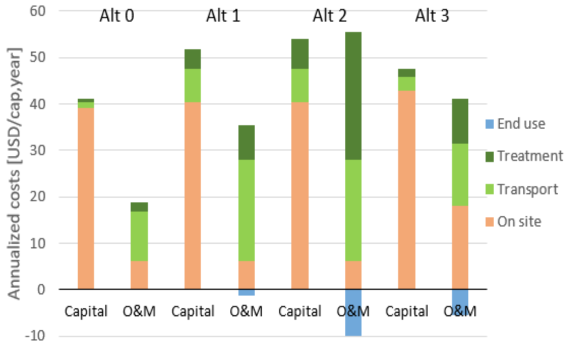

Figure 17. Annualized capital and O&M costs for different steps in the sanitation process on site versus off site for each alternative system. Construction and maintenance costs for UDDT included.

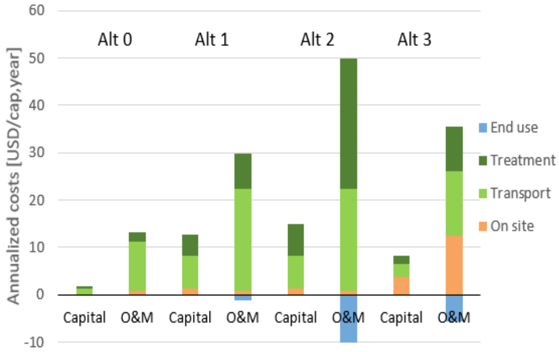

Figure 18. Annualized capital and O&M costs for different steps in the sanitation process on site versus off site for each alternative system. Construction and maintenance costs for UDDT excluded.

When summarizing the on site, transport, treatment and end use costs, alternative 2 had the highest annualized capital costs and O&M costs and alternative 0 the lowest, see Table 29. Alternative 1 and 3 had rather similar annualized costs, but alternative 1, with a larger number of infrastructure needed, had higher capital costs while alternative 3 with a high electricity consumption, had higher O&M costs.

Table 29. Scores for total annualized capital versus O&M costs per capita and year for each alternative including construction of UDDT. Final scores as the average of the two scores

Alternative	Alt 0	Alt 1	Alt 2	Alt 3
Capital costs [USD/capita,year]	41	52	54	48
Score (capital costs)	4	2	2	3
O&M costs [USD/capita,year]	19	34	45	35
Score (O&M costs)	5	3	2	3
Final score	**5**	**3**	**2**	**3**

The result reporting the lowest capital and O&M costs for alternative 0, not collecting nor treating the urine, was expected. Neither was the report of alternative 2, with most sanitation steps and materials in flow, having the highest capital and O&M costs, unexpected. The final score was determined by the choice of scoring scales, but since the relative difference between especially the O&M costs varied notable between alternative 0 (lowest), alternative 1 and 3 (middle) and alternative 2 (highest), the rating was strengthened. However, due to many assumptions and on many occasions lack of local sources, the capital and O&M costs should not be viewed as absolute numbers. Another uncertainty was the lack of information about a suitable discount rate which affected the calculations of the annualized costs to a high extent. Despite the uncertainties in the result, except from indicating which alternative is the financially most and least sustainable, the result can highlight which costs are the highest, enabling analysis of where most money has potential to be saved if the system can be optimized.

Worth to note is the relatively small annualized capital costs for all four alternatives in comparison to the construction costs of the actual UDDTs, see Figure 17 and 18. The result also shows salaries represent the highest costs for all alternatives. This is not unexpected since all waste is collected manually, while relatively small machines are used for the transports and treatment. However, the result indicates how important it is to evaluate the number of staff needed for a financially sustainable system, while still providing acceptable working conditions. An example is the staff operating the Makenutri device in alternative 2, which could potentially be decreased from four persons to one, if using the larger Makenutri version *400V* with a separate sedimentation basin (Personal Communication, Olsson, 2019). This would decrease the cost for staff with 12 % and the annual O&M costs with 4 USD/capita,year, resulting in an O&M cost closer to the limit for being scored 3 for alternative 2.

Economical value of recycled products

Alternative 1, that only produces humus, consequently had the lowest total amount of fertilizer and yearly values since the stored urine did not result in any financial value. Alternative 2 produces more than ten times more fertilizers (humus-Gainutri mix) than alternative 1 and almost twice as much as alternative 3, also had the highest yearly value, see Table 30. Looking at the relative value of the fertilizers compared to the cost of the additives, alternative 1 and 3 have more than twice versus four times the relative value of alternative 2.

Table 30. Amount and values of the produced fertilizers from urine and faeces every year and relative value of cost for additives

Alternative	**Alt 0**			**Alt 1**			**Alt 2**			**Alt 3**		
Value for produced products												
	[USD/ ton]	[ton/ year]	[USD/ year]	[USD/ ton]	[ton/ year]	[USD/ year]	[USD/ ton]	[ton/ year]	[USD/ year]	[USD/ ton]	[ton/ year]	[USD/ year]
Humus				145	37	5 351						
Humus-Gainutri mix							99	454	45081			
N-enriched humus										153	40	6 085
Dried urine										138	137	18861
Total [USD/year]			**0**			**5351**			**45081**			**24946**
% of value of cost for additives			**0 %**			**161 %**			**76 %**			**318 %**

Alternative 0 did not produce any products and was scored with the lowest score, 1, see Table 31. Alternative 2 had the highest total fertilizer value per year and was scored 5.

Table 31. Value of the produced products and corresponding final score for the different alternative systems

Alternative	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 3**
Total value [USD/year]	0	5 351	45 081	24 946
Value [USD/capita,year]	0	1.2	10	5.5
Final score	**1**	2	**5**	**4**

The results showed clear differences in the value of the produced products for each alternative system, where alternative 2 had the highest value of almost twice the value of alternative 3 and 8 times of alternative 1, see Table 31. The reason for the low value of alternative 1 is the stored urine assumed being donated for free due to lack of demand. Since the evaluation of the social aspects was limited, a possibility is that urine in future could be sold to suitable farmers and thus the total value for alternative 1 be increased.

Worth to note is the low relative value of the fertilizers in alternative 2, of 76 % of the total costs of the additives, see Table 30. The estimated cost for the required ZeoPeat, imported from Sweden to Bolivia, is higher than the total value of the produced humus-Gainutri mixture, see Table 27, which also explains the reason behind the high fertilizer income. However, this cost can potentially be lowered after pilot tests, if potential sources of zeolite in Bolivia or alternatively in Argentina, Peru or Chile (Mindat, n.d.) can be confirmed as secure and peat exchanged to locally found biochar (Personal Communication, Olsson, 2019). Another interesting result in this analysis is that the value per ton is lower for the humus-Gainutri mixture (99 USD/ton) than for pure humus (145 USD/ton) or dried urine (138 USD/ton). This is explained by the high soil improvement properties of humus increasing the fertilizer value, see Table 5. Even if the properties of humus also are accounted for in humus-Gainutri, the additional value is relatively low, since the proportion of humus in the dry weight is less than 10 % of the total dry mass, see Table 30. The zeolite contents also contributed to the soil improvement properties for Gainutri, but due to a small content of zeolite, the value per ton for humus-Gainutri was still the lowest of the three fertilizers. Dried urine has not proved to contain soil improvement properties, but due to higher nutrient values than humus-Gainutri, especially N which are lost to the N water in the Makinutri process for alternative 2, the value per ton is still higher.

Since Gainutri and dried urine are not yet at the market in Bolivia, several assumptions were made for the assessment. Therefore the actual fertilizer values could be both higher or lower than assessed. An uncertainty is that the amount of K could not be calculated with equations from research like N and P, since a clear mathematical relation could not be found. If the content of K in faeces and urine could be measured in laboratory the estimated value for the fertilizers could be either higher or lower. Similarly is for the content of N and P, which are build on equations rather than actual measurements. Finally if the actual amount of faeces and urine differ from the assumption of 51 kg faeces/capita,year and 450 L urine/capita,year, the total amount of fertilizers would also change.

To set appropriate values of the produced fertilizers, the nutrient content is recommended to be measured in a pilot test for the fertilizers after treatment rather than in the fresh faeces and urine. It is important to mix the dried urine originating from a number of UDDTs on a central level, to avoid variation in nutrient in the fertilizer because of different nutrient intake depending on the food consumption in the family. Thus a fertilizer with predictable nutrient content can be achieved. As well as analyzing the nutrient content, the proportion of the nutrients in available form, that is absorbed by plants, is essential to study. In a study from 2018, 20 % Gainutri in peat could prove substantial amounts of nutrients potentially available for plant uptake (Caspersen & Ganrot, 2018). In a similar way, in all suggested fertilizers, the availability of nutrients and performance in comparison with commercial fertilizers need to be validated on local crops in Montero, in cooperation with agricultural extension services. Even if the high pH in the dried urine could be beneficial for the acid soils around Montero, the effect on plant roots and soil animals of the high pH needs to be analyzed. Generally, the value of fertilizers could potentially increase significantly in future, as the resources of N and P for producing commercial fertilizers are getting more scarce, as indicated in research (Cordell & White, 2011; Jönsson, 2019).

4.1.5 Socio-Cultural

Social acceptance: farmers

Among the three interviewed farmers the size of the farm was between 28 - 400 ha and all the farmers cultivated sugar cane and/or sorghum for commercial use, see Table 32. All the farmers applied fertilizers once a year on their crops but the types and amounts varied. Generally the amount of fertilizer applied was 100 kg/ha,year and urea was used by all three farmers. While the first farmer additionally used NPK 15-15-15 fertilizer the third one sometimes combined sulfur and phosphate fertilizers with the urea, according to soil analysis performed by an organization he was a part of which also contributed to deliveries for larger quantities of fertilizers. For small quantities for this farmer and for the two other farmers, the fertilizer was collected by the farmers themselves, at distances of 25 - 50 km from their farms. All three interviewed farmers used machines and tractors for spreading the fertilizers, but the specific types varied.

Table 32. Background information about the three interviewed farmers and their corresponding farm lands

#	Age	Gender	Size of farm	Type of crops	Type of production	Fertilizer used	Quantity of fertilizer	Frequency of application	Variation for different crops	Self collection or delivery of purchased fertilizer	Application method for fertilizers
1	38	Male	200 ha	Sugar canes	Commercial: To industries of sugar alcohol	NPK: 15-15-15 Urea	100 kg/ha, year	Once a year	/	Self collection (50 km distance from farm)	By tractor with fertilizer spreader
2	23	Male	28 ha	Sugar canes, sorghum	Commercial	Urea	80 kg/ha, year	Once a year	No	Self collection (25 km, farm located in Minero)	Tractor seeder
3	?	Male	400 ha	Sugar canes, sorghum	Commercial: Sorghum for feed	Urea, sulfur, phosphorus (what is recommended according to analysis)	100-300 kg/ha, year	Once a year	Variation according to analysis	Self collections for small quantities, delivery included for bigger (part of organization)	Hydraulic spreader

For the open interview questions, several different perspectives were highlighted. The first farmer prioritized mainly fertilizer of a powdered or granulated form because of how easy it was to handle with the existent machines, therefore excluding liquid stored urine from his interests. The third farmer pointed out that the cost against the benefit was important, including required amount fertilizers, transports and other additional costs more than just the cost per ton fertilizer, see Table 33. The second farmer was not interested in any of the suggested fertilizers, stating that they would be hard to spread on large scale and require purchase of different machines.

Table 33. The three farmers' attitude and comments about using different fertilizers from treated urine and faeces

#	Products from UDDTs that the farmer can consider using	Reason why prefered fertilizer(s)	To what price can the farmer consider buying the fertilizer	The characteristics the fertilizers need to have for the farmer to use it	Cares about pathogens in fertilizer	Other
1	Any powdered or granulated fertilizer (humus, dried urine, Gainutri-humus mixture)	Easy to spread and to get NPK to farms	Cheaper or same price as current fertilizers	Easy to handle: powdered or granulated form	No, sugar cane is used for processed alcohol only	Positive attitude towards recycling nutrients back to farms
2	None	Hard to spread on **big** farms	None	Need a suitable machine for each of the fertilizers to use fertilizers regularly at big scale	No mention	Recommends humus for smaller farms
3	Any of the suggested (humus, dried urine, Gainutri-humus mixture, liquid urine)	If they are beneficial taking the overall cost into account	The cost of the fertilizer per kg is not everything	Need a full cost analysis to know if beneficial (needed quantity, if other machines are needed, more transports, more labour etc)	No mention	/

Since alternative 0 had no recyclable products to the farms, it was not evaluated with the criterion *Social acceptance: farmers*. Alternative 1 showed a social acceptance from 2 out of 3 farmers for the humus and 1 out of 3 farmers for the liquid urine due to a more difficult consistency to spread. The final score was therefore the average of 3, see Table 34. For alternative 2 and 3, two out of three farmers had a social acceptance towards using all the produced products at their farm, if the price was low compared to the beneficial. This contributed to a final score of 4 for each system.

Table 34. Summary of social acceptance among farmers to the products from treated faeces and urine and corresponding scoring for each alternative system

Alternatives	Alt 0	Alt 1		Alt 2	Alt 3	
Product	/	Humus	Liquid urine	Gainutri-Humus	N-enriched humus	Dried urine
Farmer 1	/	yes	no	yes	yes	yes
Farmer 2	/	no	no	no	no	no
Farmer 3	/	yes	yes	yes	yes	yes
Frequency acceptance	/	67%	33%	67%	67%	67%
Product score	/	4	2	4	4	4
Final score	/	3		4	4	

Social acceptance: farmers was the criterion with the largest uncertainty in this analysis due to the low number of performed interviews, why the final scores have been marked with striped colours. Therefore the result can only be an indication of a higher social acceptance among the farmer to granulated or powdered fertilizers rather than fertilizers in liquid form, such as stored urine. A possibility is that there are a group of farmers who are positive towards using liquid urine as a fertilizer for their crops, which can be indicated by farmer 3 who was positive to any fertilizer if they were beneficial enough. On the other hand, FSH in El Alto has sold the humus from the vermicompost to farmers, while the stored urine is donated for free to an agricultural organization due to lack of demand (Personal Communication, Suntura, 2019), further motivating the higher social acceptance towards the granular humus than the liquid urine.

According to a study of the social acceptance of 467 farmers in Switzerland towards liquid and grainy (solid) urine-based fertilizers, the attitude were surprisingly positive as long as the fertilizer was hazard free and had a low to moderate price, (Lienert et al., 2003) with 57 % stating that the idea was good or very good and 42 % willing to purchase the fertilizer. No significant correlation between the social acceptance and the type of crops could be shown. However, among the farmers who would not purchase the fertilizer, the majority had no habit of using fertilizers on their crops. The same study indicates that over three times more farmers found grainy fertilizers useful than liquid ones. This strengthens the result in the interviews for this report, leaning towards a higher social acceptance for humus, Gainutri and dried urine compared with the liquid stored urine. The social acceptance in developing countries of using the waste from UDDT's is further emphasized in a study from Kenya, where most of the UDDT users are reported applying the waste in their own farmlands (Uddin et al., 2012).

To gain a better understanding for the social acceptance, more interviews, preferably with a more diverse group of farmers with different genders, ages and cultivated crops are recommended to be done. This is highly important, to be able to secure that the produced fertilizers can be sold. If not, additional costs will be added and the goal itself of recycling nutrients to the agriculture can not be reached. All three interviewees emphasised the importance of the fertilizer being possible to spread without the need of purchasing new machines. In a future pilot test, it is therefore essential to analyze the properties of the fertilizer in relation to the existing agricultural machines. A strategy proved effective for increasing the social acceptance among farmers is to demonstrate for farmers the potential of treated sanitation waste as fertilizer (Hashemi & Han, 2019).

Affordability

From the analysis of the mean salary for the different quintiles for men and women, the maximum cost for the sanitation per household to be defined affordable was more than 6 times more for the fifth quintile compared to the first, see Table 35. The difference in maximum affordable cost between the lowest and the highest income quintile was larger for women than for men.

Table 35. Mean income per quintile of the population in the Santa Cruz district and affordable sanitation for each quintile. The affordability index that maximum 3 % of the household's income can be used for sanitation costs was used for the calculations

	If income for household comes from 1 man		If income for household comes from 1 woman		If income for household comes from 1 man + woman	
Quintile	**Mean income (men) [USD/year]**	**Affordable sanitation cost [USD/UDDT,year]**	**Mean income (women) [USD/year]**	**Affordable sanitation cost [USD/UDDT,year]**	**Mean income (man+ woman) [USD/year]**	**Affordable sanitation cost [USD/UDDT,year]**
First	3 861	116	2 318	70	6179	185
Second	6 308	189	5 034	151	11 341	340
Third	8 561	257	7 811	234	16 372	491
Fourth	11 833	355	12 763	383	24 586	738
Fifth	25 033	751	28 541	856	53 575	1 607

According to the calculations of the costs for the sanitation service per household, alternative 0 had the lowest costs and alternative 2 the highest, while alternative 1 and 3 had similar costs, in between the other two alternatives, see Table 36. A similar result is shown in the number of quintiles for whom the sanitation service is considered affordable. If the construction of the UDDT is only paid by the households and the entire household income comes only from one income holder, only the highest quintile can afford most of the sanitation solutions.

