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Resource Recovery and Reuse (RRR) Project

Output 7

Health and environmental risk and impact assessments of waste reuse business models proposed for Lima

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Health assessments

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Executive summary health assessments

For the 4 targeted feasibility cities of the RRR project, the health components around the selected business models (BM) employed two methodologies, with two different foci: Health Risk Assessment (HRA) and the Health Impact Assessment (HIA). The HRA aimed at identifying health risks associated with the input resources (e.g. faecal sludge, waste water) of proposed BMs and defining what control measures are needed for safeguarding occupational health and producing outputs (e.g. treated waste water, soil conditioner) that are compliant with national and international quality requirements. The HIA aimed at identifying potential health impacts (positive or negative) at community level under the scenario that the proposed BMs are implemented at scale in Lima. The magnitude of potential impacts was determined by means of a semi-quantitative impact assessment. The feasibility studies in Lima were oriented towards nine BMs that were selected due to their potential in the given context. These BMs are:

- Model 2b: Energy service companies at scale: MSW to energy (electricity)
- Model 3: Energy generation from own agro-industrial waste
- Model 4: Onsite energy generation by sanitation service providers
- Model 8: Beyond cost recovery: the aquaculture example
- Model 9: On cost savings and recovery
- Model 13: Informal to formal trajectory in wastewater Irrigation: sale/auctioning wastewater for irrigation
- Model 15: Large-scale composting for revenue generation
- Model 17: High value fertilizer production for profit
- Model 21: Partially subsidized composting at district level

Evidence-base of the HRIA

A broad evidence-base was assembled for the health risk and impact assessment (HRIA). At a large scale (i.e. city level) this entailed the collection of secondary data on the epidemiological profile, environmental exposures and the health system of Hanoi. This included statistics of health facilities from urban, peri-urban and rural areas in and around Hanoi city, as well as data from the peer-reviewed and grey literature. The literature review had a focus on (i) soil-, water- and waste-related diseases; (ii) respiratory tract diseases; and (iii) vector-borne diseases, since these disease groups are closely associated with unsafe disposal of waste and waste recovery. At a small scale, primary data was collected at the level of existing RRR activities by means of participatory data collection methods and direct observations. A total of seven existing RRR cases were investigated in Lima area:

- Case 1: Wastewater treatment for irrigation: Fundo Palo Alto
- Case 2: MSW collection service- San Luis Municipality-Recyclers
- Case 3: Treated wastewater for irrigation/fertilizer/energy: Parque Zonal Huascar
- Case 4: High quality branded/certified organic fertilizer form faecal sludge and municipal solid waste (MSW) & onsite energy generation: ECO Granja “Camila” (pig farm)

- Case 5: Phyto-remediative water treatment and fish production (Tilapia ponds): urban agricultural family business, Carapongo, Lurigancho
- Case 6: High Quality Branded/Certified Organic Fertilizer from Faecal Sludge X-runners - Dry toilets- Sanitation Solution in urban Areas
- Case 7: Phyto-remediative water treatment and fish production (Tilapia ponds): Union University

The cases were studied considering the given context and by following a similar methodology in all 4 feasibility study cities. An additional important component of the case studies were an assessment of the use and acceptability of personal protective (PPE) among the workforce.

In addition to the standardised methodology of the health component around these seven existing RRR cases, the city of Lima benefited from a complementary in-depth study on the concentration of heavy metals, protozoa and helminth eggs were carried out in the frame of the pre-testing of the Sanitation Safety Planning (SSP) manual in Lima. For the pre-testing of the SSP manual in Lima, two study sites were selected: the agricultural area in Cono Este (peri-urban area of Lima) and the Parque Husacar in Lima city. In the frame of those two case studies, the team led by Dr Julio Moscoso collected a large number of environmental samples (water, soil and plant) for determining the presence and/or concentration of heavy metals, bacteria, protozoa and helminth eggs. Hence, the data generated by the SSP manual trials make an important contribution to the evidence-base of the HRIA.

Summary of findings of the literature review and in-depth studies

According to health statistics from the districts where the data collection activities at the level of existing RRR cases took place (i.e. Lurigancho, Villa el Salvador and Lurin districts, and San Luis municipality), respiratory diseases, diseases of the digestive system and different infectious and parasitic diseases were the leading causes of morbidity at the represented health facilities in 2009, 2010 and 2011. A closer look at the statistics reveals that upper respiratory tract infections and intestinal infections are the principal cause for consulting a health facility, with most patients being under the age of 5 years.

With regard to access to sanitation facilities, the 2012 Peru Demographic and Health Survey (PDHS) found that three in four households in urban areas have access to piped drinking water inside their house and are connected to the sewerage system [15]. In Lima, the percentage of houses that are connected to the sewerage system is 90.3%, which is clearly above the national average. In 2012, 6.3% of the households in Lima collected their drinking water from a pipe or fountain outside their house or apartment.

Against this background, it is not surprising that helminthic infections are not a major health concern in urban and peri-urban areas of Lima. Intestinal protozoa infections are of greater public health concern, particularly in children.

The burden of chronic respiratory diseases and cardiovascular diseases is relatively high in Peru, accounting for 4% and 22% of total mortality (all ages, both sexes), respectively.

Depending on the season, a broad range of mosquito vectors such as *Anopheles spp*., *Aedes spp*. and *Culex spp*. are present in Peru. Therefore, various vector-borne diseases are endemic in the country, particularly in the jungle areas in the north. The most important vector-borne disease in Peru is Dengue, but also malaria, leishmaniasis and Chagas disease are important public health concerns. However, none of those vector-borne diseases is of public health relevance in Lima

Exposure to noise, air pollution, contaminated drinking water, contaminated surfaces and contaminated food products are important environmental determinants of health. The findings of the environmental sampling at the Cono Este study can be summarised as follows:

- Water samples: none of the average values for heavy metals exceeded the national threshold. Protozoa concentrations above the national limit of 0 protozoa per 1 L were detected in water samples from each sampling site. Also helminth eggs were detected in most samples, though the average concentration did not exceed the national limit of ≤1 helminth egg per 1 L.
- Soil samples: concentrations of arsenic and led exceeded national limits at two of the three sampling sites. Cadmium was above the national threshold at one study site.
- Grass samples at UPeU: helminth eggs (A*. Lumbricoides* and *Strongyloides* sp.) were detected on grass surfaces irrigated with wastewater.
- Vegetable samples collected at Carapongo: all the vegetable samples showed contamination with protozoa eggs. Helminth eggs were less of an issue.
- Fish: fish cultivated at the Nievería site showed concentrations of TTC exceeding the national limit of 100 TTC/g (maximum). The maximum concentration of TTC of fish cultivated at the Carapongo site was 3.3 TTC/g.

Findings of the environmental sampling at the Parque Huascar study site are as follows:

- Water samples: none of the average values for heavy metals exceeded the national threshold. The crude water from the waste water treatment plant (WWTP) showed protozoa concentrations above the national limit of 0 protozoa per 1 L and also high concentrations in TTC (up to $7x10^7$ TTC/100mL). Also helminth eggs were detected in all crude water samples.
- Soil samples: concentrations of chrome exceeded national limits in soil of the green areas and agricultural surfaces of Parque Huascar. Larvae of *Ascaris* spp. and *Strongyloides* spp. were detected in soil samples of the green areas.
- Grass samples: as for the soil samples, helminth larvae (*Ascaris* spp. and *Strongyloides* spp.) were detected on grass surfaces irrigated with wastewater. No protozoa were found in grass samples. Interestingly, very high concentrations of TTC were measured on grass samples (up to $2x10^5$ TTC/g).

Key findings of the HRA

All of the identified occupational health risk – such as exposure to pathogens, skin cuts or inhalation of toxic gases – can be managed by providing appropriate PPE, health and safety education to workers and appropriate design of the operation and technical elements.

Biological hazards mostly derive from human and/or animal wastes that serve as inputs *per se* for the proposed BM (e.g. animal manure or human faeces) or are a component thereof (e.g. human waste in wastewater). For meeting pathogen reduction rates, a series of treatment options are at disposal. The HRA provides guidance on which treatment options are required for what reuse option. When it comes to the implementation of the BM, the challenge will be to respect indicated retention times and temperatures for achieving the required pathogen reduction rates. Since the proposed retention times may also have financial implications, it is important that these are taken up by the financial analysis.

Chemical hazards primarily concern wastewater fed BMs. The environmental sampling in Lima area showed variation in heavy metal concentration, often exceeding national and international thresholds. This clearly indicates that irrigation with wastewater is of concern in Lima from a health and environmental perspective, though high local variation might apply. This needs to be taken into account for the planning of any wastewater fed BM, i.e. environmental sampling is indicated for identifying suitable locations. Where threshold values of toxic chemicals exceed national and WHO guideline values, physiochemical treatment for removing toxic chemicals such as heavy metals are required. Also co-composting with wastewater sludge is only an option if the sludge is compliant with heavy metal thresholds. In addition, for both irrigation with treated wastewater and the use of sludge-based soil conditioner, chemical parameters of receiving soils need to be taken into account. Of note, reuse of sludge is currently prohibited in Peru.

In terms of physical hazards, sharp objects deriving from contaminated inputs (e.g. faecal sludge or MSW) ending-up in soil conditioner are a risk that has been identified for a number of BM. This will require careful pre-processing of inputs and sieving of End-products. Moreover, users need to be sensitised about the potential presence of sharp objects in the soil conditioner and advised to wear boots and gloves when applying the product. Also emissions such as noise and volatile compounds are of concern at workplace and community level. While PPE allows for controlling these hazards at workplace level, a buffer zone between operation and community infrastructure needs to be respected so that ambient air quality and noise exposure standards are not exceeded. Of note, the actual distance of the buffer zone is depending on the level of emissions. Finally, for businesses involving burning processes and power plants, fire/explosion and electric shock are risks of high priority that need to be managed appropriately.

Overall, the health risks associated with most of the proposed BM can be mitigated with a reasonable set of control measures. Concerns about heavy metals and other chemical contaminants remain for all the wastewater-fed BM. From a health perspective, wastewater fed agriculture (Model 8) in Lima needs to be promoted with care, also since the concentration of heavy metals is likely to further increase over time due to accumulation in the soils. Models 2b, 15, 17 and 21, all of which use municipal solid waste (MSW) as an input, are only an option if no medical waste from health facilities is mixed with common MSW.

Key findings of the HIA

The objective of the HIA was to assess potential health impacts at community level of proposed BMs for Lima under the assumption that the control measures proposed by the HRA are deployed. This included consideration of both potential health benefits (e.g. business is resulting in reduced exposure to pathogens as it entails treatment of wastewater) and adverse health impacts (e.g. exposure to toxic gases by using briquettes as cooking fuels). Since the HIA aimed at making a prediction of potential health impacts of a given BM under the assumption that it was implemented at scale, a scenario was defined for each BM as an initial step. The scenario was then translated into the impact level, the number of people affected and the likelihood/frequency of the impact to occur. By means of a semi-quantitative impact assessment, the magnitude of the potential impacts was calculated.

A summary of the nature and magnitude of anticipated health impacts for each of the proposed BM is presented in Table 1. Most of the proposed BMs have the potential for resulting in a minor to major positive health impact. Under the given scenarios, Model 9 (treated wastewater for irrigation/fertilizer/energy: on cost savings and recovery), 13 (informal to formal trajectory in wastewater irrigation: sale/auctioning wastewater for irrigation) and Model 8 (the aquaculture example) have the greatest potential for having a positive impact since it will result in a reduction in exposure to pathogens at community level. It has, however, to be noted that this only applies if the wastewater (untreated or treated) used is compliant with national and international quality requirements regarding toxic chemicals. The other BMs are anticipated to only have a minor positive or insignificant impact on community health.

Table 1 – Summary table of anticipated health impacts and their respective magnitude

Business model	Scale of the BM: applied scenario	Anticipated health impact	Magnitude (score)
Model 2b – Energy service companies at scale: MSW to energy (electricity)	Two plants as proposed by the business will be implemented in Lima.	Impact 1: changes in health status due to access to electricity	**Insignificant (0)**
Model 3 – Energy generation from own agro-industrial waste	Two plants as proposed by the business will be implemented in Lima, resulting in 500 people that will have a reduce exposure to manure	Impact 1: changes in health status due to access to electricity	**Insignificant (0)**
		Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Minor positive impact (15)**
Model 4 – Onsite energy generation in enterprises providing sanitation services	10 villages in rural and peri-urban areas of Lima will implement the BM with a population of 1,000 each	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (30)**
		Impact 2: changes in health status due to access to electricity	**Insignificant (0)**
Model 8 – Beyond cost recovery: the aquaculture example	3 operations serving 500 farmers. Products irrigated with safe irrigation water and safe fish from the aquaculture will be consumed by 150,000 consumers	Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases	**Major positive impact (4,535)**
Model 9 – On cost savings and recovery	Scenario of Cono Este: 5,600 farmers, 700,000 consumers and 22,000 people downstream will be impacted	Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases	**Major positive impact (25,030)**
		Impact 2: reduction in exposure to chemicals and heavy metals	**Moderate positive impact (28)**
		Impact 3: changes in	**Insignificant**

		health status due to access to electricity	**(0)**
Model 13 – Informal to formal trajectory in wastewater Irrigation: sale/auctioning wastewater for irrigation	Scenario of Cono Este: 5,600 farmers, 700,000 consumers and 22,000 people downstream will be impacted	Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases	**Major positive impact (25,030)**
		Impact 2: reduction in exposure to toxic chemicals (e.g. heavy metals)	**Moderate positive impact (28)**
Model 15 – Large-scale composting for revenue generation	Two centralised co-composting plants are installed in Lima, serving 2'000 households each	Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases	**Minor positive impact (4)**
Model 17 – High value fertilizer production for profit	Two centralised co-composting plants are installed in Lima, serving 2'000 households each	Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases	**Minor positive impact (4)**
Model 21 – Partially subsidized composting at district level	No health impacts anticipated		**Insignificant (0)**

Executive summary environmental assessments

For the Environmental Impact Assessment (EIA), business model flow diagrams are used as a tool to visualize both impact assessments. The EIA takes into consideration the "Technology Assessment", which comprises an extensive literature review on technologies for resource recovery also identifying potential environmental hazards and measures of mitigation.

Within the scope of this assessment, the environmental impact of the business models are not assessed in detail, as information on facility scale and specific location in the city was not available. Rather, with the level of technical detail currently available, the EIA shows potential environmental hazards, which should be recognized and mitigated during implementation.

More detailed analysis of specific environmental impacts can follow at a later stage if treatment infrastructure has been clearly defined based of an analysis of market demand for End-products and the respective determination of treatment goals. Such an evaluation would have to include detailed laboratory analyses of the waste streams to be utilized, so that treatment technologies can be selected and designed in detail.

Currently, and based on the EIA as a stand-alone component, the feasibility of business models cannot be ranked, which is the reason for all business models resulting in "medium feasibility". Ultimately, the implementing business has to mitigate the identified potential environmental hazards, which will results in little, or no environmental impact.

Table 2 provides a summary for all business models, the respective waste streams, End-products technologies, processes and potential environmental hazards, including proposed mitigation measures.

Table 2 – Summary table of anticipated environmental impacts and proposed mitigation

BM	Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
2b	• MSW • AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasifi-cation • Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Residuals (tar, char, oil) • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Collection/Storage/ Disposal at appropriate location • Solid/liquid residue post-treatment
3	• AIW • AM	• Ethanol • Electricity	• Fermentation, Distillation Technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Fermen-tation • Distillation • Biogas to electricity conversion	• Hazardous air emissions • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Solid/liquid residue post-treatment

4	• Feces • Urine • FS	• Biogas -> Cooking fuel	• Single stage • Multi-stage • Batch	• Anaerobic digestion	• Air emissions • Solid residue (digestate) • Liquid effluent	• Maintenance of anaerobic digester • Solid/liquid residue post-treatment
8	• WW	• Fish • Treated WW	• Duckweed • Aquaculture	• Pond treatment	• Heavy metals in effluent and/or sludge from WW treatment • Solid residue (sludge from WW treatment)	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treatment
9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conven-tional WW treatment • Biogas to electricity conversion	• Heavy metals in effluent and/or WW sludge • Solid residue (sludge from WW treatment) • Air emissions	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treament • Maintenance of anaerobic digester
13	• WW	• Water (for reclamation)	• Conventional WW treatment with limited nutrient removal • Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Conventional WW treatment • Land application	• Groundwater contamination (heavy metals/patho-gens) • Contamination of irrigated crops • Solid residue (sludge from WW treatment)	• Crop selection • Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • 2006 WHO guidelines • Solid residue (sludge from WW treatment) post-treatment
15	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
17	• MSW • FS	• Fertilizer (NPK added)	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