Table 36. Affordability in USD/household,year of each sanitation system for certain quintiles including or excluding the construction of the actual UDDT. The analysis was performed for scenarios of one man as income holder of the household, one woman and for one man and one woman

	Cost sanitation service [USD/household, year]			
Alternative	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 3**
Incl. UDDT construction	269	387	448	373
Number of quintiles affordable (1 man)	2	1	1	1
Number of quintile affordable (1 woman)	2	1	1	2
Number of quintiles affordable (1 man + 1 woman)	4	3	3	3
Excl. UDDT construction	68	186	247	172
Number of quintiles affordable (1 man)	5	4	3	4
Number of quintiles affordable (1 woman)	5	3	2	3
Number of quintiles affordable (1 man + 1 woman)	5	4	4	5

When excluding the construction cost of the UDDT and when only including the income for one man over 18 years old in each household, all quintiles could afford sanitation alternative 0 without further subsidizes, the four highest quintiles could afford alternative 1 or 3 and the three highest quintiles could afford alternative 2, which results in corresponding scores, see Table 37.

Table 37. Affordability of each sanitation system for certain quintiles when 1 man contributes to the full household income and when excluding the construction cost of the UDDT

Alternative	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 3**
Quintiles affordable (1 man)	1, 2, 3, 4, 5	2, 3, 4, 5	3, 4, 5	2, 3, 4, 5
Final score	**5**	**4**	**3**	**4**

The results of affordability shows big differences in which quintiles the alternatives are affordable for, depending on the number of income holders in the household as well as if subsidies from the government or the Swedish embassy exists or not, see Table 36. An important note is that the required subsidies for the systems to be affordable should be related to the existing subsidies of the capital costs for the conventional centralized system in Montero. Generally in this analysis, alternative 0 is most affordable and alternative 2 least, which is directly correlated with the capital and O&M costs, see section 4.1.4. Since new UDDTs have been constructed in Montero only when subsidies from the Swedish embassy have been offered (Personal Communication, UNICEF, 2019), the assumption to analyse affordability excluding the annualized costs for construction of the UDDT, can be motivated.

On the other hand, the amount of income holders in a household is more uncertain. The case when only one woman is the income holder of the household is assumed unlikely in a less developed country like Bolivia unless the household lacks a man. Reports stated 2015 that Bolivia is one of the 18 countries where the woman need to ask her husband for permission to work (Thomson, 2015). However, especially for poorer families, many times both the man and the woman need to work to manage financially. Verick (2014) explains the female labour force participating in developing countries as a U-shape, where the poorest women work of necessity, while in a further step towards development, more work in industry benefits labour for men rather than women. In the last step of development more women gets education resulting in higher female labour. In the case when both a man and woman are income holders of the household, all quintiles would be considered affordable for alternative 3 and not only for alternative 0. Also, alternative 2 would be considered affordable for the four highest quintiles instead of three, see Table 37.

A source of error with the evaluation of affordability is the relatively low number of data (7500 people) over the income in the Santa Cruz department. Another weakness is that only 33 % of the interviewees provided information about their income. A possibility is that a certain group of people, potentially the ones with a lower salary, lacked the understanding of how to fill in the information. The questionnaire could possible have confused some of the interviewees, when asking about the salary and the frequency of when the person received the salary with a long list of alternatives such as weekly, every second week, monthly, every second month, every third month etc (INE, 2018). Another scenario is that a certain group of people, potentially with either a high or low income, are more reluctant towards providing the information. At last, an uncertainty is that no affordability index relating to the sanitation was found for Bolivia, why this analysis was performed from data from Chile and Argentina.

4.1.6 Technical-Organizational

Required technical-organizational capacity

For the criterion *Technical-Organizational capacity* the factor *Arena and communication* did not vary depending on the sanitation alternative. Today COSMOL has an arena for communication with the UDDT users, in form of their weekly visits. This arena enables possibilities for handling potential conflicts with the users, reviewing the usage of the UDDT as well as providing information about changes and news. The aspects that prevent from awarding *Arena and communication* with the highest score are earlier problems with some households converting their UDDTs to water toilets and in some cases declining the collection services by COSMOL, why the factor was score 4 for all four alternatives, see Table 40.

Alternative 0, 1 and 3 needed 2 - 3 infrastructure components and *Implementation* was therefore scored the medium score 3 for each of the alternatives. Alternative 2 needed 4 infrastructure components and was scored the slightly lower score 2, Table 38.

Table 38. Number of infrastructure components for each alternative system and corresponding score for *Implementation*

Technical component	References	Function	Availability	Requirements	Alternative concerned			
					Alt 0	Alt 1	Alt 2	Alt 3
Solar panels	(Unpublished, COSMOL, 2019f)	For generating lights	Bolivia		x	x	x	x
Brush cutter	(Personal Communication, COSMOL, 2019c)	For clearing burial area	Bolivia		x			
Electric pump	(Personal Communication, Suntura, 2019)	For pumping liquid urine	Bolivia	Need to be fitted with hose		x	x	
Vacuum trucks	(Personal Communication, Suntura, 2019)	For transporting liquid urine	Cheaper if shipped from Asia / the US			x	x	
Makenutri 200V	(Personal Communication, Olsson, 2019)	For separating urine	Shipped from Sweden	Need to change some spare parts			x	
Urine dehydrating device	(Personal Communication, Simha, 2019)	For drying urine	Components in Bolivia or Brazil	Construction needed				x
Total infrastructure					**2**	**3**	**4**	**2**
Score					**3**	**3**	**2**	**3**

For the factor *System in operation* alternative 0 required the least number of O&M tasks and was scored with the highest score, while alternative 2 required the most O&M tasks and was scored with the lowest score, see Table 39.

Table 39. Number of operation & maintenance (O&M) tasks and corresponding score for *System in operation* for each alternative system

O&M task	References	Frequency	Frequency rank	Alternative concerned			
				Alt 0	Alt 1	Alt 2	Alt 3
Social visits	Calculations	Daily	Daily/weekly	x	x	x	x
Preparing drying material of lime and sawdust	Assumption	1-2 a week	Daily/weekly	x	x	x	x
Collecting faeces	Calculations	Daily	Daily/weekly	x	x	x	x
Adding lime to burial site	Calculations, 15 containers /day collected	Daily	Daily/weekly	x			
Collecting urine with vacuum tank	Calculations	Daily	Daily/weekly		x	x	
Emptying urine at WWTP with vacuum tank	Calculations	Daily	Daily/weekly		x	x	
Collecting dried urine	Calculations	Daily	Daily/weekly				x
Control of humidity and temperature of faeces/ humus	(Personal Communication, Suntura, 2019)	Twice a week	Daily/weekly		x	x	x
Monitoring of humidity in faeces/ humus by addition of water	(Personal Communication, Suntura, 2019)	Twice a week	Daily/weekly		x	x	x
Taking samples for laboratory analysis	(Personal Communication, COSMOL, 2019f)	1-2 times a year	Yearly	x	x	x	x
Fill Makenutri 200V with ZeoPeat and urine	(Personal Communication, Olsson, 2019)	Daily	Daily/weekly			x	
Operate Makenutri 200V	(Personal Communication, Olsson, 2019)	Daily	Daily/weekly			x	
Mix Gainutri, humus and urea	Calculations, 6 chambers filled every month	1-2 times a week	Daily/weekly			x	
Prepare drying media of lime and sawdust for urine drying	Table F.5	Daily (calculations, >90 boxes needed per day)	Daily/weekly				x
Mix humus and dried urine	Assumption	Once a month	Daily/weekly				x
Summary			Daily/weekly	4	7	10	8
			Yearly	1	1	1	1
Score				**4**	**3**	**2**	**3**

The final score for the technical-organizational capacity for all alternatives corresponded to the majority of scores among the three factors, see Table 40. Alternative 0 gained a higher final score, mainly due to less required O&M tasks for system in operation, while alternative 2 gained a lower score than the other alternatives due to a higher amount of infrastructure needed, see Table 38, 39 and 40.

Table 40. Scores for the three factors evaluating the technical-organizational capacity and and final score for each alternative system

Alternative system	Alt 0	Alt 1	Alt 2	Alt 3
Arena and communication	4	4	4	4
Implementation	3	3	2	3
System in operation	4	3	2	3
Score (majority)	**4**	**3**	**2**	**3**

The *Arena and communication* can potentially be improved in future since the UDDTs since last year are constructed by COSMOL which provides information of the contracts and included collection services and visits (Personal Communication, COSMOL, 2019b). This will likely decrease the number of unsatisfied users, and thereby also decrease the change of UDDTs into water toilets or users resigning from the collection services. However since all the alternative sanitation systems would be equally affected by this potential communication improvement the result does not change considerably.

Similarly to other criteria, the choice of scale for the scoring strongly affected the result. Alternative 3, which was close to the limits between two scores for the *Implementation*, could potentially have been awarded with a final score of 4 instead of 3. On the other hand, a weakness in the evaluation is that the scores only consider the number of O&M tasks and infrastructure and not the actual complexity for each units. An example is the brush cutter for alternative 0 which is a relatively simple implement compared to urine drying device that need to be constructed for alternative 3. This motivates the lower final score for alternative 3. Similarly the vacuum tanks for alternative 1 and 2 and the Makenutri 200V device for alternative 2 are more complex implements than the brush cutter. For *System in operation*, adding lime to the burial site (the only task for only alternative 0) can be assumed as simpler than operating Makenutri 200 V (alternative 2) and collecting the urine with the vacuum tank (alternative 1 and 2). This also motivates alternative 0 as less technically complex than the other three systems and alternative 2 as the most complex.

Worth to be noted is that all four systems with UDDTs, also for this criterion, have relatively small variation in comparison with other sanitation solutions. Compared with a conventional sewage network the infrastructure that needs to be implemented is low, which can be illustrated by the planned WWTP for the wastewater in Montero, with multiple automatic filters (Personal Communication, COSMOL 2019c). When comparing the number of O&M tasks for different sanitation solutions, it is relatively large for these UDDT systems compared to the conventional system where most steps are automatic. At the same time, more maintenance is likely needed for the conventional system, due to potential break downs of the automatic machinery. Lastly, in this analysis the robustness of the systems is not analyzed. Increased prices of fuel and electricity in future and power failures could for example also affect the technical sustainability of the systems.

4.2 SUSTAINABILITY OF ALTERNATIVE SANITATION SYSTEM

Considering the entire sustainability assessment, the system of today for the UDDTs in Montero, alternative 0, was considered more and less sustainable depending on the category. *Alternative 0 has sustainable* capital and O&M costs (score 5), while on the other hand no income was gained from sold fertilizers (score 1), see Table 41. Alternative 0 was also considered sustainable according to the *Technical-Organizational* (score 4) and *Socio-Cultural* category (score 5). The least sustainable categories were *Health* (average score 2), *Resource Use* (average score 3) and *Environment* (score 2) since none of the waste fractions were treated and recycled.

Alternative 1 was more sustainable than alternative 0 from the perspective of the categories *Environment* (score 4) and *Resource Use* (average score 3.5). Alternative 1 scored the lowest score for the category *Financial* (average score 2.5) due to medium sized capital and O&M costs while the value of the produced fertilizers were low. Generally alternative 1 was considered the intermediate system from a sustainable point of view, being awarded with the most number of score 3 and no bottom score 1 nor top score 5.

For alternative 2 the category *Health* was considered more sustainable (average score 4) than alternative 1. The alternative had only a few more potential health risks for workers while the ABP-reductions were completely fulfilled. Also for the *Financial* category, alternative 2 was considered more sustainable (average score 3.5) even though the capital and O&M costs were the highest, due to a much higher value of the produced fertilizer. Alternative 2 was also considered the most sustainable system within the category *Resource Use* (score 4) with a high nutrient recovery and relatively low energy consumption. The nutrient recovery could be increased further if the N water could be used in agriculture. To ensure no risk for infection, storage up to 4 months is recommended. The downside with alternative 2 was the low score for the *Technical-Organizational* category (score 2), resulting from the highest number of required infrastructure as well as O&M tasks. Potentially the financial sustainability would be higher if zeolite and peat could be purchased and mixed locally and the operation with Makenutri optimized in future.

For alternative 3, the category *Health* was the considered most sustainable (average score 4) together with alternative 2, due to fulfilled ABP-reductions while the number of health risks for workers were similar to the other alternatives. Together with alternative 1, alternative 3 was the most sustainable system considering the category *Environment* (average score 4). Considering the category *Resource Use* alternative 3 was scored lower than alternative 2 (average score 3.5), even though the nutrient recovery was higher, because of the high energy consumption from the dehydration device. According to the limited results from the interviewing material, alternative 3 was together with alternative 2 considered having the highest social acceptance among farmers (score 4). If the urine dehydration process could be optimized further after testing the technique locally, or a fan requiring less watt with the same efficiency, could be found, the energy consumption could be decreased to large extents. The system would thus be considered more sustainable regarding *Resource use*.

Table 41. Result table with sustainability rating for each criterion and alternative solution

Category	Criteria	Indicator	Scale	Alternative 0	Alternative 1	Alternative 2	Alternative 3
Health	Health risk: workers	*Likelihood and severity of potential health risks for workers [score] (1)	Risk score [1 – 5] (very high to very low)	3	3	2	3
	Risk of infection from products after treatment	*log reduction for indicator bacteria [log reduction] (2) * log reduction for viable Ascaris eggs [log reduction]] (2)	Risk score [1 – 5] ABP (reduction fulfilled: yes/partly/no)	1	3	5	5
Resource use	Potential of reuse of nutrients	*Amount of N and P recycled [%](2) *Mass of N and P recycled [kg/capita, year] (2)	Score [1 – 5] (nothing - very high)	1	3	4	5
	Energy consumption	*Total energy consumption on site [% of yearly energy consumption at household level] (2) *Total energy consumption off site [% of yearly energy consumption at household level] (2)	Score [1 – 5] (very high - very low)	5	4	4	2
Environmental	Potential environmental risks	*Likelihood and severity of potential environmental risks [score] (1)	Risk score [1 – 5] (very low to very high)	2	4	3	4
Financial	Operation, maintenance and capital costs	*OM costs [USD/capita,year] (2) *Capital cost [USD/capita,year] (2)	Score [1 – 5] (very high - very low)	5	3	2	3
	Economical value of recycled products	*Value of recycled products in comparison with mineral fertilizer [USD/capita,year] (2)	Score [1 – 5] (no value – very high value)	1	2	5	4
Socio-cultural	Social acceptance: farmers	*Farmers attitude towards using treated urine and feces in agriculture [ ] (1)	Score [1 – 5] (very negative - very positive)	-	3	4	4
	Affordability	*Cost for collection service in relation to salary [USD/household,year] (2)	Score [1 – 5] (not affordable to affordable)	5	4	3	4
Technical-organizational	Required technical-organizational capacity	*Complicity of what is needed on organizational level in relation to existing capacity [colours] (1)	Score [1 – 5] (very little – very much required)	4	3	2	3

(1) Qualitative analysis (2) Quantitative analysis

4.3 GENERAL UNCERTAINTIES

Since the choice of scales is not taken from other studies or literature, they contribute to a certain source of error. For some criteria the scale is more narrow than for others, to allow variation in the scores for the alternatives. For the semi-quantitative matrices, data over likelihood and severity of potential risks, could only be found from WHO's Guidelines in a few cases, while the rest were defined by motivations. From this, a possible variation in how strict each risk is evaluated, can exist. If more infrastructure components would have been reviewed for the technical-organizational criterion, such as burial site, chambers and urine storage tanks, the alternatives could potentially have been scored differently.

Generally, local data was lacking and little or no research has been found for the innovative treatment techniques in a climate similar to the one in Montero. This has led to numerous assumptions, especially for the cost calculations. Only for a few items of infrastructure, national prices could be found online, while the access to stores were limited during the last weeks of field work in Bolivia, after the presidential elections. For several criteria, data originates from different sources, since no earlier research, comparing all the techniques in this analysis, exists. An example that shows this is the nutrient recovery, where the data for the stored urine and humus from vermicompost are taken from sampling results in El Alto, with limited data of 2-5 samples per fraction. The nutrient recovery of the other fertilizers are gained from personal communication with researchers of the technologies. This data can potentially be weak due to difficulties in predicting what happens during the treatment in Montero, with a different climate from where the research has been performed before. Another possibility, is that the researchers are biased and estimates a higher recovery rate rather than a lower for their own technique.

The family size in Montero varies considerably between different households. In this analysis the average number was assumed to be the same as an average of the 60 UDDTs under construction, which agreed with the assumption that families with UDDTs are generally bigger than families connected to the sewage network. However, some of the future areas where the UDDTs will be build might be more central areas, with smaller families, which contributes to an additional source of error in the calculated absolute numbers.

4.4 RECOMMENDATIONS

An important study to be done is to evaluate the social acceptance towards using different types of fertilizers from UDDTs among a larger and more diverse group of local farmers, to make sure which of the fertilizers can be sold after treatment. A latter step, is to decide among local stakeholders, the importance of each criterion, to weigh the criteria with relative percentages. From these weights and the result matrix, a final result of the most sustainable alternative sanitation system, can be found. To verify how strict each score is set, there is a need to compare the sustainability with conventional solutions in Montero, such as an expansion of the septic tanks or sewage net and improvement of the WWTP.

Further recommended studies are laboratory tests of the nutrient content and test cultivation, to validate and demonstrate for farmers the value of the produced fertilizers. The vermicompost is recommended to be tested locally, to evaluate if treatment under the higher mean temperature in Montero can inactivate Ascaris sufficiently or decide if urea addition is needed. Since toilet paper is thrown in the toilet in El Alto (Proyecto NODO, 2014), it should be evaluated if the separation of toilet paper from the faeces in Montero, affects the vermicompost process negatively, as indicated in research by (Rieck et al., 2012). If not, the separation is assumed to be positive, decreasing the risk of other waste, such as plastics, entering the toilet with the toilet paper. By checking pH and density of the humus, an appropriate amount of urea, sufficient to inactivate Ascaris, can be added. By controlling the amount of additives in general, the annualized costs can be reduced. A more sustainable alternative to *ZeoPeat*, for example by mixing locally found zeolite and biochar needs to be investigated, as well as the potential demand of the N water in irrigation close to the WWTP, to introduce alternative 2 in large scale after a pilot test. Similarly, an investigation whether larger solar panels with batteries at the UDDT, that also can supply the fans, are worth to invest in, is recommended for alternative 3.

To ensure no risks for infection from the fertilized crops, the humus from vermicompost without urea treatment, should not be used on crops that are to be eaten raw, unless pilot tests can prove sufficient reduction of Ascaris. Since sugar cane is the dominating crop in summer, representing around 90 % of the crops in the farmlands around Montero, these restrictions might not affect the demand on the fertilizer negatively.

5 CONCLUSIONS

In this study, the sustainability of three innovative dry sanitation systems, collecting and treating faeces and urine from the UDDTs in Montero, have been assessed by multiple criteria, in relation to the present system. The first alternative, transferring urine with vacuum truck to a storage during 4 months and treating faeces centrally in a vermicompost, had both strengths and weaknesses compared to the actual sanitation system. At first, it can be considered a more sustainable alternative from a health and environmental perspective without demanding much higher technical-organizational requirements. The annualized costs are also relatively low, but the financial value of the product is lower than for the alternative systems. The vermicompost has not shown sufficient reduction of Ascaris in research studies and as a result the produced humus can only be used with restrictions. Regarding the stored urine, the interviews with farmers indicate a less social acceptance towards a liquid fertilizer.

When instead of storing liquid urine, treating it by ion exchange with ZeoPeat after collection and mixing the product with humus from the vermicompost and urea (alternative 2), the produced fertilizer can be used on any crops without risk of infection. Alternative 2 is thus together with alternative 3 considered the most sustainable alternative from a health perspective and has also a higher total value of the fertilizer. Since the entire product is in solid form, the interviews indicate a higher social acceptance. However, due to a larger number of treatment steps, demanding more infrastructure and O&M tasks, the system is considered less sustainable from the technical-organizational point of view. Similarly, the system has higher annualized costs.

Drying the collected urine immediately in connection to the UDDT and using dried urine to treat humus from vermicompost (alternative 3), demands less technical-organizational requirements and has lower annualized costs than alternative 2. The highest nutrient recovery is achieved from the system and the produced product has indicated a high social acceptance from the interviews. The downside is the high energy consumption from the urine dehydration device, preventing the system from being most sustainable considering the resource use. Except this, the system is among the most environmentally sustainable.

In conclusion, all three innovative systems are more sustainable than the actual system, from a health, resource use and environmental perspective. On the other hand, they require more technical-organizational capacity and have higher annualized costs where fewer people afford the system unless the sanitation costs are subsidized. However, the required subsidies should be related to the existing subsidies of the capital costs for the conventional centralized system in Montero. When producing solid products from urine, a higher value of the fertilizer is achieved, making the system more financially sustainable. To strengthen the result in this analysis, local pilot tests and test cultivation with the produced fertilizers need to be done. Recommended future studies are laboratory tests of the nutrient content, to evaluate the economic value. The vermicompost is recommended to be tested in Montero to validate if the treatment under high mean temperature can inactivate Ascaris sufficiently without urea additions. Another important study is to evaluate the social acceptance towards using different fertilizers from UDDTs among a larger and more diverse group of local farmers to make sure that the produced fertilizers can be sold.

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Appendix A Laboratory result of soil parameters from burial site, Montero

Samples from burial site at Montero Wastewater Treatment Plant after different amount of burial time were analyzed regarding the existence of different pathogens in 2018, see Table A.1.

Table A.1. Laboratory test of samples in burial site, WWTP, Montero, in August 2018 (Quebracho-S.R.L., 2018)

Sample (burial time)	**Humidity (%)**	**pH**	**Temp (°C)**	**Total coliforms (CFU/g WW)**	**Fecal coliforms (CFU/gWW)**	**E Coli (abundance)**	**Protozoan cysts**	**Helminth eggs**	**Larvae (obsev.)**
SU-07 (drying chamber)	5.5	8.31	23.2	5.0E06	2.0E+06	yes	Abundance of E Hystolytica	Few eggs of Ascaris Spp, T Trichura	no observ
SU-06 (1 week)	65.9	8.22	23.0	4.4E+06	4.0E+05	yes	Abundance of E Hystolytica	Few eggs of Ascaris Spp, T Trichura	no observ.
SU-05 (1 month)	66.0	9.54	23.8	4.0E+0.5	2.1E+05	yes	Abundance of E Hystolytica	Few eggs of Ascaris Spp, T Trichura	no observ.
SU-04 (6 month)	32.3	7.54	23.8	2.5E+0.5	1.5E+04	yes	Abundance of E Hystolytica	Few eggs of Ascaris Spp, T Trichura	no observ.
SU-03 (1 year)	42.32	7.46	23.8	6.0E+04	5.0E+03	yes	Abundance of E Hystolytica	Few eggs of Ascaris Spp,	no observ.
SU-02 (2 years)	81.3	8.25	23.3	2.5E+04	<1	no	Abundance of E Hystolytica	no observ.	no observ.
SU-01 (3 years)	66.97	7.41	23.6	2.0E+04 t	<1	no	Abundance of E Hystolytica	no observ.	no observ.

Appendix B Samples and design factors from Foundacion Sumaj Huasi

Laboratory measures from FSH, El Alto, 2010-2011 (Personal Communication, Suntura, 2019), see Table B.1 and B.2 and design values from the vermicompost in El Alto, see Table B.3.

Table B.1. Samples of humus from vermicompost, El Alto 2011 over nitrogen (N), phosphorus (P) and potassium (K)

Parameter	Unit	Sample		Median	weight % in humus
		1	2		
N	weight %	1.2	2.1	1.65	1.65
P	mg/kg	9858	2939	6.4	0.64
K	mg/kg	17242	2389	9.8	0.98

Table B.2. Samples of stored urine, El Alto 2010 over nitrogen (N), phosphorus (P) and potassium (K)

Parameter	Unit	Sample					Median	weight % in urine
		1	2	3	4	5		
N	mg/L	3968	440	4606	4026	3418	3968	0.40
P	mg/L	297	311	303	322	285	303	0.3
K	mg/L	1420	1870	1925	1845	1719	185	0.18

Table B.3. Design values from vermicompost in El Alto operated by Fundation Sumaj Huasi

Properties	Design value	Reference
Dimension double chamber	2 x (2 x 8 x 0.9) = 28.8m^2	Proyecto NODO (2014)
Capacity double chamber	16100 kg	"
Dimension drying chamber	2.2 x 12 x 0.9 = 23.8 m^2	"
Mass reduction after vermicompost	12 %	"
Frequency of stirring in top 20 cm	Every 2-3 week	Personal Communication, Suntura, (2019)
Frequency of water added	3 times a week	"
Water needed	1 m3 every second week	"
Worms needed from start	3 kg/m^3	"
Maximum inorganic salt content	5 mg/g	Silveti et al. (2011)
Maximum ammonia levels	1 mg/g	"

Appendix C Design factors for dehydration boxes for urine drying

Drying capacity: Minimum 20 L urine/day,m^3 at 50 °C (Personal Communication, Simha, 2019)
Urine production: 400-500 L/year,pe (MMAyA, 2010)
Urine produced per household (UDDT) and month: mean(400;500) · 4,5 12 = 168.75 L
Required area for an average household: A= 168.75/(20 · 30) = 0,28 m^2
One box of approximately 50x60 cm^2 with a height of 20 cm is enough for urine drying for up to 4-5 people. 450 L urine/year,pe is an estimate for adults being at home the whole day. Since children have less production and since many family members are away during the day, the dimensions allow for visitors to the house.

10 g lime to dissolve in 1 litre urine (Personal Communication, Simha, 2019).
Lime required per month and UDDT for increasing the pH to prevent ammonia losses: 10 g/L urine · 168.75 L urine = 1687.5 g = 1.69 kg
Total dry media per month and UDDT = 6 kg
Sawdust per month and UDDT = 6 - 1.69 = 4.31 kg

The design data depending on the family size is shown in Table C.1 and C.2. For efficient dehydration the relationship between the solid dry media and the liquid urine should be 1:1 on a daily basis (Personal Communication, Simha, 2019). The average household with 4.5 family members produces 5.5 L urine per day, see Table C.1. 6 kg drying media is therefore sufficient for families with up to 4-5 members. For larger families 2 dehydration boxes with a total of 12 kg drying media is needed, see Table C.2.

Table C.1. Produced urine and required collection frequency depending on the family size

People/UDDT	Urine/day (L)	Urine/month (L)	Emptying times per month (calculations)
1	1.2	38	0.2
2	2.5	75	0.4
3	3.7	113	0.7
4	4.9	150	0.9
4.5	5.5	169	1
5	6.2	188	1.1
6	7.4	225	1.3
7	8.6	263	1.6
8	9.9	300	1.8
9	11.1	338	2.0
10	12.3	375	2.2

Table C.2. Dimension of required amount drying media per month, number of dehydration boxes and interpreted emptying frequency depending on family size

People/UDDT	Drying media [kg]	# of boxes	Fan operation time time [h/day]	Emptying times per month (defined)	Emptying frequency (interpretation)
1	6	1	3	0.25	every fourth month
2-3	6	1	6	0.5	every second month
4-5	**6**	**1**	12	**1**	**every month**
6-7	12	2	12	1.5	every third week
8-10	12	2	12	2	every second week

Small families with 1-3 members use the same type of box and the same amount of dry media as the average families, but need collection less frequent since the urine production is lower. For the households with 6-10 people, needing two connected dehydration boxes, only the first box is collected at a time while the the second one replaces the first and a new box with drying media is connected. This is because the second box only receives the excess urine from the first box. It is important that the collection frequency takes place according to the requirements. If collection occurs too often to little urine has been collected and dried and the nutrient value lower than expected, while if collection occurs too seldom the dehydration device risks to be flooded.

Fan operation time needed for 4-5 people is assumed to 12 hours a day (Personal Communication, Simha, 2019). For families with fewer members less time is needed related to the smaller amount produced urine, see Table C.2. For larger families, 12 hours operation time a day is assumed being sufficient since larger amount urine produced is compensated by the two boxes

Appendix D Workshop about sustainability criteria, Montero 19/09-19

A workshop among stakeholders and other key persons about sustainability criteria for sanitation solutions was led by SEI and UNICEF the 19 of September 2019. During the workshop the involved were split up in four mixed groups where they went through four steps:

1. Individual brainstorming of the 8-10 most important criteria for sanitation systems.
2. Reviewing the proposed criteria in the small groups and connect similar criteria with each other.
3. Add 0-3 stickers (dots) individually according to the importance of each criteria, where 3 dots indicates *very important*. Several criteria could get the same amount of dots from one group.
4. Summarize in each group which top 5 criteria got the highest total score.

The top three criteria from the result was compiled in *Excel* together with the relative importance in % within the group, see Table D.1.

Table D.1. Top three prioritized sustainability criteria for sanitation system in Montero among stakeholders. The different colours indicate the four different discussion groups

Group 1	Total dots:	205		
Category	**Criterios**	**Dots**	**% of dots**	**Rating**
	Contamination the water sourses	**14**	**6,8**	**1**
Environment	**Capacity of recicle nutrients**	**12**	**5,9**	**3**
Economical	**Arrange a fair rate**	**13**	**6,3**	**2**
Group 2	Total dots:	148		
Category	**Criterios**	**Dots**	**% of dots**	**Rating**
Environment	**Protection of hydraulic resourses**	**14**	**9,5**	**3**
Tecnical-Institutional	**Coopertive with urban municipal plan**	**15**	**10,1**	**2**
Economical	**Economical sustainability of the services**	**18**	**12,2**	**1**
Group 3	Total dots:	143		
Category	**Criterios**	**Dots**	**% of dots**	**Rating**
Health	**Reduce disease and mortality for children and infantils**	**16**	**11,2**	**1**
Socio-cultural	**Social acceptance of systems**	**12**	**8,4**	**3**
Economical	**Financially sustainable**	**13**	**9,1**	**2**
Group 4	Total dots:	79		
Category	**Criterios**	**Dots**	**% of dots**	**Rating**
Socio-cultural	**Need to change habits**	**10**	**12,7**	**1**
Tecnical-Institutional	**Complexity in organization**	**9**	**11,4**	**3**
Economical	**Operation and maintainence cost**	**9**	**11,4**	**2**

Appendix E Comparison between Bolivian and Swedish nutrient design values

Calculations of feces produced per person and year in Bolivia:

Table E.1. Indata to calculations (Bolivian data)

Information	Value	Source
Feces incl. dry material [g/cap,yr.]	170	MMAyA (2010), data from FSH
Density feces [kg/m^3]	700-1040	MMAyA (2010)
Density sawdust [kg/m^3]	210	https://www.simetric.co.uk/si_materials.htm, https://www.aqua-calc.com/calculate/volume-to-weight/substance/sawdust
Feces in FSH tanques [%]	55	Silveti et al. (2011)
Dry material in FSH tanques [%]	45	Silveti et al. (2011)
Mass toilet paper [kg/cap,yr.]	8.9	Vinnerås et al. (2006)
Volume urine [L/cap,yr.]	400-500	MMAyA (2010)

Total mass for feces incl dry material: 170 g/cap,day $\cdot$ 0.001 kg/g $\cdot$ 365 day/yr = 62.05 kg/cap,yr.
Average density feces: $\frac{700+1040}{2}$=870 kg/m^3
Percentage of toilet paper: $\frac{8.9kg/cap,yr}{62.05}$ $\cdot$ 100 = 14.34 %
Percentage of sawdust: 45 % - 14.34 % = 30.66 %

m = mass, V = volume, ρ = density
$m_{feces}=V_{feces} \cdot \rho_{feces}$ = 0.55V $\cdot$ 870 kg/cap,yr. = 478.5V kg/cap,yr.
$m_{sawdust}=V_{sawdust} \cdot \rho_{sawdust}$ = 0.3066V $\cdot$ 210 kg/cap,yr. = 64.38 V kg/cap,yr.
$m_{toilet.paper}$=8.9 kg/cap,yr.
$m_{total} = m_{feces} + m_{sawdust} + m_{toilet.paper}$
62.05 = 478.5V + 64.38V + 8.9 (kg/cap,yr.)
62.05 - 8.9 = (478.5 + 64.38)V
53.15 = 542.9V
V=$\frac{53.15kg/cap,yr.}{542.9kg/m^3}$=0.10 m^3/cap,yr.
m_{feces}=478.5 $\cdot$ 0.10 = 47.85 kg/cap,yr.

For minimum density in interval (700 kg/m^3): $m_{feces.max}$ = 45.54 kg/cap,yr.
For maximum density in interval (1040 kg/m^3): $m_{feces.min}$ = 47.77 kg/cap,yr.