21	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

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Abbreviations

AIDS	Acquired Immune Deficiency Syndrome
ARI	Acute Respiratory Infections
BM	Business Model
Cd	Cadmium
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
Cr	Chromium
Cu	Copper
dB	Decibel
EIA	Environmental Impact Assessment
Fe	Iron
FGD	Focus Group Discussion
HIA	Health Impact Assessment
HRA	Health Risk Assessment
HRIA	Health Risk and Impact Assessment
IL	Impact Level
KII	Key Informant Interviews
LF	Lympahtic Filariasis
LoF	Likelihood or Frequency
MINAM	Ministerio del Ambiente
MINSA	Ministerio de Salud
MSW	Municipal Solid Waste
NCD	Non-communicable Disease
NO_x	Nitrogen Oxides
NPK	Nitrogen, Phosphorus and Potassium
NWSC	National Water and Sewerage Cooperation
PA	People Affected
Pb	Lead
PDHS	Peru Demographic and Health Survey
PM	Particulate Matter
PPE	Personal Protective Equipment
PTAR	Huascar Wastewater Treatment Plant
RRR	Resource, Recovery and Reuse
RS	Risk Score
SO_x	Sulphur Oxides
SSP	Sanitation Safety Planning
STH	Soil-transmitted helminth
STI	Sexually Transmitted Infection
TTC	Thermo Tolerant Coliform
UPCH	Universidad Peruana Cayetano Heredia
UPeU	Universidad Peruana Unión
USEPA	United States Environmental Protection Agency
UTI	Urogenital Tract Infection
WHO	World Health Organization
WWTP	Wastewater Treatment Plant
YYL	Years of Life Lost
Zn	Zinc

Annexes

1 Introduction

Outcome 7 of the resource, recovery and reuse (RRR) project entails the assessments of health and environmental risks for proposed waste reuse business models (BMs). For the strategic health planning components of Outcome 7, different forms of health assessments are available with different foci, i.e. from workplace health to community health, as illustrated in Figure 1. Since both workplace health and community health are of concern for the feasibility studies of proposed BMs, a health risk assessment (HRA) and health impact assessment (HIA) methodology were employed [1]. Health needs of communities in Lima were also considered in the frame of baseline data collection activities such as the characterisation of the epidemiological profile and the assessment of environmental exposures. BM flow diagrams were developed to identify outputs posing health and environmental risks. The environmental impact assessment (EIA) and HRA take into consideration the “Technology Assessment” report {Schoebitz, 2014 #137}, which comprises an extensive literature review on technologies for resource recovery also identifying potential environmental hazards and measures of mitigation.

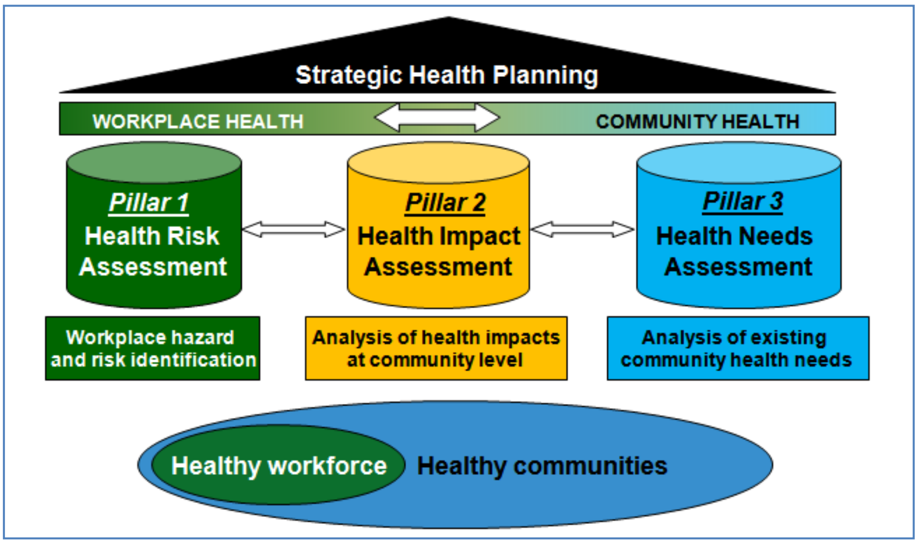

Figure 1 – Different types of health assessments and their interlinkages

The specific objectives of the health assessments were:

- To characterise the general disease profile and exposures to environmental health hazards linked to waste streams in Lima
- To identify common occupational and community health risks associated with existing RRR activities in Lima
- To evaluate the acceptability of control measures to mitigate health risk in Lima
- To define control measures required for safeguarding occupational health and ensuring safe products for each of the BMs proposed for Lima
- To assess residual health risks with the proposed control measures in place

- To assess potential health impacts at community level (positive or negative) of proposed BMs for Lima under the assumption that the proposed control measures (see previous objective) are deployed

The specific objectives of the EIA were:

- To create BM flow diagrams, identify BM outputs (e.g. emissions into air) that could form a potential environmental hazard
- To identify the specific potential environmental hazards of identified outputs (e.g. polycyclic aromatic hydrocarbons)
- To identify technical solutions for mitigation of potential environmental hazards to prevent a negative environmental impact (e.g. activated carbon, scrubbers)
- To provide guidance on technical solutions that have to be recognizes when implementing waste-based BMs

Within the scope of the EIA, the environmental impact of the business models are not assessed in detail, as information on facility scale and specific location in the city was not available. Rather, with the level of technical detail currently available, the EIA shows potential environmental hazards, which should be recognized and mitigated during implementation. More detailed analysis of specific environmental impacts can follow at a later stage if treatment infrastructure has been clearly defined based of an analysis of market demand for End-products and the respective determination of treatment goals. Such an evaluation would have to include detailed laboratory analyses of the waste streams to be utilized, so that treatment technologies can be selected and designed in detail.

Chapter 2 provides an overview of the tools and methods that were deployed for assembling the baseline data to inform the specific objectives above and introduces the HRA, HIA and EIA methodologies. In Chapter 3, the evidence-base for the HRA and HIA is summarized in five sub-chapters (i.e. epidemiological profile; environmental parameters; self-reported health issues by workers of reuse cases; and acceptability and use of personal protective equipment). At the core of the present report are the HRA, HIA and EIA in Chapter 4..

2 Methodology

In order to assemble the information needed for the HRA and HIA components, a methodological triangulation was carried out (see Figure 2). At a large scale (i.e. city level) this entailed the collection of secondary data on the epidemiological profile, environmental exposures and the health system of Lima. At a small scale, primary data was collected at the level of existing RRR activities by means of participatory data collection methods and direct observations. In addition, in-depth studies on the concentration of heavy metals, protozoa and helminth eggs were carried out in the frame of the pre-testing of the Sanitation Safety Planning (SSP) manual in Lima.

Section 2.1 provides an overview of the survey tools and methods that were employed for the different baseline data collection activities. The full description of survey tools and methods is available in Annex I ('Methodology and tools for feasibility studies: baseline data collection for the health risk and impact assessments'). A summary of the key findings of the different data collection activities is provided in Chapter 3. These data serve as evidence-base for the HRA and HIA in Chapters 4 and 5.

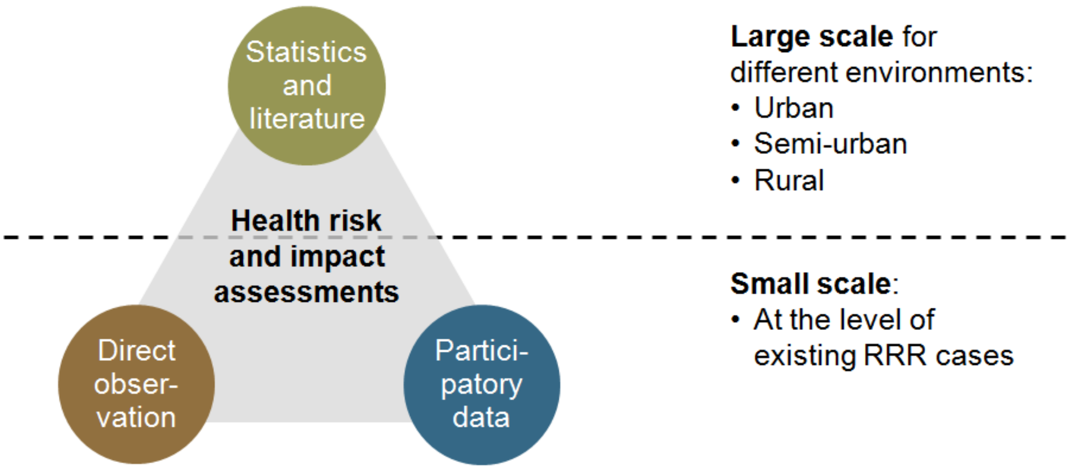

Figure 2 – Methodological triangulation for the health risk and impact assessments

2.1 Baseline data collection activities

The description of the epidemiological profile, environmental parameters and other contextual information of Lima is a crucial element of the health assessments. The baseline data collection activities involved the assembling of secondary data, as well as primary data collection exercises. The data from various sources is presented in Chapter 3, entitled 'evidence-base of the HRA and HIA'. In order to remain focused on health issues that have a direct link to sanitation systems and resource reuse activities, the epidemiological profile is structured along three disease groups: (i) soil-, water- and waste-related diseases; (ii) respiratory tract diseases; and (iii) vector-borne diseases.