Design data of feces produced per person and year in Sweden:
m_{feces} = 51 kg/cap,yr.
V_{urine} = 290 - 550 L/cap,yr

Table E.2. Total protein and vegetable protein from FAO data from different countries

Country	Tot protein	Veg protein	Veg protein (%)	Source
Sweden (1992)	98	34	35	Jönsson & Vinnerås (2004)
China (2000)	86	56	65	Jönsson & Vinnerås (2004)
Uganda (2000)	55	45	82	Jönsson & Vinnerås (2004)
Bolivia (2013)	66	36	55	FAO (2013)

Appendix F Assumptions and design factors for cost calculations

Table F.1. General assumptions

Average 4.5 people per household/UDDT	Average of 50 UDDT under construction in Montero. UDDT assumed to be located in poorer area with bigger families than average (INE (2015), 2012 average: 4,1 people/household)
Collection frequency of faeces: every 3 month	Actual demand of services in Montero (Unpublished, COSMOL 2019b)
One driver and one co-worker needed for each collection	Actual requirement for collection (Unpublished, COSMOL 2019a)
Time at each household for collection: 15 min including social visit	Assumption
Average distance COSMOL-UDDT: 4.5 km	Average of distances of the neighbourhood with existing UDDTs and UDDTs under construction (see map in Figure 1) calculated with Google Earth
Average distance COSMOL-WWTP: 5.4 km	
Average distance UDDT-WWTP: 6.4 km	
Average distance between UDDTs during visits/collection: 2 km	
Routes to WTTP per day after collection: 2	Assume one route before lunch and one after
Mean speed truck: 30km/h	Average of 20 km/h at smaller roads between UDDT, 40 km/h between COSMOL and WWTP (Unpublished, COSMOL. R.L., 2019c)
Working time per week: 40 hours	8 hours every day, 5 working days
Gas consumption gasoline truck: 9 km/L	8-10 km/L depending on age (Unpublished, COSMOL. R.L., 2019c)
Gas consumption diesel truck: 7 km/L	Specific for dumping truck
Gas cost: Bs 3.74/L for gasoline, Bs 3.72/L for diesel	https://www.globalpetrolprices.com/ (2019-01-11)
1 Bs = 0.145 USD , 1 SEK = 0,103 USD	(XE, 2199) (October 2019)
Salary: Bs 3424/month for driver/treatment worker /social worker, Bs 3188/month for co-worker, Bs 3059/month for cleaner	COSMOL, plan from 2015
Energy consumption gas: 34.5MJ/L for gasoline, 38.3 MJ/L for diesel	https://www.iangv.org/natural-gas-vehicles/natural-gas/ (2019-01-11)
Produced faeces per year and person: 51 kg	Swedish data from Jönsson & Vinnerås (2004). Calculations from Bolivian data MMAyA (2010) gives similar results
Produced urine per year and person: 450 L	Average from Bolivian data MMAyA (2010)
Cost for electricity: Bs 0.77/kWh	Electricity fee for Santa Cruz department (EJU, 2019)

Table F.2. Assumptions and references for alternative 0

#	Item	References and assumptions	#	Item	References and assumptions
1	UDDT	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e)	15	Painting/ structure maintenance UDDT	General cost from World.Bank.Group (n.d.)
2	Small truck	(Unpublished, COSMOL, 2019f). Lifespan 5 years since used trucks purchased generally (Personal Communication, COSMOL, 2019c). Assumption: 2 times to WWTP/day. Average 4000 containers/year. Max time burial and preparation of drying material per visit to WWTP: 1h 15 min. Average driving distance per collection: 18 km. Up to 10 containers/collection. See Equation 21	16	Drying material	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: 15 kg per 3 month (60kg tank). 30 % needs one bag more per collection. See Equation 35
3	Motorbike (social visits)	(Proyecto NODO, 2014). Assumption: Driving distance per day for visits: 22 km. 4 for social visits, 2 for tidying. 7.5 min at each UDDT. 10 min to leave COSMOL. 50 social visits per day and personal. See Equations 22, 23, 24 and 25	17	Selling extra drying material	5 Bs/bag (Unpublished, COSMOL, 2019f) Assumption: 30 % of households need to buy more drying material every 3rd month See Equation 20
4	Clothes/ safety protection	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overalls, 1 raincoat, 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask, 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. Calculation: 89% of working hours (needing safety protection) is transport, see Equation 26 - 32.	18	Personal costs transport	Calculation: 92 % of personal hours is for transport, see Equation 37 and 38
5	Burial area	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: 50 % extra area between holes. 600 m2 needed for burial during 2 years, see Equation 34. Double area for extra drying	19	Fuel truck	Assumption: Collection twice/day, 5 days a week, 52 weeks a year. Using gasoline See Equation 40
6	Disinfection area	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: one is enough since it is outside	20	Fuel motorbikes	Assumption: 6 motorbikes. Driving 5 days a week, 52 weeks a year. Using gasoline See Equation 41
7	Improvement lab	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f). Half the capacity used for storing drying material for <100 UDDT (Unpublished, COSMOL 2019c). Assumption: 80 % of cost when building bigger. 2 units needed for 1000 UDDTs	21	Maintenance truck	(Personal Communication, COSMOL, 2019c)
8	Solar panel	COSMOL's cost calculations from 2015 (Unpublished, COSMOL,2019f) Assumption: same amount as improvement labs	22	Maintenance motorbikes	(Unpublished, COSMOL R. L. 2019c) Assumption: 6 motorbikes. 25 % less maintenance than for truck per motorbike
9	Toilet	COSMOL's cost calculations for UDDT from 2019 (Unpublished, COSMOL, 2019e) Assumption: 2 needed since more staff working regularly with 1000 UDDTs	23	Disinfection containers and trucks	(Unpublished, COSMOL, 2019f) Assumption: 10 times more UDDTs but same amount of trucks, assume 5 times more
10	Access door	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f)	24	Disinfection clothes	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one full time worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 83% disinfection for transport See Equation 43 and 44
11	Brush cutter	To clean burial area from plants 1-2 a year (Personal Communication, COSMOL, 2019c)	25	Containers for faeces	(Unpublished, COSMOL, 2019f) Assumption: 10 % new containers every year
12	Drying chambers	To dry the faeces that are more wet than normal before burial. Only 25-50% of capacity used today (Personal Communication, COSMOL, 2019g). Assumption: 6 needed for 1000 UDDTs	26	Personal costs treatment	Calculation: 8 % of personal hours is for treatment, see Equation 37 and 39
13	Clothes/ safety protection	(Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overalls, 1 raincoat 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask , 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. Calculation: 11% of working hours (needing safety protection) is treatment, see Equation 26 - 33	27	Fuel for cutting machine	Assumption: Average 1.3 L fuel per year for cutting 1-2 a year
14	Value products	No recyclable products produced	28	Lime for burial	Assumption: 20 containers per hole. 2 kg between every container. 12 kg for floor and walls of hole. See Equation 46
			29	Changing fences and painting	Assumed 50% of investment cost for burial area every 3 year

			30	Disinfection clothes treatment	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, Bs5/L, one full time worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 83% disinfection for treatment See Equation 43 and 45
			31	Burial material to landfill	96.97 Bs/m3 (CYPE ingenieros n.d., Tasa de disposición final por entrega de mezcla sin clasificar de residuos inertes.) Assumption: faeces need to be transported to landfill after 2 years when most of pathogens have been inactivated. 20 containers/hole. 4000 containers per year. See Equation 47
			32	Transport burial material	Assumption: 5 km (Anesapa, 2010) from WWTP. Capacity truck: 2 m^3. 8 m^3/week transported, see Equation 48 and 49.
			33	General equipment	(Unpublished, COSMOL, 2019f) Assumption spade, hose, measuring tape etc
			34	Soil quality test	(Unpublished, COSMOL, 2019f) Once a year
			35	Value products	No recyclable products produced

Income for sold extra drying material:

$$bags_{sold} \cdot cost_{bag} \tag{20}$$

Trucks needed for collection of faeces:

$$containers.day = \frac{containers.year}{weeks.per.year \cdot working.days} \tag{21}$$

motorbikes needed for weekly social visits for alternative 0:

$$social.visits.per.day = \frac{(weeks.per.year - collection.per.year.and.UDDT) \cdot amount.of.UDDTs}{weeks.per.year \cdot working.days} \tag{22}$$

$$\begin{gathered} time_{UDDTs.per.staff} = time_{at.UDDT} + time_{driving} = \\ time_{per.UDDT} \cdot visits_{per.staff} + \frac{distance}{driving.speed} + 2 \cdot time_{leaving.COSMOL} \end{gathered} \tag{23}$$

$$motorbikes_{social.visits} = staff_{social.visits} = round.up(\frac{social.visits_{day}}{visits_{per.staff}}) \tag{24}$$

motorbikes needed for tidying every second week:

$$motorbikes_{tidying} = staff_{tidying} = \frac{staff_{social.visits}}{2} \tag{25}$$

Cost working clothes for alternative 0:

$$cost_{clothes.per.staff} \cdot (staff_{faeces} + staff_{tidying} + 0.5 \cdot staff_{social.visits}) \tag{26}$$

Percentage of working clothes for transports for alternative 0 (assuming that the percentage of time workers together put on transport is the relative cost of working clothes related to transport):

$$time_{collection} = containers.day \cdot time_{UDDT} \tag{27}$$

$$time_{driving} = distance_{COSMOL.UDDT.WTTP.COSMOL} \cdot speed_{average} \tag{28}$$

$$time_{faeces} = time_{collection} + time_{driving} + visits.WTTP.per.day \cdot time_{WWTP.per.visit} \tag{29}$$

$$time_{driving.motorbike} = routes.per.day \cdot distance_{COSMOL.UDDT.COSMOL} \cdot speed_{average} + time_{leaving} \tag{30}$$

$$time_{tidying} = time_{social.visits} = time_{driving.motorbike} + time_{per.UDDT} + visits.per.day \tag{31}$$

$$working.clothes_{transport} = \frac{staff_{faeces} \cdot (time_{collection} + time_{driving}) + staff_{tidying} \cdot time_{tidying} + 0.5 \cdot staff_{social.visits} \cdot time_{social})}{staff_{faeces} \cdot time_{faeces} + staff_{tidying} \cdot time_{tidying} + 0.5 \cdot staff_{social.visits} \cdot time_{social})} \tag{32}$$

Percentage of working clothes for treatment:

$$working.clothes_{treatment} = 100 - working.clothes_{transport} \tag{33}$$

The rest of working clothes needed for treatment services.
Area needed for holes in burial area:

$$area_{burial} = \frac{time_{burial} \cdot containers_{year}}{containers_{per.hole} \cdot (area_{hole} + area_{between.holes})} \tag{34}$$

Amount of drying material needed

$$bags_{per.year} \cdot weight_{bag} \cdot UDDTs \tag{35}$$

Costs for staff for alternative 0

$$cost_{staff0} = cost_{staff.faeces} + cost_{staff.social} + cost_{staff.tidying} \tag{36}$$

Cost staff for transport for alternative 0:

$$staff_{transport} \frac{staff_{faeces} \cdot (time_{collection} + time_{driving}) + staff_{tidying} \cdot time_{tidying} + \cdot staff_{social.visits} \cdot time_{social})}{staff_{faeces} \cdot time_{faeces} + staff_{tidying} \cdot time_{tidying} + \cdot staff_{social.visits} \cdot time_{social})} \tag{37}$$

$$cost_{staff.transport0} = cost_{staff} \cdot staff_{transport} \tag{38}$$

Cost staff for treatment for alternative 0:

$$cost_{staff.treatment0} = cost_{staff} \cdot staff_{treatment} \tag{39}$$

Fuel cost for truck:

$$cost_{fuel.per.year.truck} = fuel_{truck} \cdot cost_{gasoline} = \frac{distance_{driving}}{fuel_{consumption}} \cdot cost_{gasoline} \tag{40}$$

Fuel cost for motorbike for alternative 0:

$$cost_{fuel.per.year.motorbike} = fuel_{motorbike0} \cdot cost_{gasoline} = \frac{distance_{driving0}}{fuel_{consumption}} \cdot cost_{gasoline} \tag{41}$$

Cost for disinfection of clothes for alternative 0:

$$cost_{per.worker} = volume_{per.worker} \cdot cost_{per.L} \cdot (staff_{faeces} + staff_{tidying}) \tag{42}$$

Cost disinfection clothes during transport for alternative 0:

$$disinfection_{transport0} = \frac{staff_{faeces} \cdot (time_{collection} + time_{driving}) + staff_{tidying} \cdot time_{tidying}}{staff_{faeces} \cdot time_{faeces} + staff_{tidying} \cdot time_{tidying}} \tag{43}$$

$$cost_{disinfection.transport0} = cost_{per.worker} \cdot disinfection_{transport0} \tag{44}$$

Cost disinfection clothes during treatment for alternative 0:

$$cost_{disinfection.treatment0} = cost_{perworker} \cdot (1 - disinfection_{transport0}) \tag{45}$$

Cost for lime for burial:

$$cost_{lime} = containers_{faeces} \cdot lime_{per.container} + \frac{containers_{faeces} \cdot lime_{per.hole}}{containers_{hole}} \tag{46}$$

Cost burial material to landfill:

$$cost_{landfill} = volume_{faeces} \cdot cost_{per.m^3} = \frac{containers_{faeces}}{containers_{per.hole}} \cdot volume_{hole} \cdot cost_{per.m^3} \tag{47}$$

Cost for transporting burial material to landfill:

$$cost_{driving.landfill} = \frac{2 \cdot distance_{landfill} \cdot \frac{volume_{faeces.year}}{capacity_{truck.m3}}}{fuel_{consumption}} \cdot cost_{fuel} \tag{48}$$

$$transports_{landfills} = \frac{\frac{volume_{faeces.year}}{weeks.per.year}}{capacity_{truck}} \tag{49}$$

No extra trucks nor staff assumed to be needed needed.

Table F.3. Assumptions and references for alt 1

#	Item	References and assumptions	#	Item	References and assumptions
1	UDDT	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e)	20	Painting/ structure maintenance UDDT	General cost from World.Bank.Group (n.d.)
2	Urine collection tanks	Tanks 200-300L from Tank-burg, locally purchased in Bolivia	21	Drying material	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f), Assumption: 15 kg per 3 month (60kg container). 30 % needs one bag more per collection.See equation 35
3	Small truck	(Unpublished, COSMOL, 2019f). Lifespan 5 years since used trucks purchased generally (Unpublished, COSMOL, 2019c). Assumption: 2 times to WWTP/day. Average 4000 containers/year. Max time burial and preparation of drying material per visit to WWTP: 1h 15 min. Average driving distance per collection: 18 km. Up to 10 containers/collection. See Equation 21	22	Selling extra drying material	5 Bs/bag (Unpublished, COSMOL, 2019f) Assumption: 30 % of households need to buy more drying material every 3rd month See Equation 20
4	Vacuum truck	(Personal Communication, Suntura, 2019). Lifespan 5 years since used trucks purchased generally (Unpublished, COSMOL, 2019c). Assumption: 5 vacuum trucks. 2 times to WWTP on 3 working day Average driving distance per truck and day: 30 km. Time at each UDDT: 20 min, emptying at WWTP per visit: 0.5h. Visit to WWTP after 26 UDDTs. Emptying at UDDT every second week See Equations 50, 51, 52, 53 and 54	23	Personal costs transport	Calculation: 72% of personal hours is for transports, see Equation 66, 69 and 70
5	motorbike (social visits)	(Proyecto NODO, 2014). Assumption: Driving distance per day for visits: 22 km. 2 for social visits, 2 for tidying. See Equation 55, 56 and 25	24	Fuel truck	Assumption: Collection twice/day, 5 days a week, 52 weeks a year. Using gasoline See equation 40
6	Clothes/ safety protection	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overalls, 1 raincoat, 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask, 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. Calculation: 71% working hours (needing safety protection) is transport, see Equation 57, 58 and 59	25	Fuel vacuum truck	Assumption: 5 vacuum trucks. Driving 5 days a week, 52 weeks a year. Using gasoline See Equation 72 and 73
7	Disinfection area	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: One is enough since it is outside	26	Fuel motorbikes	Assumption: 4 motorbikes. Driving 5 days a week, 52 weeks a year. Using gasoline See Equation 74
8	Improvement lab	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f). Half the capacity used for storing drying material for <100 UDDT (Unpublished, COSMOL 2019c). Assumption: 80% of cost when building bigger. 2 units for 1000 UDDT +1 extra for storing humus.	27	Maintenance trucks	(Unpublished, COSMOL R. L. 2019c)
9	Solar panel	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: same amount as improvement labs	28	Maintenance motorbikes	(Unpublished, COSMOL R. L. 2019c) Assumption: 4 motorbikes. 25 % less maintenance than for truck per motorbike
10	Toilet	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e) Assumption: 2 needed since more staff working regularly with 1000 UDDTs	29	Fuel vacuum pump	Consumption 6 L/h (Kennedy-Walker, R, 2015) Assumptions: 0.5 min pumping per UDDT, 8 min pumping per visit to WWTP.(suction at 10m3/h and discharging at 25 m3/h common. Visit to WWTP after 26 UDDTs. Emptying at UDDT every second week. See Equation 76 and 77
11	Access door	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f)	30	Disinfection containers and trucks	(Unpublished, COSMOL, 2019f) Assumption: 10 times more UDDTs, 6 more trucks, assume 8 times more disinfection needed
12	Vermicompost chambers	Volume chamber: 28.8m3, 559 kg faeces + drying material per m3 in FSH (Proyecto NODO, 2014). 14 chambers needed in Montero, see Equation 63	31	Disinfection clothes transports	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one fulltime worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 69% disinfection for transport See Equation 78, 79 and 80
13	Drying chamber	To dry humus after vermicompost, 23.8 m3, (Proyecto NODO, 2014). Density humus: 720 kg/m3 (Yadav et al., 2010) 1 is enough to dry and store humus for up to 5 month See Equation 64 .	32	Containers for faeces	(Unpublished, COSMOL,. 2019f) Assumption: 10 % new containers every year
14	Wheel barrow	Price on local market in Montero. Assumption: 4 needed.	33	Personal costs treatment	Calculation: 28% of personal hours is for transports, See Equation 66 and 71
15	Electric pump	For emptying and transferring stored urine (Personal Communication, Suntura, 2019)	34	Electricity for pump	50 m3/h, 4kW (Bominox, 2014). See Equation 82
16	Hose for pump	Price on local market for 100m long hose + tap	35	Worms	3kg/m2. Area chamber: 32m2. Bs350/kg worms (Personal Communication, Suntura, 2019) See Equation 83

17	Urine storage tank	Tanks 5000 L from Tank-burg, locally purchased in Bolivia, see Equation 65	36	Water for vermicompost	1m3/chamber and 2 weeks needed. 1m3 per chamber and 9 month can be reused in a new chamber (Personal Communication, Suntura, 2019) No cost for water from well for COSMOL (Personal Communication, COSMOL, 2019c)
18	Clothes/ safety protection	(Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overalls, 1 raincoat, 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask , 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. Calculation: 29% of working hours hours (needing safety protection) is treatment See Equation 57 - 61	37	Fertilizer bags	50kg fertilizer per bag. Bs 3-4 per new bag (Personal Communication, CIAT, 2019a)
19	Value of product	Production of humus from vermicompost Calculations, see Equations 10 - 11, Table 5 and 30	38	Maintenance treatment area	(Unpublished, COSMOL, 2019f) Assumption: same treatment costs of WWTP as for Alternativ 0
			39	Disinfection clothes treatment	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one fulltime worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 31 % disinfection for treatment See Equation 78 and 81
			40	General equipment	(Unpublished, COSMOL, 2019f)
			41	Soil quality test	(Unpublished, COSMOL, 2019f)

Vacuum trucks needed for collection of liquid urine:

$$tanks_{before.WWTP} = \frac{capacity_{truck}}{urine_{two.weeks}} = \frac{capacity_{truck}}{\frac{urine_{per.year.cap}}{2weeks.per.year} \cdot cap.per.tank} \tag{50}$$

$$tanks_{per.4h} = \frac{(4 - time_{driving})}{time_{at.UDDT}} = \frac{4 - \frac{2 \cdot distance_{COSMOL.UDDT} + distance_{between.UDDTs}}{speed}}{time_{at.UDDT}} \tag{51}$$

$$tanks_{per.4h.incl.WTTP} = \frac{(4 - (time_{driving} + time_{driving.emptying.atWWTP})}{time_{at.UDDT}} = \frac{4 - (\frac{2 \cdot distance_{COSMOL.UDDT} + distance_{between.UDDTs}}{speed} + \frac{2 \cdot distance_{UDDT.WWTP}}{speed_{to.WWTP}} + time_{emptying})}{time_{at.UDDT}} \tag{52}$$

–>11 tanks/4 h, 8 tanks/4 h when visit to WTTP. Emptying frequency every third 4-hour shift (half day). Empty after half of the third shift (11+11+4=26 tanks) and collect 4 tanks after emptying at WWTP.

$$tanks_{week.and.truck} = days_{work} \cdot shift_{per.day} \cdot (\frac{2}{3} \cdot tanks_{shift} + \frac{1}{3} \cdot tanks_{shift.incl.WWTP}) = 5days/week \cdot 2shifts/day \cdot (\frac{2}{3} \cdot 11 + \frac{1}{3} \cdot 8) = 101tanks/week \tag{53}$$

$$collection_{tanks.per.week} = \frac{UDDTs}{weeks} = \frac{1000}{2} = 500 \tag{54}$$

5 trucks collecting >100 tanks per week is enough to collect a total of 500 tanks a week.