2.1.1 Data collection at the level of existing RRR cases

With the goal to determine the range and magnitude of potential occupational and community health risks associated with the proposed BMs for Lima, a number of existing RRR cases were assessed. In addition, it was considered important to evaluate the cultural and financial acceptability of health risk mitigation measures in the given context. The selection of existing RRR cases aimed at covering cases that have as many as possible commonalities with the BMs proposed for the feasibility studies in Lima. In total, 7 existing RRR cases were analysed:

- Case 1: Wastewater treatment for irrigation: Fundo Palo Alto
- Case 2: MSW collection service- San Luis Municipality-Recyclers
- Case 3: Treated wastewater for irrigation/fertilizer/energy: Parque Zonal Huascar
- Case 4: High quality branded/certified organic fertilizer form faecal sludge and municipal solid waste (MSW) & onsite energy generation: ECO Granja "Camila" (pig farm)
- Case 5: Phyto-remediative water treatment and fish production (Tilapia ponds): urban agricultural family business, Carapongo, Lurigancho
- Case 6: High Quality Branded/Certified Organic Fertilizer from Faecal Sludge X-runners - Dry toilets- Sanitation Solution in urban Areas
- Case 7: Phyto-remediative water treatment and fish production (Tilapia ponds): Union University

For the data collection at the level of existing RRR cases, a specific set of tools and methods was developed. A detailed description of the different working steps and associated survey tools is provided in Annex I. The main steps can be summarized as follows:

1. Case description: this includes a system flow diagram and a process description, as well as the identification and characterization of different exposure groups (i.e. farmers, workers, local community and consumers)
2. Identification of health hazards, exposure routes and validation of existing control measures: this step was carried out by means of the 'tool for hazard identification, control validation and risk assessment'
3. Risk assessment: the ranking of the risk associated with each health hazard aimed at identifying which of the health hazards are already well controlled or insignificant, while highlighting those that represent a major health risk. For this purpose a semi-quantitative risk assessment was performed
4. Key informant interviews (KII) and community focus group discussions (FGD): the KII were carried out (i) with the RRR case business owner/operator and (ii) health care providers in proximity to the RRR case. In the community living in proximity to the RRR business case, FGD were conducted. Both KII and FGD were guided by semi-structured questionnaire routes
5. Worker questionnaire: a questionnaire-based interview was conducted with the workers of existing RRR cases, covering the following topics: (i) worker health; (ii) worker risk perception; (iii) worker safety (e.g. use and acceptance of personal protective equipment (PPE)); (iv) reasons for potentially missing PPE; and (v) willingness to pay for potential controls/mitigation.

The data that were collected in the different case studies are summarised in Annex II.

2.1.2 In-depth studies

In addition to the data collection activities at the level of existing RRR cases, in-depth studies on the concentration of heavy metals, protozoa and helminth eggs were carried out in the frame of the pre-testing of the Sanitation Safety Planning (SSP) manual in Lima.

For the pre-testing of the SSP manual in Lima, two study sites were selected: the agricultural area in Cono Este (peri-urban area of Lima) and the Parque Husacar in Lima city. In the frame of those two case studies, the team led by Dr Julio Moscoso collected a large number of environmental samples (water, soil and plant) for determining the presence and/or concentration of heavy metals, bacteria, protozoa and helminth eggs. Hence, the data generated by the SSP manual trials make an important contribution to the evidence-base of the HRIA. The detailed methodology and findings of the trials are presented elsewhere [2, 3]. A summary of key environmental parameters is provided in Chapter 3.

2.2 Health risk assessment

The objectives of the HRA were: (i) to identify potential biological, chemical and physical hazards and hazardous events associated with the proposed BMs in the given context; (ii) to define a set of mitigation measures that need to be incorporated in the final BM description for eliminating or controlling the identified risks; and (iii) to assess the residual health risk with the proposed control measures in place, taking into account the technical efficiency and cultural acceptability in the given context. For this purpose, the HRA combined the findings of the various data collection activities with the technology of the proposed BMs. The ultimate goal of the HRA was to assess whether potential health risks of proposed BMs can be managed appropriately. The approach described in the subsequent sub-chapters has been applied to each BM proposed for Lima.

2.2.1 Input characterization and quality requirements for outputs

As an entry point for the HRA, input-resources of the BM (e.g. solid and liquid waste products) were characterized in terms of composition and potential associated health hazards. Source documents for this initial step were the ‘technology assessment’ and the ‘waste supply and availability’ reports for Lima [4]. For the outputs of the BM, quality requirements at national level are listed as per the institutional analysis for Lima [5]. Where no national standards were available, international standards are referenced such as those set by the WHO guidelines on the safe use of wastewater, excreta and greywater or the United States Environmental Protection Agency (USEPA) [6].

2.2.2 Identification of potential health hazards linked to specific processes

In consideration of the epidemiological and environmental baseline data for Lima, potential biological, chemical and physical health hazards were identified for each of the processes described for the BM:

- Biological hazards: constituents with the potential for impacts on occupational and public health such as viruses bacteria, pathogenic protozoa, helminth eggs and disease vectors
- Chemical hazards: chemicals with the potential for causing acute or chronic health effects, i.e. organic and inorganic substances and those with accumulative effects such as heavy metals and pharmaceuticals
- Physical hazards: dangers that could result in injury to the workers (e.g. open water bodies, working at height, noise pollution and radiation)

In a next step, hazardous events linked to each of the identified hazards (e.g. discharge of untreated waste or release of toxic gases) were described. Potential exposure groups were also taken into account in this process. Finally, general issues (e.g. operational matter), which cannot be assigned to a specific process of the BM but would rather affect the entire operation, were also added to the list of hazardous events in order to be considered in the subsequent steps of the risk assessment.

2.2.3 Identification and appraisal of control measures

For each of the health hazards and hazardous events identified under the previous step, options available to control the hazard were listed. The full range of control measures were considered such as physical barriers (e.g. screening or filtration), physical processes (e.g. sedimentation, decomposition), chemical treatment options (e.g. chlorination), disease prophylaxis (e.g. preventive chemotherapy), behavioural measures (e.g. health education), protective measures (e.g. PPE) and modifications/additions to the design of the technical components of the BM (e.g. covering open water bodies, access restriction, retention basins, protection shields and backup generators). Since in many cases multiple control options for a given hazard exist, a prioritization was made by rating the technical efficiency and acceptability (which includes cost considerations) of the proposed measure. This rating of the ‘mitigation potential’ of the control measure was based on the multiplication of a technical efficiency score (low: 1; medium: 2; and high: 3) with the acceptability score (low: 1; medium: 2; and high: 3). Resulting values were classified into three levels of mitigation potential:

- Low mitigation potential of the control measure: range 1-3;
- Medium mitigation potential of the control measure: range 4-6; and
- High mitigation potential of the control measure: range 7-9.

For the appraisal and mitigation of biological health hazards, the pathway of pathogens through the technical process of the BM was determined and log reduction rates were indicated as per the 2006 WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (here after referred to as ‘WHO 2006 Guidelines’) [6] and other source documents. In consideration of the reuse scenario of the different products of the BM, it was evaluated whether the technical processes of the BM (e.g. retention time; processing temperature) allow for compliance with the pathogen thresholds defined by WHO, as well as national standards. Recommendations for improving pathogen reduction throughout the process were made where indicated. In case the targeted reduction rate could not be achieved along the technical process of the BM, a multi-barrier approach, as proposed by the WHO Guidelines, was considered, with additional control measures at the level of inputs, reuse activities or consumers. The acceptability and feasibility of such 'outside the system' control measures was taken into account in the subsequent risk assessment.

The appraisal and mitigation of chemical health hazards followed the same process as for biological hazards, though, no log reduction rates apply and considerable data gaps exist. For chemical hazards with unknown transformation and elimination processes, the worst case scenario (i.e. no reduction by simple physical processes) applied.

In most instances, physical health hazards can be mitigated by means of PPE, which has a high technical efficiency if applied appropriately. Since workers will often operate multiple processes, the choice of PPE needed has to be made on an individual basis. Therefore, the summary term PPE was used for the control measure indication. Guidance on which type of PPE is required to prevent specific physical hazards is provided in Annex II.