Motorbikes needed for weekly social visits beyond social visits during collection of liquid urine:

$$social.visits.per.day = \frac{weeks.per.year - collection_{urine.year.UDDT} - collection_{faeces.year.UDDT} \cdot amount.of.UDDTs}{weeks.per.year \cdot working.days} \tag{55}$$

$$motorbikes_{social.visits} = staff_{social.visits} = round.up(\frac{social.visits_{day}}{visits_{per.staff}}) \tag{56}$$

Cost working clothes for alternative 1:

$$cost_{clothes.per.staff} \cdot (staff_{faeces} + staff_{tidying} + 0.5 \cdot staff_{social.visits} + staff_{urine} + staff_{vermicompost}) \tag{57}$$

Percentage of working clothes for transports for alternative 1:

$$working.clothes_{transport} \frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot t_{tid} + 0.5 \cdot staff_{s.v} \cdot t_{s.v} + staff_u \cdot (t_e + t_d)}{staff_f \cdot t_f + staff_{tid} \cdot t_{tid} + 0.5 \cdot staff_{s.v} \cdot t_{s.v} + staff_u \cdot (t_e + t_d) + staff_v \cdot t_v} \tag{58}$$

, where f = faeces, t_c = time$_{collection}$, t_d = t$_{driving}$, tid = tidying, $s.v$ = social visits, u = urine, t_e

= time$_{emptying}$ and v = vermicompost
Cost working clothes for treatment for alternative 1:

$$cost_{clothes.per.staff} \cdot working.clothes_{transport} \tag{59}$$

Cost working clothes for treatment for alternative 1:

$$working.clothes_{treatment} = 100 - working.clothes_{transport} \tag{60}$$

$$cost_{clothes.per.staff} \cdot working.clothes_{treatment} \tag{61}$$

Vermicompost chambers needed:

$$mass_{faeces.9month} = faeces_{per.capita.year} \cdot cap.per.UDDT \cdot UDDTs \cdot \frac{9}{12} \tag{62}$$

$$amount_{chambers} = \frac{capacity_{needed}}{volume_{chamber}} = \frac{\frac{mass_{faeces.9month} + mass_{drying.material.9month}}{compaction.rate}}{volume_{chamber}} \tag{63}$$

Drying chambers needed for humus for alternative 1:

$$time_{drying.max} = \frac{volume_{chamber} \cdot month/year}{volume_{humus}} = \frac{volume_{chamber} \cdot month/year}{\frac{(mass_{faeces9month} + mass_{drying.material.9month} \cdot \frac{12}{9}) \cdot mass_{reduction}}{density_{humus}}} \tag{64}$$

–>One drying chamber has the capacity to dry the humus produced during one year can be dried up to 5 month. 1 month is sufficient according to FSH in El Alto.

Urine storage tanks needed at WWTP:

$$tanks_{urine.storage} = \frac{volume_{urine.person.year} \cdot time_{storage} \cdot cap.per.UDDT \cdot UDDTs}{capacity.tanks} \tag{65}$$

Costs for staff for alternative 1

$$cost_{staff} = cost_{staff.faeces} + cost_{staff.social} + cost_{staff.tidying} + cost_{staff.urine} + cost_{staff.vermicompost} \tag{66}$$

Cost staff for transport for alternative 1:

$$time_{driving.urine} = 2 \cdot (\frac{2 \cdot distance_{COSMOL.UDDT} + distance_{between.UDDTs}}{speed_{driving}} + \frac{1}{3} \cdot \frac{2 \cdot distance_{UDDT.WWTP}}{speed_{driving.WTTP}}) \tag{67}$$

$$time_{emptying} = time_{suction} + \frac{1}{3} \cdot time_{WTTP} = 2 \cdot (\frac{2}{3} \cdot 11 \cdot time_{UDDT} + \frac{1}{3}(\cdot 8 \cdot time_{UDDT} + time_{WWTP})) \tag{68}$$

$$\frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot t_{tid} + \cdot staff_{s.v} \cdot t_{s.v} + staff_u \cdot (t_e + t_d)}{staff_f \cdot t_f + staff_{tid} \cdot t_{tid} + \cdot staff_{s.v} \cdot t_{s.v} + staff_u \cdot (t_e + t_{d.u}) + staff_v \cdot t_v} \tag{69}$$

, where f = faeces, t_c = time$_{collection}$, $t_d.u$ = t$_{driving.urine}$, tid = tidying, $s.v$ = social visits, u = urine, t_e = time$_{emptying}$ and v = vermicompost

$$cost_{staff.transport} = cost_{staff} \cdot staff_{transport} \tag{70}$$

Cost staff for treatment for alternative 1:

$$cost_{staff.transport} = cost_{staff} \cdot staff_{treatment} \tag{71}$$

Fuel cost for vacuum truck:

$$distance_{driving.total} = 2 \cdot (2\dot{d}istance_{UDDT.WWTP} + distance_{between.UDDT}) + \frac{1}{3} \cdot 2 \cdot distance_{UDDT.WWTP} \cdot trucks \cdot workingdays \cdot weeks \tag{72}$$

$$cost_{fuel.per.year} = fuel_{driving.truck} \cdot cost_{gasoline} = \frac{distance_{driving.total}}{fuel_{consumption.truck}} \cdot cost_{gasoline} \tag{73}$$

Fuel cost for 4 motorbike:

$$cost_{fuel.per.year} = 4 \cdot fuel_{motorbike} \cdot cost_{gasoline} = 4 \cdot \frac{distance_{COSMOL.UDDT.COSMOL}}{fuel_{consumption.motorbike}} \cdot cost_{gasoline} \tag{74}$$

Fuel cost for vacuum pump:

$$amount_{visit.WWTP.per.year} = collections_{per.year.UDDT} \cdot \frac{UDDTs}{tanks.per.visit.WWTP} \tag{75}$$

$$time_{pumping} = collections_{per.year.UDDT} \cdot UDDTs \cdot time_{pumping.UDDT} + amount_{visit.WWTP.per.year} \cdot time_{pumping.WWTP} \tag{76}$$

$$cost_{fuel.vacuum.pump} = fuel_{year} \cdot cost_{fuel} = fuel_{consumption} \cdot time_{pumping} \cdot cost_{fuel} \tag{77}$$

Cost for disinfection of clothes for alternative 1:

$$cost_{per.worker} \cdot (staff_{faeces} + staff_{tidying} + staff_{urine} + staff_{vermicompost}) \tag{78}$$

Cost disinfection clothes during transport for alternative 1:

$$disinfection_{transport1} = \frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot t_{tid} + staff_u \cdot (t_e + t_d)}{staff_f \cdot t_f + staff_{tid} \cdot t_{tid} + staff_u \cdot (t_e + t_d) + staff_v \cdot t_v} \tag{79}$$

, where f = faeces, t_c = time$_{collection}$, t_d = t$_{driving}$, tid = tidying, $s.v$ = social visits, u = urine, t_e = time$_{emptying}$ and v = vermicompost

$$cost_{disinfection.transport1} = cost_{disinfection1} \cdot disinfection_{transport1} \tag{80}$$

Cost disinfection clothes during treatment for alternative 1:

$$cost_{disinfection.treatment1} = cost_{disinfection1} \cdot (1 - disinfection_{transport1}) \tag{81}$$

Cost for electricity for pump for liquid urine for alternative 1:

$$cost_{electricity.pump1} = electricity_{per.year1} \cdot cost_{electricity} = \frac{volume_{urine}}{speed_{pumping}} \cdot consumption_{pump} \cdot cost_{electricity} \tag{82}$$

Cost for worms:

$$cost_{worms.total} = mass_{worms.per.area} \cdot area_{chamber} \cdot chambers \cdot cost_{worms.mass} \tag{83}$$

Fertilizer bags for alternative 1 per year:

$$mass_{fertilizer1} = mass_{humus} = reduction.rate \cdot (mass_{faeces} + mass_{drying.material}) \tag{84}$$

$$cost_{fertilizer.bags1} = bags_{amount1} \cdot cost_{mean.bag} = \frac{mass_{fertilizer1}}{mass_{bag}} \cdot cost_{mean.bag} \tag{85}$$

Table F.4. Assumptions and references for alternative 2

#	Item	References and assumptions	#	Item	References and assumptions
1	UDDT	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e)	22	Painting/ structure maintenance UDDT	General cost from World.Bank.Group (n.d.)
2	Urine collection tanks	Tanks 200-300L from Tank-burg, locally purchased in Bolivia	23	Drying material	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: 15 kg per 3 month (60kg container) See Equation 35
3	Small truck	(Unpublished, COSMOL, 2019f). Lifespan 5 years since used trucks purchased generally (Personal Communication, COSMOL, 2019c). Assumption: 2 times to WWTP/day. Average 4000 container/year. Max time burial and preparation of drying material per visit to WWTP: 1h 15 min. Average driving distance per collection: 18 km. Up to 10 containers/collection. See Equation 21	24	Selling extra drying material	(Unpublished, COSMOL, 2019f) Assumption: 30 % of households need to buy more drying material every 3rd month, see Equation 20
4	Vacuum truck	(Personal Communication, Suntura, 2019). Lifespan 5 years since used trucks purchased generally (Unpublished, COSMOL, 2019c). Assumption: 5 vacuum trucks. 2 times to WWTP on 3 working day Average driving distance per truck and day: 30 km. Time at each UDDT: 20 min, emptying at WWTP per visit: 0.5h. Visit to WWTP after 26 UDDTs. Emptying at UDDT every second week See Equations 50, 51, 52, 53 and 54	25	Personal costs transport	Calculation: 57% of personal hours is for transports, see Equation 98, 96 and 97
5	Motorbike (social visits)	(Proyecto NODO, 2014). Assumption: Driving distance per day for visits: 22 km. 2 for social visits, 2 for tidying. See Equation 55, 56 and 25	26	Fuel truck	Assumption: Collection twice/day, 5 days a week, 52 weeks a year. Using gasoline See Equation 40
6	Clothes/ safety protection	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overalls, 1 raincoat, 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask, 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. Assumption: 7h/day at WTTP urea worker, 1.5h/day packing for Makenutri worker (15min/batch empty/ fill, 10 min/batch transfer. Calculation: 59% working hours (needing safety protection) is transport, see Equation 86- 91	27	Fuel vacuum truck	Assumption: 5 vacuum trucks. Driving 5 days a week, 52 weeks a year. Using gasoline See Equation 72 and 73
7	Disinfection area	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: One is enough since it is outside	28	Fuel motorbikes	Assumption: 4 motorbikes. Driving 5 days a week, 52 weeks a year. Using gasoline See Equation 74
8	Improvement lab	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f). Half the capacity used for storing drying material for <100 UDDT (Unpublished, COSMOL 2019c). Assumption: 80% of cost when building bigger. 2 units for 1000 UDDT +5 extra for storing humus-Gainutri + 1 for storing ZeoPeat	29	Maintenance trucks	(Unpublished, COSMOL R. L. 2019c)
9	Solar panel	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: same amount as improvement labs	30	Maintenance motorbikes	(Unpublished, COSMOL R. L. 2019c) Assumption: 4 motorbikes. 25 % less maintenance than for truck per motorbike
10	Toilet	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e) Assumption: 2 needed since more staff working regularly with 1000 UDDTs	31	Fuel vacuum pump	Consumption 6 L/h (Kennedy-Walker, R, 2015) Assumptions: 20 min pumping per UDDT, 30 min pumping per visit to WWTP. Visit to WWTP after 26 UDDTs. Emptying at UDDT every second week, see Equation 76 and 77
11	Access door	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f)	32	Disinfection containers and trucks	(Unpublished, COSMOL, 2019f) Assumption: 10 times more UDDTs, 6 more trucks, assume 8 times more disinfection needed
12	Vermicompost chambers	Volume chamber: 28.8m3, 559 kg faeces + drying material per m3 in FSH (Proyecto NODO, 2014). 14 chambers needed in Montero. See Equation 63	33	Disinfection clothes transports	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one full time worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 54% disinfection for transport, Equation 101 and 102
13	Drying chamber	23.8 m3, (Proyecto NODO, 2014). Density humus: 720 kg/m3 (Yadav et al., 2010). To dry humus-Gainutri mix after separate treatment. 6 is enough to dry and store humus up to 2.5 month, Equation 93 - 94	34	Containers for faeces	(Unpublished, COSMOL,. 2019f) Assumption: 10 % new containers every year
14	Wheel barrow	Price on local market in Montero. Assumption: 8 needed.	35	Personal costs treatment	Calculation: 43% of personal hours is for treatment see Equations 98 - 99
15	Electric pump	For emptying and transferring fresh urine and N-water from Makenutri treatment. (Personal Communication, Suntura, 2019) Assumption: 80% N-water from urine assumed (Personal Communication, Ganrot, 2019)	36	Electricity for pump	50 m3/h, 4kW (Bominox, 2014) See Equation 104 and 105
16	Makenutri 200V	Price on local market for 100m long hose + tap	37	Worms	3kg/m2. Area chamber: 32m2, Bs 350/kg worms (Personal Communication, Suntura, 2019) See Equation 83

17	Shipping cost Makenutri	(Personal Communication, Olsson, 2019). Lifespan 10 years, 170L/batch, 2 batches/Makenutri and day. 23 units needed, see Equation 95	38	Water for vermicompost	1m3/chamber and 2 weeks needed. 1m3 per chamber and 9 month can be reused in new chamber (Personal Communication, Suntura, 2019) No cost for water from well for COSMOL (Personal Communication, COSMOL, 2019g)
18	Shipping cost Makenutri	23 Makenutri can fit in one transport. 2500USD/ transport (Personal Communication, Olsson, 2019) but assumption 2 separate deliveries	39	Fertilizer bags	50kg fertilizer per bag. Bs 3-4 per new bag (Personal Communication, CIAT, 2019a) See Equation 108 - 109
19	Stirrer Makenutri	608USD/device. Price incl delivery to Bolivia at Ebay. Need to be changed every 7th year (Personal Communication, Olsson, 2019).	40	ZeoPeat	20% of urine mass to get good N recovery, 1200 sek/ ton (Personal Communication, Ganrot, 2019) See Equation 110
20	Clothes/ safety protection	(Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overals, 1 raincoat, 1 pair of steeltoe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask , 1 face mask filter, 2 gloves, 2 hats, 2 embrodery of clothing). Half the cost for workers only doing social visits. Assumption: 7h/day at WTTP urea worker, 1.5h/day packing for Makenutri worker (15min/batch empty/ fill, 10 min/batch transfer) Calculation: 59% working hours (needing safety protection) is transport, see Equation 86- 92	41	Electricuty Makenutri	0.5 kWh/ Makenutri batch, 170L urine/batch 2 batches per day (Personal Communication, Olsson, 2019) See Equation 111
21	Value of product	Production of humus-Gainutri from vermicompost and treatment with Makenutri from urine, Calculations, see Equations 10 - 11, Table 5 and 30	42	Urea	Bs3000/ton (Personal Communication, CIAT, 2019a) 3.07 % urea for 3 log reduction of Ascaris in Humus-Ganitrut mixture (Fidjeland, J, n.d.) see Table I.1, equation 106 and 107
			43	Maintenance treatment area	(Unpublished, COSMOL, 2019f) Assumption: same treatment costs of WWTP as for Alternativ 0
			44	Disinfection clothes treatment	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one full time worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 46% disinfection for treatment See Equation 100 - 103
			45	General equipment	Assumption: 10% more than alt 0 (Unpublished, COSMOL, 2019f)
			46	Soil quality test	(Unpublished, COSMOL, 2019f)