2.2.4 Semi-quantitative risk assessment

By means of a semi-quantitative risk assessment, the theoretical residual risks of the proposed BM were assessed, i.e. under the assumption that the identified control measures are in place. For this purpose the **impact level** (IL) (ranging from insignificant to catastrophic) and the **likelihood or frequency** (LoF) of the hazardous event to occur were determined for each of the identified health hazards, according to the definitions provided in Table 3. Of note, for determining the likelihood or frequency of occurrence, the mitigation potential (i.e. the combination of technical effectiveness and acceptability of the proposed control measure) was taken into account. The combination of the likelihood or frequency with the level of impact resulted in a **risk score** (RS) (RS = IL x LoF; low risk: <6; moderate risk: 7–12; high risk: 13–32; and very high risk: ≥32) as illustrated by the risk matrix in Figure 3. The entire rating was based on a modified Delphi approach {Rowe, 1999 #90}; a technique intended for use in judgement and forecasting situations in which pure model-based statistical methods are not practicable. In practice this means that the risk assessment was performed by multiple assessors who found an agreement on the final rating.

Table 3 – Definition of impact level, and likelihood for the HRA (adapted from [7])

IMPACT LEVEL (I)		
Category	**Score**	**Description**
Insignificant	**1**	No health consequences anticipated and no impact on normal operations
Minor impact	**2**	Impact not resulting in any perceivable or measurable health effect; easily manageable disruptions to operation; no rise in complaints anticipated
Moderate impact	**4**	Impact resulting in minor disability (e.g. fever, headache, diarrhoea, small injuries) or unease (e.g. noise, malodours); may lead to complaints or minor community annoyance; operations may be disrupted for short duration
Major impact	**8**	Impact resulting in moderate disability (e.g. acute intoxication, malaria, injury) or minor disability of long duration; may lead to legal complaints and major community concerns; operations could be significantly affected by the impact
Catastrophic impact	**16**	Impact resulting in severe disability, chronic disease or even loss of life; major investigation by regulator with prosecution are likely; can lead to complete failure of system
LIKELIHOOD or FREQUENCY (LoF)		
Category	**Score**	**Description**
Very unlikely	**1**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is very unlikely that exposure to the health hazard will occur (odds: <5%). Frequency: once every 5 years
Unlikely	**2**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is unlikely that exposure to the health hazard will occur (odds: 5–40%). Frequency: once a year
Possible	**3**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is possible that exposure to the health hazard will occur (odds: 41-60%). Frequency: once a month
Likely	**4**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is likely that exposure to the health hazard will occur (odds: 61-95%). Frequency: once a week
Almost certain	**5**	In consideration of the technical effectiveness and local acceptability of proposed control measures, it is almost certain that exposure to the health hazard will occur (odds: >95%). Frequency: once a day

Risk score: (RS) = (IL) x (LoF) Very high risk >32 High risk 13–32 Moderate risk 7–12 Low risk <6	IMPACT LEVEL (IL)				
	Insignificant (1)	Minor impact (2)	Moderate impact (4)	Major impact (8)	Catastrophic impact (16)
LIKELIHOOD or FREQUNCY (LoF): 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

Figure 3 – Semi-quantitative assessment matrix (adapted from [7])

2.3 Health impact assessment

The objective of the HIA was to assess potential health impacts at community level of proposed BMs for Lima under the assumption that the control measures proposed by the HRA are deployed. This included consideration of both potential health benefits (e.g. operation resulting in reduced exposure to pathogens since it entails treatment of wastewater) and adverse health impacts (e.g. toxic emissions of an operation, which cannot be avoided). The findings of the various data collection activities served as evidence-base for the HIA. The approach described in the subsequent sub-chapters has been applied to each BM proposed for Lima.

2.3.1 Definition of impact pathways

The impact definition is a description of the pathway(s) the BM may impact on the health status of affected communities (e.g. decrease in the incidence of diarrhoeal diseases due to reduced pathogen loads in irrigation water). Once the potential impact pathways of a BM were identified, literature that provides evidence for the direction and magnitude of the potential health impacts was reviewed and reference added.

2.3.2 Semi-quantitative impact assessment

By means of a semi-quantitative risk assessment, the potential health impacts of the proposed BM were characterized in terms of nature (positive or negative) and magnitude (minor to major). For this purpose the **IL** (ranging from major negative impact to major positive impact), the **LoF** of the impact to occur and the estimated number of **people affected** (PA) were determined for each of the identified potential health impact (see definitions provided in Table 3). Of note, in order to be able to make an estimation of people affected, an assumption was made about the scale a BM could reach in Lima area. The assumption was clearly stated at the end of the introduction of the HIA of each BM.

The combination of the IL with the LoF and the estimated number of people affected resulted in the magnitude of the health impact (Magnitude = IL x LoF x PA; low positive impact: 0–4; moderate positive impact: 10–4,499; high positive impact: ≥4,500; low negative impact: 0– -4; moderate negative impact: -10– -4,499; and high negative impact: ≤-4,500) (see risk matrix in Figure 4). As for the HRA, the rating for the HIA was based on a modified Delphi approach (Rowe and Wright, 1999).

Table 4 – Definition of impact level and likelihood for the HIA (adapted from [8])

IMPACT LEVEL (IL)		
Category	**Score**	**Description**
Major positive impact	**1**	Impact reduces incidence of diseases or injury, resulting in severe disability, chronic disease or even loss of life
Moderate positive impact	**0.5**	Impact reduces incidence of diseases or injury, resulting in moderate disability that may require hospitalisation (e.g. acute intoxication, malaria, injury) or minor disability of long duration
Minor positive impact	**0.1**	Impact reduces incidence of disease or injury, resulting in minor disability of short duration (e.g. acute diarrhoea, acute respiratory infection) that does not require hospitalization
Insignificant	**0**	Impact not resulting in any perceivable or measurable health effect
Minor negative impact	**-0.1**	Impact increases incidence of diseases or injury, resulting in minor disability of short duration (e.g. acute diarrhoea, acute respiratory infection) that does not require hospitalization
Moderate negative impact	**-0.5**	Impact increases incidence of diseases or injury, resulting in moderate disability that may require hospitalisation (e.g. acute intoxication, malaria, injury) or minor disability of long duration
Major negative impact	**-1**	Impact increases incidence of diseases or injury, resulting in severe disability, chronic disease or even loss of life
PEOPLE AFFECTED (PA)		
Category	**Score**	**Description**
Individual cases	**1**	A few individuals are concerned by the impact (e.g. road traffic accidents)
Specific population	**100**	A relatively small specific population group is concerned by the impact (e.g. people living in proximity to an operation)
Medium population group	**1,000**	A medium size population group is concerned by the impact (e.g. people living downstream a river that may be contaminated by an operation)
Large population group	**10,000**	A large population group is concerned by the impact (e.g. consumers of a widely used product of an operation)
Major population group	**100,000**	A major population group is concerned by the impact (e.g. a small city that will gain access to safe drinking water)
LIKELIHOOD or FREQUENCY (LoF)		
Category	**Score**	**Description**
Very unlikely	**0.05**	It is very unlikely that the impact will occur (odds: <5%). Frequency: once every 5 years
Unlikely	**0.3**	It is unlikely that the impact will occur (odds: 5–40%). Frequency: once a year
Possible	**0.5**	It is possible that the impact will occur (odds: 41-60%). Frequency: once a month
Likely	**0.7**	It is likely that the impact will occur (odds: 61-95%). Frequency: once a week
Almost certain	**0.95**	It is almost certain that the impact will occur (odds: >95%). Frequency: once a day

		PEOPLE AFFECTED (PA)				
		Individual cases	Specific population	Medium population group	Large population group	Major population
		1	**100**	**1,000**	**10,000**	**100,000**
IMPACT LEVEL (IL) Major positive impact	**1**	0.05	30	500	7,000	95,000
Moderate positive impact	**0.5**	0.03	15	250	3,500	47,500
Minor positive impact	**0.1**	0.01	3	50	700	9,500
Insignificant	**0**	0.00	0.00	0.00	0.00	0.00
Minor negative impact	**-0.1**	-0.01	-3	-50	-700	-9,500
Moderate negative impact	**-0.5**	-0.03	-15	-250	-3,500	-47,500
Major negative impact	**-1**	-0.05	-30	-500	-7,000	-95,000
		0.05	**0.3**	**0.5**	**0.7**	**0.95**
		Very unlikely	Unlikely	Possible	Likely	Almost certain
		LIKELIHOOD or FREQUENCY (LoF)				

Figure 4 – Impact assessment matrix (adapted from [8])

2.4 Environmental Impact Assessment

The EIA is based on the same input characterization and quality requirements for outputs as the HRA. Each business model consists of a process for the conversion of waste into a resource. Along the process of conversion, several potential environmental hazards were identified and mitigation measures considered. These hazards and mitigation measures are presented in this report in the last section of each business model chapter. The technology assessment report describes technologies for mitigation in more detail {Schoebitz, 2014 #137}. A more thorough impact assessment, based on environmental pollution, can be performed once business models are selected, that must include specific information such as scale, location and market demand for End-products.