Cost working clothes for alternative 2:

$$cost_{clothes.per.staff} \cdot (staff_{faeces} + staff_{tidying} + 0.5 \cdot staff_{social.visits} + staff_{urine} + staff_{vermicompost} + staff_{urea} + staff_{Makenutri}) \quad (86)$$

Time Makenutri workers:

$$batches_{per.staff.day} = \frac{volume_{urine.cap.year} \cdot cap.per.UDDT \cdot UDDTs}{weeks.per.year \cdot capacity_{Makenutri} \cdot staff_{Makenutri} \cdot working.days} \quad (87)$$

$$t_{emptying.filling} = time_{emptying.filling.per.batch} \cdot batches_{per.staff.day} \quad (88)$$

$$t_{transfer} = time_{transfer.per.batch} \cdot batches_{per.staff.day} \quad (89)$$

Percentage of working clothes for transports for alternative 2:

$$\frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot t_{tid} + 0.5 \cdot staff_{s.v} \cdot t_{s.v} + staff_u \cdot (t_e + t_d)}{staff_f \cdot t_f + staff_{tid} \cdot t_{tid} + 0.5 \cdot staff_{s.v} \cdot t_{s.v} + staff_u \cdot (t_e + t_d) + staff_v \cdot t_v + staff_{urea} \cdot t_{urea} + staff_M \cdot (t_{ef} + t_{tr} + t_p)} \quad (90)$$

, where f = faeces, t_c = time$_{collection}$, t_d = t$_{driving}$, tid = tidying, $s.v$ = social visits, u = urine, t_e = time$_{emptying}$ and v = vermicompost, M = Makenutri, t_{ef} = time$_{emptying.filling}$, t_{tr} = time$_{transfer}$, t_p = time$_{packing}$

Cost working clothes for treatment for alternative 2:

$$cost_{clothes.per.staff} \cdot clothes_{transport} \quad (91)$$

Cost working clothes for treatment for alternative 2:

$$cost_{clothes.per.staff} \cdot clothes_{treatment} = cost_{clothes.per.staff} \cdot (1 - clothes_{transport}) \quad (92)$$

Drying chambers needed for humus for alternative 2 (assuming 2.5 month storing enough):

$$proportion_{humus.of.mix} = \frac{mass_{humus}}{mass_{humus} + mass_{Gainutri} + mass_{urea}} \quad (93)$$

$$chambers_{drying} = \frac{2.5}{time_{drying.max}} \cdot \frac{chambers_{drying.humus}}{proportion_{humus.of.max}} \quad (94)$$

Amount of Makenutri devices needed:

$$batches_{per.day} = \frac{batchesper.staff.day \cdot staff_{Makenutri}}{batches_{per.Makenutri.day}} \quad (95)$$

Costs for staff for alternative 2:

$$cost_{staff2} = cost_{staff.faeces} + cost_{staff.social} + cost_{staff.tidying} + cost_{staff.urine} + cost_{staff.vermicompost} + cost_{staff.urea} + cost_{staff.Makenutri} \quad (96)$$

Cost staff for transport for alternative 2:

$$cost_{staff.transport2} = cost_{staff.transport1} \quad (97)$$

$$staff_{transport} = \frac{cost_{staff.transport2}}{cost_{staff}} \quad (98)$$

Cost staff for treatment for alternative 2:

$$cost_{staff.treatment} = cost_{staff} \cdot staff_{treatment} = cost_{staff} \cdot (1 - staff_{transport}) \quad (99)$$

Cost for disinfection of clothes for alternative 2:

$$cost_{per.worker} \cdot (staff_{faeces} + staff_{tidying} + staff_{urine} + staff_{vermicompost} + staff_{urea} + staff_{Makenutri}) \quad (100)$$

Cost disinfection clothes during transport for alternative 2:

$$cost_{disinfection.transport2} = cost_{disinfection.transport1} \quad (101)$$

$$disinfection_{transport2} = \frac{cost_{disinfection.transport2}}{cost_{disinfection.clothes}} \quad (102)$$

Cost disinfection clothes during treatment for alternative 2:

$$cost_{disinfection.treatment2} = cost_{disinfection2} \cdot (1 - disinfection_{transport2} \quad (103)$$

Cost for electricity for pump for liquid urine + N water:

$$volume_{pumped} = volume_{urine} + volume_{Nwater} = volume_{urine} + 0.8 \cdot volume_{urine} \quad (104)$$

$$cost_{electricity.pump} = electricity_{per.year} \cdot cost_{electricity} = \frac{volume_{pumped}}{speed_{pumping}} \cdot consumption_{pump} \cdot cost_{electricity} \quad (105)$$

Cost urea treatment per year:

$$mass_{urea} = percentage_{urea} \cdot (mass_{humus} + mass_{Ganiutri}) \quad (106)$$

$$cost_{urea.treatment} = cost_{urea} \cdot mass_{urea} \quad (107)$$

Fertilizer bags for alternative 2 per year:

$$mass_{fertilizer2} = mass_{humus-Gainutri.mix} = mass_{humus} + mass_{Gainutri} + mass_{urea} \quad (108)$$

$$cost_{fertilizer.bags2} = bags_{amount2} \cdot cost_{mean.bag} = \frac{mass_{fertilizer2}}{mass_{bag}} \cdot cost_{mean.bag} \quad (109)$$

Mass ZeoPeat needed per year:

$$mass_{ZeoPeat} = 0.2 \cdot volume_{urine} \cdot cost_{ZeoPeat} \quad (110)$$

Cost electricity for Makenutri per year:

$$cost_{electricity.Makenutri} = electricity_{batch} \cdot \frac{volume_{urine.year}}{volume_{batch}} \cdot cost_{electricity} \quad (111)$$

Table F.5. Assumptions and references for alternative 3

#	Item	References and assumptions	#	Item	References and assumptions
1	UDDT	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e)	24	Painting/ structure maintenance UDDT	General cost from World.Bank.Group (n.d.)
2	Urine drying box	One box for most families. 10USD/box in Sweden (Personal Communication, Simha, 2019) Assume box for the same price as in Sweden can be purchased in Bolivia or Brazil	25	Drying material (faeces)	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: 15 kg per 3 month (60kg container). See Equation 35
3	Passive solar heater	Cost including local labour costs for constructing solar panels 0.6 m^2 without glazing: 21USD/3.2m^2 foam board, starter color ducts: 4USD, inlet baffle: 4 USD, screen: 14USD/3.2 m2, others 25USD/3.2 m2 (Built.It.Solar, 2013) wooden beam Bs65/3 m (Unpublished, COSMOL, 2019e). Assumption: 4 collectors can be made on one day, daily salary (same as driver) (Unpublished, COSMOL, 2019f) See Equation 112 - 118	26	Selling extra drying material	(Unpublished, COSMOL, 2019f) Assumption: 30 % of households need to buy more drying material every 3rd month, see Equation 20
4	Electricity connection	(Personal Communication, Simha, 2019)	27	Maintenance drying device	(Personal Communication, Simha, 2019)
5	Pipes to urine drying	4 m pipes + valve (Unpublished, COSMOL, 2019e)	28	Drying media (urine)	1.69kg lime/month.UDDT, 4.31kg sawdust/ month.UDDT (Appendix C), (Personal Communication, Simha, 2019), Equation 132
6	Fan in drying box	From ebay including delivery to Perú. Assume +3 USD/fan included to deliver to Bolivia from Perú	29	Electricity for fan	80 W fan operating 12 hour/day for average household (Personal Communication, Simha, 2019), see Equation 133
7	Rain cover drying box	Simple construction of wood Assumption: (duralit roof: 1/10 of UDDT roof, wooden beam 4.4 m) (Unpublished, COSMOL, 2019e) See Equation 119	30	Personal costs transport	Calculation: 64% of personal hours is for transports, see Equation 134 - 136
8	Timer for fan	To be able to set which over the fan should operate Assumption: same as international price on market	31	Fuel truck	Assumption: 3 trucks. Collection twice/day, 5 days a week, 52 weeks a year. Using gasoline 567 USD/truck. see Equation 40
9	Installation costs	(Personal Communication, Simha, 2019)	32	Fuel motorbikes	Assumption: 5 motorbikes. Driving 5 days a week, 52 weeks a year. Using gasoline See Equation 138
10	Small trucks	(Unpublished, COSMOL, 2019f). Lifespan 5 years since used trucks purchased generally (Personal Communication, COSMOL, 2019c). Assumption: 2 times to WWTP/day. Average 4000 containers/year. Max time burial and preparation of drying material per visit to WWTP: 1h 15 min. Average driving distance per collection: 18 km. Up to 10 containers/ collection. Average 1 drying box/UDDT 2 trucks needed for dried urine, see Equation 21, 120 - 122	33	Maintenance trucks	(Unpublished, COSMOL R. L. 2019c)
11	Motorbikes (social visits)	(Proyecto NODO, 2014). Assumption: Driving distance per day for visits: 22 km. 3 for social visits, 2 for tidying. 25, 123 and 124	34	Maintenance motorbikes	(Unpublished, COSMOL R. L. 2019c) Assumption: 4 motorbikes. 25 % less maintenance than for truck per motorbike
12	Clothes/ safety protection	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: For one worker (2 overalls, 1 raincoat, 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask, 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. 7 h/day for WWTP workers. Calculation: 60% working hours (needing safety protection) is transport, see Equation 125 - 130.	35	Disinfection containers and trucks	(Unpublished, COSMOL, 2019f) Assumption: 10 times more UDDTs, 2 more trucks, assume 6 times more disinfection needed
13	Disinfection area	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: One is enough since it is outside	36	Disinfection clothes	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one full time worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 55% disinfection for transport See Equation 139-141
14	Improvement lab	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f). Half the capacity used for storing drying material for <100 UDDT (Personal Communication, COSMOL, 2019c). Assumption: 80% of cost when building bigger. 2 units for 1000 UDDT +1 extra for storing humus + for storing alkaline dry media + 1 for dry urine	37	Containers for faeces	(Unpublished, COSMOL,. 2019f) Assumption: 10 % new containers every year
15	Solar panel	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f) Assumption: same amount as improvement labs	38	Personal costs treatment	Calculation: 36% of personal hours is for treatment, see Equation 134 - 136
16	Toilet	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019e) Assumption: 2 needed since more staff working regularly with 1000 UDDTs	39	Worms	3kg/m2. Area each chambers: 32m2 (Personal Communication, Suntura, 2019) see Equation 83

17	Access door	COSMOL's cost calculations from 2015 (Unpublished, COSMOL, 2019f)	40	Water for vermicompost	1m3/chamber and 2 weeks needed. 1m3 per chamber and 9 month can be reused in new chamber (Personal Communication, Suntura, 2019). No cost for water from well for COSMOL (Personal Communication, COSMOL, 2019g)
18	Vermicompost chambers	Volume chamber: 28.8m3, 559 kg faeces + drying material per m3 in FSH (Proyecto NODO, 2014). 14 chambers needed in Montero, see Equation 63	41	Fertilizer bags	50kg fertilizer per bag. Bs 3-4 per new bag (Personal Communication, CIAT, 2019a) See Equation 143 - 145
19	Drying chamber	To dry humus after vermicompost, 23.8 m3, (Proyecto NODO, 2014). Density humus: 720 kg/m3 (Yadav et al., 2010) 1 is enough to dry and store humus for up to 5 month See Equation 64	42	Maintenance treatment area	(Unpublished, COSMOL, 2019f) Assumption: same treatment costs of WWTP as for Alternative 0
20	Wheel barrow	Price on local market in Montero. Assumption: 4 needed for humus	43	Disinfection clothes treatment	(Unpublished, COSMOL, 2019f) Assumption: 0.25 L per day and person, one full time worker: 260 working days/year, disinfection twice a day. No disinfection for social workers. 45% disinfection for treatment See Equation 139 - 142
21	Clothes/safety protection	(Unpublished, COSMOL, 2019f). Assumption: For one worker (2 overalls, 1 raincoat, 1 pair of steel toe boots, 1 pair of wellingtons, 2 pairs of safety glasses, 1 face mask , 1 face mask filter, 2 gloves, 2 hats, 2 embroidery of clothing). Half the cost for workers only doing social visits. 7 h/day for WWTP workers. Calculation: 40% working hours (needing safety protection) is treatment, see Equation 125 - 131.	44	General equipment	(Unpublished, COSMOL, 2019f)
22	Value of humus	Production of humus from vermicompost and treatment with Makenutri from urine, Calculations, see Equations 10 - 11, Table 5 and 30	45	Soil quality test	(Unpublished, COSMOL, 2019f)
23	Value of dried urine	Production of dried urine on site and treatment with Makenutri from urine, Calculations, see Equations 10 - 11, Table 5 and 30			

Cost passive solar panel for one UDDT:

$$cost_{foam.board} = cost_{foam.board.3.2m2} \cdot \frac{size_{panel}}{3.2} \tag{112}$$

$$length_{wood.needed} = round.off(2 \cdot (length_{frame} + width_{frame})) \tag{113}$$

$$cost_{wooden.frame} = length_{wood.needed} \cdot cost_{wooden.beam} \tag{114}$$

$$cost_{screen} = cost_{screen.3.2m2} \cdot \frac{size_{panel}}{3.2} \tag{115}$$

$$cost_{others} = cost_{others.3.2m2} \cdot \frac{size_{panel}}{3.2} \tag{116}$$

$$cost_{labour} = panels.per.staff \cdot fracsalary_{month} days.per.month \tag{117}$$

$$cost_{solar.panel} = cost_{foam.board} + cost_{wooden.frame} + cost_{starter.color.ducts} + cost_{screen} + cost_{inlet.baffle} + cost_{others} + cost_{labour} \tag{118}$$

Rain cover for urine dehydration box:

$$cost_{rain.cover} = \frac{cost_{duralit.UDDT}}{10} + \frac{wood_{length.required}}{3} \cdot cost_{wood.3m} \tag{119}$$

Small trucks needed for dried urine:

$$boxes_{total.per.year} = boxes_{per.year.UDDT} \cdot UDDTs = boxes_{per.month.UDDT.mean} \cdot month.per.year \cdot UDDTs \tag{120}$$

$$boxes_{collected.working.day} = \frac{boxes_{total.per.year}}{weeks.per.year \cdot working.days} \tag{121}$$

$$time_{box.collection.day} = boxes_{collected.working.day} \cdot time_{per.box} \tag{122}$$

Motorbikes needed for weekly social visits beyond social visits during collection of dried urine:

$$social.visits.per.day = \frac{weeks.per.year - collection_{dried.urine.year.UDDT} - collection_{faeces.year.UDDT} \cdot amount.of.UDDTs}{weeks.per.year \cdot working.days} \quad (123)$$

$$motorbikes_{social.visits3} = staff_{social.visits} = round.up(\frac{social.visits_{day}}{visits_{per.staff}}) \quad (124)$$

Cost working clothes for alternative 3:

$$cost_{clothes.per.staff} \cdot (staff_{faeces} + staff_{tidying} + 0.5 \cdot staff_{social.visits} + staff_{vermicompost} + staff_{dried.urine} + staff) \quad (125)$$

Percentage of working clothes for transports for alternative 3:

$$time_{collection.dried.urine} = \frac{time_{box.collection.day}}{trucks_{dried.urine}} \quad (126)$$

$$time_{driving.dried.urine} = routes_{day} \cdot \frac{(distance_{COSMOL.UDDT} + distance_{UDDT.WTTP} + distance_{WTTP.COSMOL} + driving_{between.UDDT}}{speed_{average}} \quad (127)$$

$$time_{dried.urine} = time_{collection.dried.urine} + time_{driving.dried.urine} \quad (128)$$

$$clothes_{transport3} = \frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot time_{tid} + 0.5 \cdot staff_{s.v} \cdot t_{s.v} + staff_{du} \cdot t_{c.du}}{staff_f \cdot t_f + staff_{tid} \cdot time_{tid} + 0.5 \cdot staff_{s.v} \cdot time_{s.v} + staff_v \cdot t_v + staff_{mix} \cdot t_{mix} + staff_{du} \cdot t_{du}} \quad (129)$$

, where f = faeces, t_c = time$_{collection}$, $t_d = t_{driving}$, $t_{c.du}$ = time$_{collection.dried.urine}$, tid = tidying, $s.v$ = social visits, v = vermicompost, du = dried urine and mix=mixing dried urine and N-enriched humus

Cost working clothes for transport for alternative 3:

$$cost_{clothes.transport3} = cost_{clothes.per.staff} \cdot clothes_{transport3} \quad (130)$$