3 Evidence-base for the HRA and HIA

3.1 Epidemiological profile

Over the past decade, Peru has been facing an epidemiological transition. While infectious diseases such as lower respiratory infections, diarrhoeal diseases and tuberculosis were principal causes of mortality in 1990, there is now a double burden of communicable and non-communicable, with increasing importance of non-communicable diseases and injuries [9, 10]. This change is illustrated in Figure 5, which compares the top 25 causes of years of life lost (YLLs) in 1990 and 2010 in Peru [11]. According to WHO estimates, non-communicable diseases (NCD) accounted for 66% of all deaths in Peru in 2010 [12]. Of note, there is considerable variation in the burden of diseases between the different regions of Peru and in general, infectious diseases are more important in rural areas than urban centres such as Lima.

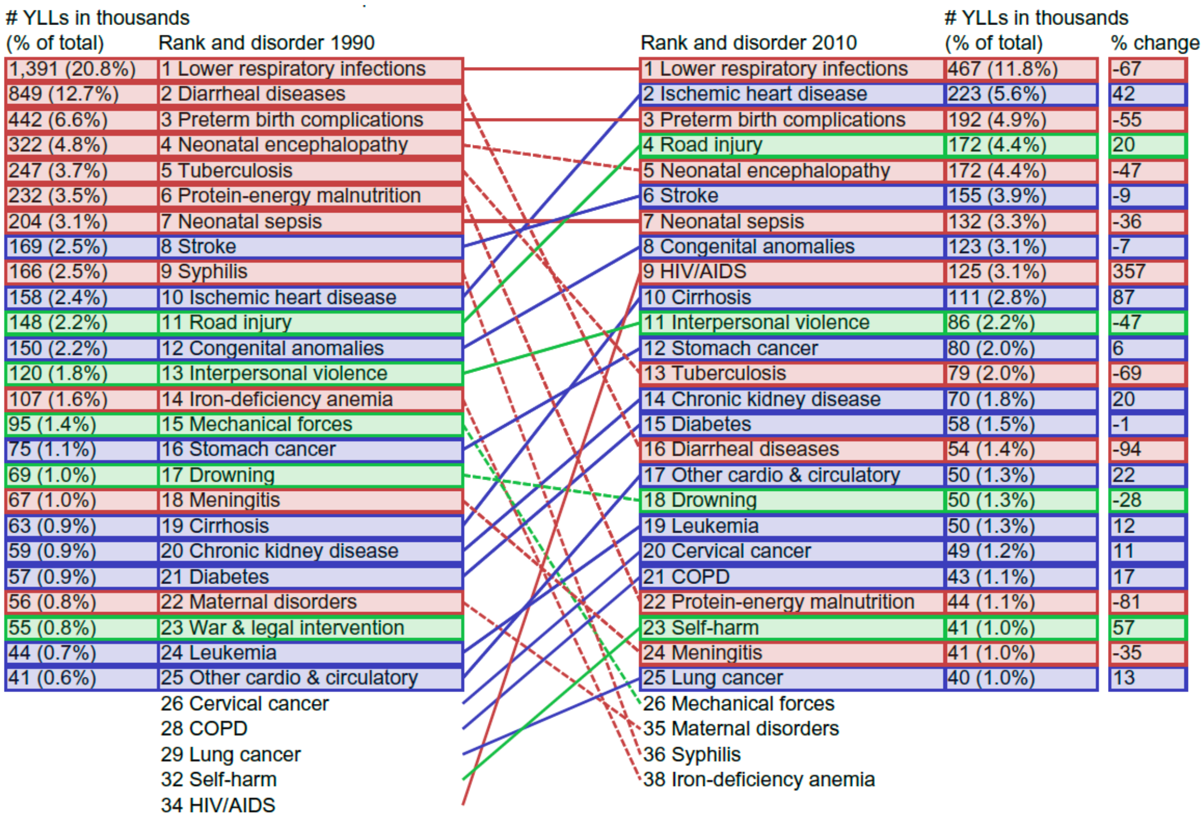

Figure 5 – Ranks for top 25 causes of YLLs 1990-2010, Peru [11]

In order to get estimates of morbidity patters in urban and peri-urban areas of Lima, statistics from principal health facilities located in the districts where the data collection activities at the level of existing RRR cases took place (i.e. Lurigancho, Villa el Salvador and Lurin districts, and San Luis municipality) were collected. In Table 5, Table 6, Table 7 and Table 8, health outcomes of reported cases in the years 2009, 2010 and 2011 are presented for Lurigancho, Villa el Salvador and Lurin districts, as well as San Luis municipality.

Independent of the location, respiratory diseases, diseases of the digestive system and different infectious and parasitic diseases were the leading causes of morbidity at the represented health facilities. A closer look at the statistics reveals that upper respiratory tract infections and intestinal infections are the principal cause for consulting a health facility, with most patients being under the age of 5 years. These diseases are mostly caused by viruses, bacteria or protozoa and have a strong link to personal hygiene and sanitation practices. Of course, also exposures to human and animal wastes or the use of unsafe drinking water play a role in this. Helminth infections are responsible for only about 2% of consultations at the represented health facilities. Overall, respiratory infections and soil- water- and waste-related diseases play are important contributors to the burden of disease in urban and peri-urban areas of Lima. Vector-related diseases are not frequently reported.

While statistics from the routine health information system provide a comprehensive overview of potential disease patterns in Lima area they have distinct limitations: (i) the diagnostics behind the statistics presented are not fully understood (ii) and not the entire population may have adequate access to health care services.

Table 5 – Disease profile Lurigancho District 2009-2011

LURIGANCHO DISTRICT (CHOSICA)	TOTAL CASES 2009-2011	Total cases 2009	Total cases 2010	Total cases 2011
Respiratory diseases	**156,225**	53,749	53,091	49,385
Diseases of the digestive system	**73,580**	23,948	26,964	22,668
Different infectious and parasitic diseases	**59,076**	20,999	19,442	18,635
Musculoskeletal disorders	**30,446**	10,196	9,966	10,284
Urogenital disorders	**28,648**	9,282	9,405	9,961
Traumatisms, intoxications, (external factors)	**25,965**	8,490	8,903	8,572
Adverse skin conditions	**24,094**	8,251	7,941	7,902
Others	**19,138**	6,393	6,458	6,287
Endocrine, nutritional and metabolic diseases	**15,558**	4,025	5,371	6,162
Pregnancy, delivery and post-natal care	**11,603**	3,149	4,303	4,151
Mental health and behavioural diseases	**11,341**	3,524	4,436	3,381
Ocular diseases	**10,683**	4,005	3,557	3,121
Blood-, liver- and immunological diseases	**8,858**	3,055	2,850	2,953
Cardiovascular diseases	**6,591**	2,215	2,250	2,126
Diseases affecting the hearing system and sinuses	**4,686**	1,640	1,680	1,366
External causes of morbidity and mortality	**2,803**	949	879	975
Neurological disorders	**2,723**	1,052	819	852
Tumours (neoplasia)	**2,548**	735	942	871
Perinatal conditions	**1,561**	589	604	368
Congenital and chromosomal abnormalities	**1,354**	465	447	442
TOTAL	**497,481**	**166,711**	**170,308**	**160,462**

Table 6 – Disease profile of Villa el Salvador District 2009-2011

VILLA EL SALVADOR DISTRICT	TOTAL CASES 2009-2011	Total cases 2009	Total cases 2010	Total cases 2011
Respiratory diseases	270,140	101,518	90,821	77,801
Diseases of the digestive system	107,843	37,131	34,671	36,041
Different infectious and parasitic diseases	96,365	35,038	31,883	29,444
Urogenital disorders	51,184	17,276	16,821	17,087
Endocrine, nutritional and metabolic diseases	40,520	14,077	11,858	14,585
Musculoskeletal disorders	33,593	11,792	11,102	10,699
Adverse skin conditions	29,286	9,716	10,560	9,010
Pregnancy, delivery and post-natal care	26,464	8,968	8,486	9,010
Traumatisms, intoxications, etc	19,916	7,050	6,108	6,758
Others	18,111	7,890	5,346	4,875
Blood-, liver- and immunological diseases	17,071	5,893	5,344	5,834
Mental health and behavioural diseases	15,100	5,685	4,777	4,638
Cardiovascular diseases	8,499	3,024	2,511	2,964
Ocular diseases	5,845	1,938	1,740	2,167
Diseases affecting the hearing system and sinuses	4,387	1,564	1,456	1,367
Neurological disorders	4,096	1,568	1,270	1,258
External causes of morbidity and mortality	3,368	1,171	1,149	1,048
Tumours (neoplasia)	2,385	850	776	759
Perinatal conditions	2,382	725	771	886
Congenital and chromosomal abnormalities	939	336	346	257
TOTAL	757,494	273,210	247,796	236,488