Cost working clothes for treatment for alternative 3:

$$cost_{clothes.treatment3} = cost_{clothes.per.staff} \cdot (1 - clothes_{transport3}) \quad (131)$$

Cost drying media per year

$$mass_{drying.media} = mass_{lime} \cdot cost_{lime} + mass_{sawdust} \cdot cost_{sawdust} \quad (132)$$

Cost for electricity for fan for dehydration device:

$$cost_{electricity.fan} = effect_{fan} \cdot time_{operation.year} \cdot UDDTs \cdot cost_{electricity} \quad (133)$$

Cost working clothes for alternative 3:

$$cost_{staff3} \cdot (cost_{staff.faeces} + cost_{staff.tidying} + cost_{staff.social.visits} + cost_{staff.vermicompost} + cost_{staff.dried.urine} + cost_{staff.mix}) \quad (134)$$

Percentage of staff for transports for alternative 3:

$$staff_{transport3} = \frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot time_{tid} + \cdot staff_{s.v} \cdot t_{s.v} + staff_{du} \cdot t_{c.du}}{staff_f \cdot t_f + staff_{tid} \cdot time_{tid} + \cdot staff_{s.v} \cdot time_{s.v} + staff_v \cdot t_v + staff_{mix} \cdot t_{mix} + staff_{du} \cdot t_{du}} \quad (135)$$

, where f = faeces, t_c = time$_{collection}$, $t_d = t_{driving}$, $t_{c.du}$ = time$_{collection.dried.urine}$, tid = tidying, $s.v$ = social visits, v = vermicompost, du = dried urine and mix=mixing dried urine and N-enriched humus

Cost staff for transport for alternative 3:

$$cost_{staff.transport3} = cost_{staff3} \cdot staff_{transport3} \quad (136)$$

Cost staff for treatment for alternative 3:

$$cost_{staff.treatment3} = cost_{staff3} \cdot (1 - staff_{transport3}) \quad (137)$$

Fuel cost for 5 motorbikes:

$$cost_{fuel.per.year} = 5 \cdot fuel_{motorbike} \cdot cost_{gasoline} = 5 \cdot \frac{distance_{COSMOL.UDDT.COSMOL}}{fuel_{consumption.motorbike}} \cdot cost_{gasoline} \quad (138)$$

Cost disinfection of working clothes for alternative 3:

$$cost_{disinfection3} = cost_{per.worker} \cdot (staff_f + staff_{tid} + staff_{du} + staff_v + staff_{mix}) \quad (139)$$

Percentage of disinfection for clothes for transports for alternative 3:

$$disinfection_{transport3} = \frac{staff_f \cdot (t_c + t_d) + staff_{tid} \cdot time_{tid} + staff_{du} \cdot t_{c.du}}{staff_f \cdot t_f + staff_{tid} \cdot time_{tid} + staff_v \cdot t_v + staff_{mix} \cdot t_{mix} + staff_{du} \cdot t_{du}} \quad (140)$$

, where f = faeces, t_c = time$_{collection}$, t_d = $t_{driving}$, $t_{c.du}$ = time$_{collection.dried.urine}$, tid = tidying, v = vermicompost, du = dried urine and mix=mixing dried urine and N-enriched humus

Cost disinfection for clothes for transport for alternative 3:

$$cost_{disinfection.transport3} = cost_{disinfection3} \cdot disinfection_{transport3} \quad (141)$$

Cost disinfection for clothes for treatment for alternative 3:

$$cost_{disinfection.treatment3} = cost_{disinfection3} \cdot (1 - disinfection_{transport3}) \quad (142)$$

Fertilizer bags for alternative 3 per year:

$$mass_{dried.urine.year} = \frac{volume_{urine.year} \cdot 1kg/m^3 + drying.media_{month.UDDT} \cdot month.per.year \cdot UDDTs}{mass.decrease} \quad (143)$$

$$mass_{fertilizer3} = mass_{humus} + mass_{dried.urine} \quad (144)$$

$$cost_{fertilizer.bags3} = bags_{amount3} \cdot cost_{mean.bag} = \frac{mass_{fertilizer3}}{mass_{bag}} \cdot cost_{mean.bag} \quad (145)$$

Appendix G Interview questions to farmers in Montero about social acceptance

Questions to farmers in Montero

- Presentation of myself and some information regarding my project (my background, goal with project and cooperation with COSMOL R.L.). Ask if they are okay with answering questions about this topic (i.e. fertilizers from excreta). Tell them that I am learning Spanish and ask if they can try and speak slowly. Ask if I can record interview, so that I make sure that I haven't misheard anything

Background information:

(observations) Gender: Age: Others:

- What is the size of your farm (in ha)?
- What kind of crops do you produce?
- Do you produce crops for own consumption or commercial use?

General questions about fertilizers:

1. What fertilizer (if any) do you currently use (type, content of NPK, quantity per ha and year)?
    a. Once per year or more?
    b. If one type: same for all crops?
       If > one type: different for different crops?

If answer no fertilizer on 1: skip question 2-4 and 6

2. What is important when you buy fertilizer?

3. Where do you buy your fertilizer? (Delivered or collected?)
    a. If delivery: is this an important requirement for the fertilizer?

4. How do you apply your fertilizer?
    a. Mechanized process?
    b. Particular equipment

Introducing presentation about proposed products:
Both the feces and urine contains big amounts N, P and K. Since almost all nutrients we eat ends up in our excreta, after treatment and reduction of pathogens these products represent excellent fertilizers. I am going to talk about three proposed fertilizers from the feces or urine from UDDTs in Montero

> *A) Humus from feces treated with worms to reduce pathogens. Method tested in El Alto Bolivia in large scale as well as researched internationally .*
>
> *B) Urine can be applied as a safe fertilizer in liquid form after storing for sufficient time*
>
> *C) Urine can be applied in dried form, after reducing the volume with an innovative dehydration process in drying media.*

Questions about using feces and urine in agriculture:

5. Which of the three mentioned products, humus (from feces), stored liquid fertilizer (from urine) and powder N-fertilizer (from urine) can you imagine using as fertilizers for your agriculture? (Cross each that you can imagine use):

   ☐ A: Fortified humus

   ☐ B: Liquid N- fertilizer

   ☐ C: Powder N-fertilizer

   Why/why not?
6. What do you think the price should be of this fertilizer in relation to your current (cross one alternative):
   A: Humus from composted feces
   - ☐ Would never buy it
   - ☐ Cheaper price than current fertilizer
   - ☐ Same price as current fertilizer
   - ☐ More than current fertilizer

   B: Liquid fertilizer from treated urine
   - ☐ Would never buy it
   - ☐ Cheaper price than current fertilizer
   - ☐ Same price as current fertilizer
   - ☐ More than current fertilizer

   C: Dried fertilizer from dehydrated treated urine
   - ☐ Would never buy it
   - ☐ Cheaper price than current fertilizer
   - ☐ Same price as current fertilizer
   - ☐ More than current fertilizer

7. What requirements do you have for the proposed fertilizers to imagine using it in your agriculture:
   ____
   ____
   - ☐ No pathogens
   - ☐ Same price as actual fertilizer
   - ☐ Cheaper price than actual fertilizer
   - ☐ Same volume or less volume per nutrients in fertilizer

8. Other comments about using fertilizers from treated feces and urine in agriculture?

Appendix H Assessment of likelihood and severity of health hazard events

Table H.1. Assessment of likelihood and severity of potential hazard events related to health risks for workers for alternative 0

	Hazard event	Hazard	Exposure route	Likelihood	Severity
1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Possible(3): Mouth cover might not always be used properly	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016).
2.		Hookworms	Skin penetration	Unlikely (2): Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
3.	Back injuries when carrying heavy containers	Back injuries	Congested	Possible (3): Frequent lifting. Risk reduced if education in ergonomic offered	Major (8): Potentially resulting in injury
4.	Traffic accident	Body injuries	Fracture, neck injury	Unlikely (2): Low speed (20-40 km/h), but seat belt seldom used or lacking	Major (8): Potentially resulting in injury
5.	Exposire to untreated urine during maintenance of pipes	All microbial pathogens	Ingestion	Likely (4): More direct contact when maintenance	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
6.		Hookworms	Skin penetration	Unlikely (2): More direct contact with maintenance	Insignificant (1): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
7.	Back injuries when maintaining burial area	Back injuries	Congested	Very unlikely (1): Non frequent work	Major (8): Potentially resulting in injury
8.	Exposire to untreated faeces during burial	All microbial pathogens	Ingestion	Possible (3): Potential contact when emptying. Mouth cover might not always be used properly	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016).
9.		Hookworms	Skin penetration	Unlikely (2): Not a common risk in Bolivia (Mollonedo & Prieto, 2006).	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
10.	Back injuries when carrying heavy containers	Back injuries	Congested	Possible (3): Frequent lifting. Risk reduced if education in ergonomic offered	Major (8): Potentially resulting in injury
11.	Falling into burial holes	All microbial pathogens	Ingestion	Unlikely (2): Has not been recorded in the past. High exposure if falling into faeces	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
12.		Body injuries	Falling	Unlikely (2): Has not been recorded in the past	Moderate (4): Low falling height, should not lead to fracture
13.	Dropping heavy containers	Body injuries	Dropping items	Possible (3): Regularly manual lifts	Moderate (4): 60 kg weight, should not cause severe injuries
14.	Contact with calcium hydroxide (lime)	Reduced breathing	Ingestion	Possible (3): Regular contact during burial. Mouth cover might not always be used properly	Minor (2): Minor effects such as irritation identified (NJDOH, 2005)
15.		Skin irritation	Contact with skin	Possible (3): Regular contact during burial. Possible contact with face and wrists	Moderate (4) Contact can severely irritate and burn skin and eyes with possible eye damage (NJDOH, 2005)

Table H.2. Assessment of likelihood and severity of potential hazard events related to health risks for workers for alternative 1

	Hazard event	Hazard	Exposure route	Likelihood	Severity
1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Possible(3): Mouth cover might not always be used properly	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016).
2.		Hookworms	Skin penetration	Unlikely (2): Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
3.	Back injuries when carrying heavy containers	Back injuries	Congested	Possible (3): Frequent lifting. Risk reduced if education in ergonomic offered	Major (8): Potentially resulting in injury
4.	Traffic accident when collecting faeces	Body injuries	Fracture, neck injury	Unlikely (2): Low speed (20-40 km/h), but seat belt seldom used or lacking	Major (8): Potentially resulting in injury
5.	Exposure to untreated urine during pumping	All microbial pathogens	Ingestion	Unikely (2): Mouth cover might not always be used properly. Pipes and tanks normally sealed	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
6.		Hookworms	Skin penetration	Very unlikely (1): Pipes and tanks normally sealed. Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Insignificant (1): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
7.	Traffic accident when collecting urine	Body injuries	Fracture, neck injury	Possible (3): Low speed (20-40 km/h), but seat belt seldom used or lacking. More routes for urin collections	Major (8): Potentially resulting in injury
8.	Exposire to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Likely (4): More direct contact when maintenance. Mouth protection might not alwaya be used properly	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
9.		Hookworms	Skin penetration	Unlikely (2): More direct contact with maintenance	Insignificant (1): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
10.	Exposure to untreated faeces when operating vermicompost	All microbial pathogens	Ingestion	Possible (3): Regular stirring under several months. No direct contact since spade used. Mouth protection might not alwaya be used	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
11.		Hookworms	Skin penetration	Unlikely (2): Regular stirring under several months. No direct contact since spade used. .	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
12.	Falling into treatment chambers	All microbial pathogens	Ingestion	Unlikely (2): Has not been recorded in the past. High exposure if falling into faeces	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
13.		Body injuries	Falling	Unlikely (2): Has not been recorded in the past	Minor (2): Very low falling height, should not lead to bigger injuries
14.	Dropping heavy containers	Body injuries	Dropping items	Possible (3): Regularly manual lifts	Moderate (4): 60 kg weight, should not cause severe injuries
15.	Back injuries when shovelling humus and moving with wheel barrow	Back injuries	Congested	Unlikely (2): Not so frequent for each of the 4 operators. When one chamber is emptied the amounts are big.	Major (8): Potentially resulting in injury
16.	Contact with calcium hydroxide (lime)	Reduced breathing	Ingestion	Unlikely (2): Little contact when preparing and pouring drying material. Mouth cover might not always be used properly	Minor (2): Minor effects such as irritation identified (NJDOH, 2005)
17.		Skin irritation	Contact with skin	Unlikely (2): Little contact when preparing and pouring drying material. Possible contact with face and wrists	Moderate (4) Contact can severely irritate and burn skin and eyes with possible eye damage (NJDOH, 2005)
18.	Exposure to untreated urine when storing	All microbial pathogens	Ingestion	Very unlikely (1): Minor contact due to transport between vacuum tank and closed storage tanks	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Many bacteria are inactivated by ammonia and high pH in urine
19.	Exposure to untreated urine if storage tanks leaks	All microbial pathogens	Ingestion	Very unlikely (1): Low risk if tanks are reviewed and exchanged within guarantied life span	Moderate (4): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Many bacteria are inactivated by ammonia and high pH in urine. Big amounts if leakage

Table H.3. Assessment of likelihood and severity of potential hazard events related to health risks for workers for alternative 2

	Hazard event	Hazard	Exposure route	Likelihood	Severity
1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Possible(3): Mouth cover might not always be used properly	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016).
2.		Hookworms	Skin penetration	Unlikely (2): Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
3.	Back injuries when carrying heavy containers	Back injuries	Congested	Possible (3): Frequent lifting. Risk reduced if education in ergonomic offered	Major (8): Potentially resulting in injury
4.	Traffic accident when collecting faeces	Body injuries	Fracture, neck injury	Unlikely (2): Low speed (20-40 km/h), but seat belt seldom used or lacking	Major (8): Potentially resulting in injury
5.	Exposure to untreated urine during pumping	All microbial pathogens	Ingestion	Unikely (2): Mouth cover might not always be used properly. Pipes and tanks normally sealed	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
6.		Hookworms	Skin penetration	Very unlikely (1): Pipes and tanks normally sealed. Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Insignificant (1): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
7.	Traffic accident when collecting urine	Body injuries	Fracture, neck injury	Possible (3): Low speed (20-40 km/h), but seat belt seldom used or lacking. More routes for urin collections	Major (8): Potentially resulting in injury
8.	Exposire to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Likely (4): More direct contact when maintenance. Mouth protection might not alwaya be used properly	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
9.		Hookworms	Skin penetration	Unlikely (2): More direct contact with maintenance	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
10.	Exposure to untreated faeces when operating vermicompost	All microbial pathogens	Ingestion	Possible (3): Regular stirring under several months. No direct contact since spade used. Mouth protection might not alwaya be used	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
11.		Hookworms	Skin penetration	Unlikely (2): Regular stirring under several months. No direct contact since spade used. .	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
12.	Falling into treatment chambers	All microbial pathogens	Ingestion	Unlikely (2): Has not been recorded in the past. High exposure if falling into faeces	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
13.		Body injuries	Falling	Unlikely (2): Has not been recorded in the past	Minor (2): Very low falling height, should not lead to bigger injuries
14.	Dropping heavy containers	Body injuries	Dropping items	Possible (3): Regularly manual lifts	Moderate (4): 60 kg weight, should not cause severe injuries
15.	Back injuries when shovelling humus and moving with wheel barrow	Back injuries	Congested	Unlikely (2): Not so frequent for each of the 4 operators. When one chamber is emptied the amounts are big.	Major (8): Potentially resulting in injury
16.	Contact with calcium hydroxide (lime)	Reduced breathing	Ingestion	Unlikely (2): Little contact when preparing and pouring drying material. Mouth cover might not always be used properly	Minor (2): Minor effects such as irritation identified (NJDOH, 2005)
17.		Skin irritation	Contact with skin	Unlikely (2): Little contact when preparing and pouring drying material. Possible contact with face and wrists	Moderate (4) Contact can severely irritate and burn skin and eyes with possible eye damage (NJDOH, 2005)
18.	Inappropriate operation of Makenutri 200V	Body injuries	Injuries from the stirrer	Unlikely (2): Lower risk if personal is well instructed	Minor (2): Electricity only on when lid is on and no access to stirrer blades. (Personal communication, Olsson, 2019)
19.	Exposure of untreated urine to pathogens in form of Gainutri	All microbial pathogens	Ingestion	Possible (3): More contact due to regular maintenance	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Many bacteria are inactivated by ammonia and high pH in urine.
20.		Hookworms	Skin penetration	Unlikely (2): More contact due to regular maintenance. Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Insignificant (1): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
21.	Contact with urea	Reduced breathing	Ingestion	Unlikely (2): If fast handling when stirring in the urea, toxic ammonia has not been emitted. Mouth protection might not always be used	Moderate (4): Symptoms may include coughing, shortness of breath
22.		Skin irritation	Contact with skin	Unlikely (2): Little contact if urea stirred in directly with spade. Possible contact with face and wrists	Minor (2): Causes irritation to skin

Table H.4. Assessment of likelihood and severity of potential hazard events related to health risks for workers for alternative 3