Table 7 – Disease profile of San Luis 2009-2011

SAN LUIS	TOTAL CASES 2009-2011	Total cases 2009	Total cases 2010	Total cases 2011
Respiratory diseases	28,334	10,378	9,547	8,409
Diseases of the digestive system	13,616	4,973	4,982	3,661
Different infectious and parasitic diseases	7,586	3,003	2,477	2,106
Urogenital disorders	6,598	2,510	2,203	1,885
Ocular diseases	5,552	1,795	1,832	1,925
Adverse skin conditions	4,714	1,721	1,582	1,411
Mental health and behavioural diseases	4,563	1,544	1,585	1,434
Musculoskeletal disorders	4,085	1,396	1,380	1,309
Traumatisms, intoxications, etc	4,073	1,348	1,336	1,389
Others	3,828	1,294	1,340	1,194
Endocrine, nutritional and metabolic diseases	2,408	925	802	681
Blood-, liver- and immunological diseases	1,717	619	532	566
Diseases affecting the hearing system and sinuses	1,332	483	437	412
Cardiovascular diseases	1,069	362	317	390
Pregnancy, delivery and post-natal care	768	365	197	206
External causes of morbidity and mortality	386	123	140	123
Neurological disorders	278	118	89	71
Tumours (neoplasia)	196	46	70	80
Perinatal conditions	149	49	45	55
Congenital and chromosomal abnormalities	113	33	38	42
TOTAL	91,365	33,085	30,931	27,349

Table 8 – Disease profile of Lurin District 2010-2011

LURIN DISTRICT	TOTAL CASES 2009-2011	Total cases 2010	Total cases 2011
Respiratory diseases	41,826	23,296	18,530
Diseases of the digestive system	29,727	15,700	14,027
Different infectious and parasitic diseases	13,316	7,384	5,932
Urogenital disorders	8,710	4,748	3,962
Endocrine, nutritional and metabolic diseases	6,093	3,592	2,501
Traumatisms, intoxications, etc	5,404	3,148	2,256
Others	4,878	2,809	2,069
Musculoskeletal disorders	4,837	2,798	2,039
Pregnancy, delivery and post-natal care	4,623	2,567	2,056
Adverse skin conditions	3,650	2,165	1,485
Blood-, liver- and immunological diseases	2,549	1,504	1,045
Mental health and behavioural diseases	1,297	501	796
Diseases affecting the hearing system and sinuses	1,269	789	480
Cardiovascular diseases	1,098	654	444
External causes of morbidity and mortality	929	570	359
Ocular diseases	832	488	344
Neurological disorders	807	448	359
Tumours (neoplasia)	544	293	251
Perinatal conditions	113	69	44
Congenital and chromosomal abnormalities	80	51	29
TOTAL	132,582	73,574	59,008

The following sub-chapters focus on soil- water- and waste-related diseases, respiratory diseases and vector-related diseases that are frequently reported in the wider Lima area. The Peruvian Ministry of Health Peru (Ministerio de Salud (MINSA)) and its epidemiological division (Dirección General de Epidemiología) have a sophisticated health information system, including geospatial disease mapping, that is publicly accessible (www.minsa.gob.pe and http://www.dge.gob.pe/salasit.php). Since this data base covers all the principal morbidities of Peru, most of the data presented is deriving from those sources [9, 13, 14].

3.1.1 Soil-, water- and waste-related diseases

The prevalence of soil-, water- and waste-related diseases depends highly on sanitation facilities and access to safe drinking water, factors which often show high local variations. With regard to access to sanitation facilities, the 2012 Peru Demographic and Health Survey (PDHS) found that three in four households in urban areas have access to piped drinking water inside their house and are connected to the sewerage system [15]. In Lima, the percentage of houses that are connected to the sewerage system is 90.3%, which is clearly above the national average [13]. In 2012, 6.3% of the households in Lima collected their drinking water from a pipe or fountain outside their house or apartment [15].

3.1.1.1 Diarrhoeal diseases

Diarrhoeal disease is the second leading cause of death in children under 5 years old, though it is both preventable and treatable. It is estimated that diarrhoea kills around 760’000 children under five each year and it is a leading cause of malnutrition in the same age group. A significant proportion of diarrhoeal disease can be prevented through safe drinking-water and adequate sanitation and hygiene. Globally, there are nearly 1.7 billion cases of diarrhoeal disease every year [16].

In Peru, 627'635 cases of acute watery diarrhoea were reported in 2013, with half of the cases affecting the U5 age group. Of those cases, 148'136 occurred in Lima, which is also linked to the high population of the capital city [14]. In 2013, the incidence of diarrhoea in Lima is at 28.69–42.69 cases per 1'000 inhabitants, which is in the medium range when compared to the other regions of the country (see Figure 6). In most cases, the specific cause of diarrhoeal disease is not determined. It has also to be noted that the numbers presented are likely to be underestimated since not all people consult a health facility in the event of acute diarrhoeal.

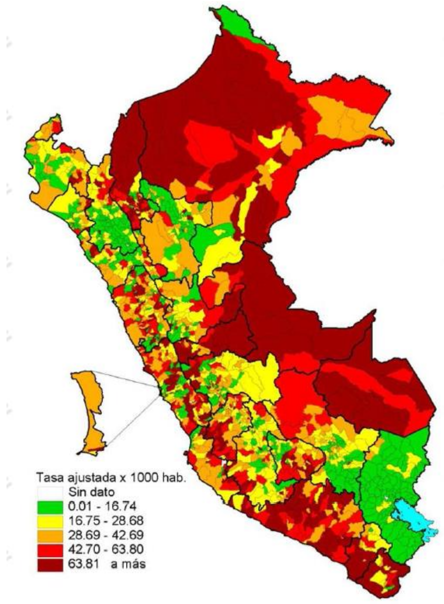

Figure 6 – Incidence of watery diarrhoea in Peru (2013) [14]

3.1.1.2 Helminth infections and intestinal protozoa

Soil-transmitted helminth (STH) infections are the most common helminth infections worldwide. Also intestinal protozoa show a worldwide distribution with infection being highest in infants and children. In Peru, helminth infections and intestinal protozoa have been widely studied in rural areas, because they are an important public health concern. The situation presents a bit different in Lima. Due to the dry climate and the urban environment, STH are less frequent than in rural areas, though intestinal protozoa are an important cause for chronic diarrhoea. No specific information on the incidence and prevalence of helminth infections and intestinal protozoa is made available by the MINSA and little studies exist on this issue in Lima. Between 2004 and 2005 a survey assessed the prevalence of infection with enteroparasites in primary schoolchildren of three national schools of an urban zone from Santiago de Surco district, Lima [17]. Stool samples of 192 children were collected and subjected to examinations in the laboratory. The following prevalence rates of intestinal protozoa were found: *Entamoeba coli*: 22.9%; *Endolimax na*na: 19.3%; and *Blastocystis* *hominis*: 12.5%. Prevalence rates of other intestinal protozoa species where below 5%. *Enterobius vermicularis* was the predominant helminth species at 10.4% of children that were infected. Hookworm and *Ascaris lumbricoides* prevalences were at 1.6% and 0.5% of the children were infected with *Trichuris trichiura*. Overall, 47.4% of the children had some form of protozoa infection and 14.6% showed a helminth infection. Interestingly, the study identified the presence of domestic animals as primary risk factor for helminth infections. Infection with intestinal protozoa was primarily associated with the absence of drinking water and sewage services. A more recent study conducted in 258 street children in orphanages across Lima found similar rates than the study from 2005 [18]. Two in three children (62.8%) were infected with pathogenic intestinal protozoa and 15.1% were infected with a helminth species (see Table 9). These two studies show clearly that intestinal protozoa and helminth infections are an important health issue among children in Lima, though many infections may be asymptomatic or result in minor disability.

Table 9 – Prevalence of intestinal parasitic infections in street children, Lima (2011) [18]

N=258	Number infected	Percentage
Protozoa	**162**	**62·8%**
Entamoeba coli	108	41·9%
Endolimax nana	83	32·2%
Giardia lamblia	44	17·1%
Chilomastix mesnilli	30	11·6%
Cyclospora cayetanensis	9	3·5%
Iodamoeba butschlii	1	0·4%
Helminths	**39**	**15·1%**
Hymenolepis nana	20	7·8%
Trichuris trichiura	13	4·7%
Ascaris lumbricoides	9	3·5%
Ancylostoma/Necator	3	1·2%

3.1.2 Respiratory tract diseases

Respiratory tract diseases are diseases that affect the air passages, including the nasal passages, the bronchi and the lungs. They range from acute infections, such as pneumonia and bronchitis, to chronic conditions such as asthma and chronic obstructive pulmonary disease.