	Hazard event	Hazard	Exposure route	Likelihood	Severity
1.	Exposure to untreated feces during collection	All microbial pathogens	Ingestion	Possible(3): Mouth cover might not always be used properly	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016).
2.		Hookworms	Skin penetration	Unlikely (2): Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
3.	Back injuries when carrying heavy containers	Back injuries	Congested	Possible (3): Frequent lifting. Risk reduced if education in ergonomic offered	Major (8): Potentially resulting in injury
4.	Traffic accident when collecting faeces	Body injuries	Fracture, neck injury	Unlikely (2): Low speed (20-40 km/h), but seat belt seldom used or lacking	Major (8): Potentially resulting in injury
5.	Exposire to dried urine during collection	All microbial pathogens	Ingestion	Unikely (2): Mouth cover might not always be used properly. Closed dehydration box.	Minor (2): Proved hygienically safe after drying. (Personal Communication, Simha, 2019).
6.		Hookworms	Skin penetration	Very unlikely (1): Closed dehydration box. Not a common risk in Bolivia (Mollonedo & Prieto, 2006)	Insignificant (1): Proved hygienically safe after drying (Personal Communication, Simha, 2019). Minor health effects for adults (WHO, 2016)
7.	Traffic accident when collecting dried urine	Body injuries	Fracture, neck injury	Unlikely (2): Low speed (20-40 km/h), but seat belt seldom used or lacking.	Major (8): Potentially resulting in injury
8.	Exposire to untreated urine during maintaining pipes	All microbial pathogens	Ingestion	Likely (4): More direct contact when maintenance. Mouth protection might not alwaya be used properly	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
9.		Hookworms	Skin penetration	Unlikely (2): More direct contact with maintenance	Minor (2): Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004). Minor health effects for adults (WHO, 2016)
10.	Exposure to untreated faeces when operating vermicompost	All microbial pathogens	Ingestion	Possible (3): Regular stirring under several months. No direct contact since spade used. Mouth protection might not alwaya be used	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
11.		Hookworms	Skin penetration	Unlikely (2): Regular stirring under several months. No direct contact since spade used. .	Minor (2): Hookworm infection in adults usually results in minor health effects (WHO, 2016)
12.	Falling into treatment chambers	All microbial pathogens	Ingestion	Unlikely (2): Has not been recorded in the past. High exposure if falling into faeces	Moderate (4): Risk of acute diarrhoea, vomiting, upper respiratory tract infection (WHO, 2016)
13.		Body injuries	Falling	Unlikely (2): Has not been recorded in the past	Minor (2): Very low falling height, should not lead to bigger injuries
14.	Dropping heavy containers	Body injuries	Dropping items	Possible (3): Regularly manual lifts	Moderate (4): 60 kg weight, should not cause severe injuries
15.	Back injuries when shovelling humus and moving with wheel barrow	Back injuries	Congested	Unlikely (2): Not so frequent for each of the 4 operators. When one chamber is emptied the amounts are big.	Major (8): Potentially resulting in injury
16.	Contact with calcium hydroxide (lime)	Reduced breathing	Ingestion	Possible (3): Possible contact when preparing and pouring drying media for urine and faeces. Mouth cover might not always be used properly	Minor (2): Minor effects such as irritation identified (NJDOH, 2005)
17.		Skin irritation	Contact with skin	Unlikely (3): Possible contact when preparing and pouring drying media for urine and faeces. Possible contact with face and wrists	Moderate (4) Contact can severely irritate and burn skin and eyes with possible eye damage (NJDOH, 2005)
18.	Contact with dried urine when mixing with humus	Reduced breathing	Ingestion	Unlikely (2): Mouth protection might not always be used properly	Insignificant (1): Urea is bond to dried urine during drying (Personal Communication, Simha, 2019)
19.		Skin irritation	Contact with skin	Unlikely (2): Face and wrists uncovered	Insignificant (1): Proved hygienically safe after drying (Personal Communication, Simha, 2019)

Appendix I Required storage time and urea addition for 3 log red of Ascaris

An increased pH and a higher total amount of NH4-tot generates a faster log reduction of Ascaris Sp, see table I.1.

Table I.1. Required storage time and urea additions generated with Fidjeland's equation to fulfill 3 log reduction of Ascaris Sp

Urea component	Natural urea in liquid urine	Natural urea in dried urine	Humus without urea additives	Added urea to humus+Gainutri	Added dried urine to humus
pH	9	10	6.9	8.8[I]	8.8[I]
temperature [C]	20	20	20	20	20
initial NH4-tot [mM]	273[II]	1499[III]	0.145[IV]	0.145[IV]	0.145[IV]
total solids [g/L]	/	500-1500[V]	900	800-1000	900
urea [mM]	0	0	0	460	105
additive [ton/year, 1000 UDDTs]	0	0	0	13.5	3.8
storage time to 3 log reduction [days]	110	14	∞	60	60

[I] 8.8: lowest potential pH when adding urea to faeces due to buffering (Nordin et al., 2009a)
[II] (Maurer et al., 2006)
[III] (Personal Communication, Simha, 2019)
[IV] (Lalander et al., 2013)
[V] Total solids for dried urine not given. Between 500-1500 g/L (assumption) gives same output

Appendix J Assessment of likelihood and severity of environmental hazards

Table J.1. Assessment of likelihood and severity of potential hazard events related to environmental risks for alternative 0

No.	Hazardous event	Hazard	Likelihood	Severity
1.	Groundwater pollution by infiltration of urine after usage	All microbial pathogens	Very likely (5): Groundwater surface <2 m below surface under normal conditions and 20-30 cm after a regular rainfall	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
2.		Nitrate/ nitrite	Very likely (5): Groundwater surface <2 m below surface under normal conditions and 20-30 cm after a regular rainfall	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
3.	Pollution to air from urine after usage	Ammonia	Possible (3): If the pipes for the urine is designed so that they are not directly ventilated and are free from damages the risk is very small (Jönsson & Vinnerås, 2004) Bigger risk when infiltrating in ground	Minor (2): Causes bad odour (WHO, 2017)
4.	Pollution to air during maintenance of pipes	Ammonia	Possible (3): Small amounts of urine left in pipes when maintaining. Possible release if ventilation while maintenance	Minor (2): Causes bad odour (WHO, 2017)
5.	Groundwater pollution if dropping containers with faeces	All microbial pathogens	Very unlikely (1): Only likely to infiltrate if the soil is oversaturated after rainfall	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
6.	Groundwater pollution if car accident	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
7.	Greenhouse gas emissions from fuel	Greenhouse gases	Very likely (5): Fuel (for transport) proved being one of the main sources for emissions of greenhouse gases (IPCC, 2019)	Major (8): Absorbs infrared radiation, traps heat in atmosphere and causes global warming (IPCC, 2019). Relatively small distances
8.	Groundwater pollution from faeces at burial site	All microbial pathogens	Very likely (5): Potential risk due to lack of impermeable layer underneath and no shelter for rain. pH >9 in 6 month needed to inactivate pathogens (WHO, 2006) is only achieved in 1 out of 7 sampling points at the burial site (source)	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)

Table J.2. Assessment of likelihood and severity of potential hazard events related to environmental risks for alternative 1

No.	Hazardous event	Hazard	Likelihood	Severity
1.	Pollution to air from urine after usage	Ammonia	Unlikely (2): If the pipes and tank for the urine is designed so that there is no direct ventilation and pipes are free from damage the leakage is less than 0.5 % (Jönsson & Vinnerås, 2004)	Minor (2): Causes bad odour (WHO, 2017)
2.	Groundwater infiltration if leakage from urine tank	All microbial pathogens	Very unlikely (1): If tanks are exchanged within the guarantied life span the risk is minimal	Minor (2): Contamnation of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
3.		Nitrate/ nitrite	Very unlikely (1): If tanks are exchanged within the guarantied life span the risk is minimal	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
4.	Pollution to air during maintenance of pipes	Ammonia	Possible (3): Small amounts of urine left in pipes when maintaining. Possible release if ventilation while maintenance	Minor (2): Causes bad odour (WHO, 2017)
5.	Groundwater pollution if dropping containers with faeces	All microbial pathogens	Very unlikely (1): Only likely to infiltrate if the soil is oversaturated after rainfall	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
6.	Groundwater pollution if car accident	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
7.	Groundwater pollution if leakage during pumping	All microbial pathogens	Very unlikely (1): If regular control of vacuum tank are performed and pumping supervised the risk is very low	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
8.		Nitrate/ nitrite	Very unlikely (1): If regular control of vacuum tank are performed and pumping supervised the risk is very low	Moderate (4): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
9.	Groundwater pollution if car accident	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
10.		All microbial pathogens	Very unlikely (1): Not likely with accident causing mayor gas leakage nor leakage of urine from vacuum tank due to low driving speed. Vacuum tank should not be damaged in smaller accident	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
11.		Nitrate/ nitrite	Very unlikely (1): Not likely with accident causing mayor gas leakage nor leakage of urine from vacuum tank due to low driving speed. Vacuum tank should not be damaged in smaller accident	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
12.	Greenhouse gas emissions from fuel	Greenhouse gases	Very likely (5): Fuel (for transport) proved being one of the main sources for emissions of greenhouse gases (IPCC, 2019)	Major (8): Absorbs infrared radiation, traps heat in atmosphere and causes global warming (IPCC, 2019). Relatively small distances
13.	Groundwater pollution of leakage from treatment chamber	All microbial pathogens	Very unlikely (1): Long life span, robust material. Low risk if chamber is checked between every batch of vermicompost	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
14.	Groundwater pollution if dropping untreated faeces during manual transfer	All microbial pathogens	Very unlikely (1): Only risk if ground is saturated after rainfall if dropped faeces are picked up when dropped	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
15.	Groundwater pollution if leakage from urine storage tanks	All microbial pathogens	Very unlikely (1): If tanks are exchanged within guarantied life span the risk is minimal	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016) Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
16.		Nitrate/ nitrite	Very unlikely (1): If tanks are exchanged within guarantied life span the risk is minimal	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
17.	Pollution to air if damage to urine storage tanks	Ammonia	Very unlikely (1): If tanks are exchanged within guarantied life span the risk is minimal	Minor (2): Causes bad odour (WHO, 2017)

Table J.3. Assessment of likelihood and severity of potential hazard events related to environmental risks for alternative 2

No.	Hazardous event	Hazard	Likelihood	Severity
1.	Pollution to air from urine after usage	Ammonia	Unlikely (2): If the pipes and tank for the urine is designed so that there is no direct ventilation and pipes are free from damage the leakage is less than 0.5 % (Jönsson & Vinnerås, 2004)	Minor (2): Causes bad odour (WHO, 2017)
2.	Groundwater infiltration if leakage from urine tank	All microbial pathogens	Very unlikely (1): If tanks are exchanged within the guarantied life span the risk is minimal	Minor (2): Contamnation of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
3.	Groundwater infiltration if leakage from urine tank	Nitrate/ nitrite	Very unlikely (1): If tanks are exchanged within the guarantied life span the risk is minimal	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
4.	Pollution to air during maintenance of pipes	Ammonia	Possible (3): Small amounts of urine left in pipes when maintaining. Possible release if ventilation while maintenance	Minor (2): Causes bad odour (WHO, 2017)
5.	Groundwater pollution if dropping containers with faeces	All microbial pathogens	Very unlikely (1): Only likely to infiltrate if the soil is oversaturated after rainfall	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
6.	Groundwater pollution if car accident	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
7.	Groundwater pollution if leakage during pumping	All microbial pathogens	Very unlikely (1): If regular control of vacuum tank are performed and pumping supervised the risk is very low	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
8.	Groundwater pollution if leakage during pumping	Nitrate/ nitrite	Very unlikely (1): If regular control of vacuum tank are performed and pumping supervised the risk is very low	Moderate (4): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
9.	Groundwater pollution if car accident	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
10.	Groundwater pollution if car accident	All microbial pathogens	Very unlikely (1): Not likely with accident causing mayor gas leakage nor leakage of urine from vacuum tank due to low driving speed. Vacuum tank should not be damaged in smaller accident	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
11.	Groundwater pollution if car accident	Nitrate/ nitrite	Very unlikely (1): Not likely with accident causing mayor gas leakage nor leakage of urine from vacuum tank due to low driving speed. Vacuum tank should not be damaged in smaller accident	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
12.	Greenhouse gas emissions from fuel	Greenhouse gases	Very likely (5): Fuel (for transport) proved being one of the main sources for emissions of greenhouse gases (IPCC, 2019)	Major (8): Absorbs infrared radiation, traps heat in atmosphere and causes global warming (IPCC, 2019). Relatively small distances
13.	Groundwater pollution of leakage from treatment chamber	All microbial pathogens	Very unlikely (1): Long life span, robust material. Low risk if chamber is checked between every batch of vermicompost	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
14.	Groundwater pollution if dropping untreated faeces during manual transfer	All microbial pathogens	Very unlikely (1): Only risk if ground is saturated after rainfall if dropped faeces are picked up when dropped	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
15.	Greenhouse gas emissions from electricity	Greenhouse gases	Possible (3): In 2015 57% of theelectricity in Bolivia were generated by natural gas, which causes methane, emissions and 14% from renewable sources. The goal for 2025 is $\sim$30% from natural gas and 74% from renewable sources (Godoy, 2017)	Major (8): Adsorbs infrared radiation, traps heat in atmosphere and causes global warming (IPCC, 2019). Methane is a greenhouse gas with impact comparable with carbon hydroxide (UCSUSA, 2014)
16.	Groundwater pollution if leakage from Makenutri	All microbial pathogens	Very unlikely (1): If tanks are exchanged within guarantied life span the risk is minimal. Long life span of container. Low risk if container are supervised while pouring urine. Small amounts treated at a time	Minor (2): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
17.	Groundwater pollution if leakage from Makenutri	Nitrate/ nitrite	Very unlikely (1): If tanks are exchanged within guarantied life span the risk is minimal. Long life span of container. Low risk if container are supervised while pouring urine. Small amounts treated at a time	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
18.	Pollution to air from urine in Makenutri	Ammonia	Unlikely (2): Low risk of ammonia leakge in relatively low temperatures (20-30 C) (Jönsson & Vinnerås, 2004)	Minor (2): Causes bad odour (WHO, 2017)
19.	Pollution to air from urea	Ammonia	Possible (3): Low risk if air-tight bag is used for urea treatment. Some release can potentially occur during storage due to ventilation	Minor (2): Causes bad odour (WHO, 2017)

Table J.4. Assessment of likelihood and severity of potential hazard events related to environmental risks for alternative 3

No.	Hazardous event	Hazard	Likelihood	Severity
1.	Pollution to air from urine after usage	Ammonia	Unlikely (2): If the pipes for the urine is designed so that there is no direct ventilation and the pipes are free from damage the leakage is less than 0.5 % (Jönsson & Vinnerås, 2004)	Minor (2): Causes bad odour (WHO, 2017)
2.	Groundwater infiltration if leakage from pipes	All microbial pathogens	Very unlikely (1): If tanks are exchanged within the guarantied life span the risk is minimal	Minor (2): Contamnation of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016). Urine is more or less clean if not cross-contaminated (Schönning & Stenström, 2004)
3.		Nitrate/ nitrite	Very unlikely (1): If tanks are exchanged within the guarantied life span the risk is minimal	Major (8): Low to moderate acute toxicity in animals with access levels of nitrate. Nitrate is partly reduced to nitrite in the body. Excessive levels, mainly in babies under 3 month can cause oxygen deficit (WHO, 2011). Remains in water bodies for decades
4.	Pollution to air during maintenance of pipes	Ammonia	Possible (3): Small amounts of urine left in pipes when maintaining. Possible release if ventilation while maintenance	Minor (2): Causes bad odour (WHO, 2017)
5.	Groundwater pollution if dropping containers with faeces	All microbial pathogens	Very unlikely (1): Only likely to infiltrate if the soil is oversaturated after rainfall	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
6.	Groundwater pollution if car accident when transporting faeces	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
7.	Groundwater pollution if car accident when transporting dried urine	Gasoline	Very unlikely (1): Very low risk with accident causing gas leakage due to low driving speed. Since trucks are purchased second hand from overseas the risk of leakage due to reduced quality is assumed	Major (8): Can cause severe damages to animals and indirectly affect the humans (Ledskog, L & Lundgren, T, 1989)
8.	Greenhouse gas emissions from fuel	Greenhouse gases	Very likely (5): Fuel (for transport) proved being one of the main sources for emissions of greenhouse gases (IPCC, 2019)	Major (8): Absorbs infrared radiation, traps heat in atmosphere and causes global warming (IPCC, 2019). Relatively small distances
9.	Groundwater pollution of leakage from treatment chamber	All microbial pathogens	Very unlikely (1): Long life span, robust material. Low risk if chamber is checked between every batch of vermicompost	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
10.	Groundwater pollution if dropping untreated faeces during manual transfer	All microbial pathogens	Very unlikely (1): Only risk if ground is saturated after rainfall if dropped faeces are picked up when dropped	Moderate (4): Contamination of groundwater by enteric pathogens has commonly been associated with disease outbreaks (Bradford, S. A. & Harvey, R. W., 2016)
11.	Greenhouse gas emissions from electricity	Greenhouse gases	Likely (4): In 2015 57% of the electricity in Bolivia were generated by natural gas which causes methane emissions and 14% renewable sources. The goal for 2025 is ∼30% natural gas and 74% renewable (Godoy, 2017). High energy consumption (Personal Communication, Simha, 2019)	Major (8): Absorbs infrared radiation, traps heat in the atmosphere and causes global warming (IPCC, 2019). Methane is a greenhouse gas with impact comparable with carbon hydroxide (UCSUSA, 2014)