3.1.2.1 Acute respiratory tract infections

Acute respiratory infections (ARI) (e.g. pneumonia) are an abnormal inflammation of the lung and have a variety of causes including bacteria, viruses, fungi or parasites. ARI are the most common cause of death in children and kills about 3 million children every year in the developing world. Children under the age of 5 years, and especially those under 2 years, constitute the greatest risk group. ARI can be spread in a number of ways. The most important transmission pathway is air-borne droplets from a cough or sneeze of an infected individual. But also transmission via wastewater and food products that are contaminated with human waste is an important transmission pathway, and thus indirectly associated with sanitation and drinking water systems, as well as resource recovery and reuse activities.

The health statistic obtained from different districts in Lima (see section 3.1) show, that respiratory diseases were the leading cause for consultations at the represented health facilities, with children of the U5 age group being most affected. Most of those cases present with upper respiratory tract infections, which are caused by a range of bacteria and viruses. Chronic respiratory tract conditions affecting the lower part of the lungs are also frequently reported at health facilities in Lima, though about 10-times less than upper respiratory tract infections.

3.1.2.2 Chronic respiratory diseases

The most common non-infectious respiratory diseases are asthma, chronic obstructive pulmonary disease (COPD), respiratory allergies and pulmonary hypertension. In 2005, COPD caused more than 3 million deaths, with 90% of those occurring in low- and middle-income countries [19]. COPD is predicted to be the third most common cause of death in 2030. Risk factors include tobacco smoking, indoor air pollution (e.g. indoor cooking with wood or coal), outdoor air pollution (e.g. burning domestic waste or traffic related dust), allergens and occupational exposure (e.g. asbestos, silica, certain gasses). In addition to causing chronic respiratory diseases, indoor and outdoor air pollution is also directly associated with cardiovascular disease such as hyper tension, stroke and cardiac infarction. The 2007 Peruvian census found that only 5% of the population in Lima was exposed to smokes from the cooking fuels coal, wood or dung [20]. This number may have further decreased in recent years.

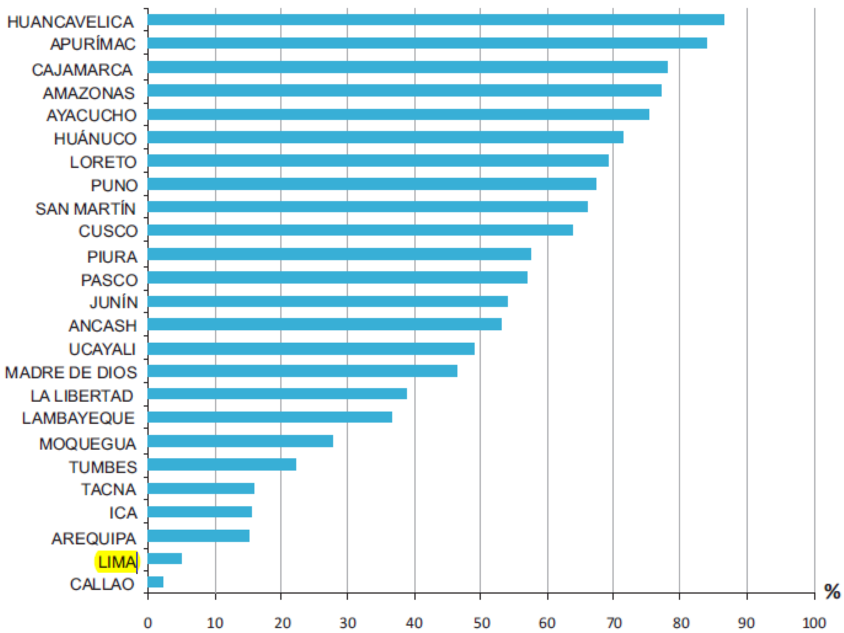

Figure 7 – Percentage of households being exposed to indoor smoke [20]

In Peru, chronic respiratory diseases and cardiovascular diseases account for 4% and 22% of total mortality (all ages, both sexes), according to estimates of the WHO (see Figure 8)

[12]. Taken together, those two health conditions account for one in 5 deaths in Peru, which makes exposure to indoor and outdoor air pollution an important public health concern.

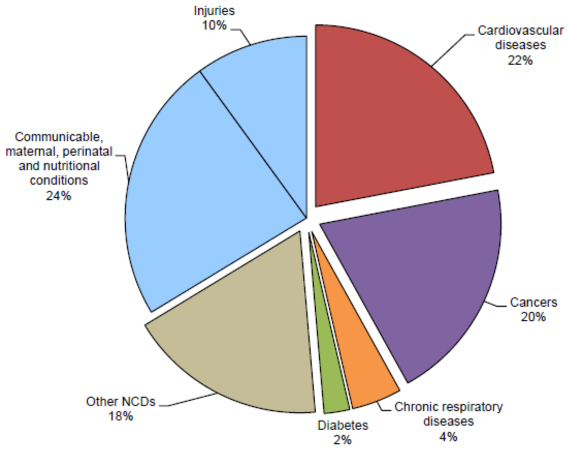

Figure 8 – NCD-related mortality (%), all ages, both sexes, Peru (2010) [12]

3.1.3 Vector-borne diseases

In the terminology of epidemiology, vectors are organisms that transmit infections from one host to another. The most commonly known biological vectors are arthropods but many domestic animals are also important vectors or asymptomatic carriers of parasites and pathogens that can affect or infect humans or other animals. In the present chapter we will focus on diseases associated with mosquito and fly vectors.

Depending on the season, a broad range of mosquito vectors such as *Anopheles spp*., *Aedes spp*. and *Culex spp*. are present in Peru. Therefore, various vector-borne diseases are endemic in the country, particularly in the jungle areas in the north. The most important vector-borne disease in Peru is Dengue, but also malaria, leishmaniasis and Chagas disease are important public health concerns.

3.1.3.1 Dengue

Dengue fever is caused by a virus transmitted by infected *Aedes* mosquitoes. It is one of the most common causes of illness in the world's tropical and subtropical regions. Symptoms are typically flu-like and in rare cases the disease develops into severe dengue (dengue hemorrhagic fever), with potentially life-threatening complications. In 2013, a total of 12'390 cases of dengue fever were reported in Peru with 17 fatalities. Most of those cases were detected in Peru's jungle regions and along the country's northern extremes (near the border with Ecuador). Although outbreaks normally occur in urban areas, Lima is usually not directly affected by the disease, meaning that no local transmission of dengue fever occurs. In 2013, no locally transmitted cases of dengue fever have been reported for Lima as shown in Figure 9 [14].

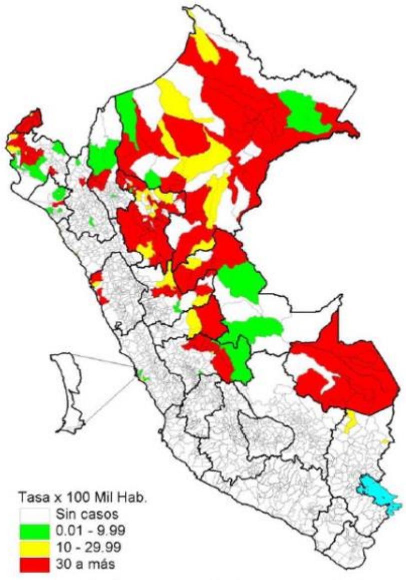

Figure 9 – Incidence of dengue fever in Peru (2013) [14]

3.1.3.2 Malaria

Malaria, a protozoan infection transmitted by anopheline mosquitoes, is the most important parasitic disease in humans. Malaria is one of the most serious public-health issues in many parts of the developing world, but especially so in sub-Saharan Africa. Malaria is also endemic in Peru, though transmission is restricted to jungle regions and along the country's northern extremes (near the border with Ecuador). The predominant *Plasmodium* species in Peru is *Plasmodium vivax*, which does generally not cause life-threatening disease. *Plasmodium falciparum*, the most dangerous *Plasmodium* species, is also endemic in the country but only about 1 in 10 malaria cases are caused by this species. Incidence maps of *P. vivax* and *P. falciparum* malaria are shown in Figure 10 for 2013 [14]. No transmission of malaria occurs in Lima due to the absence of *Anopheles* mosquitoes.

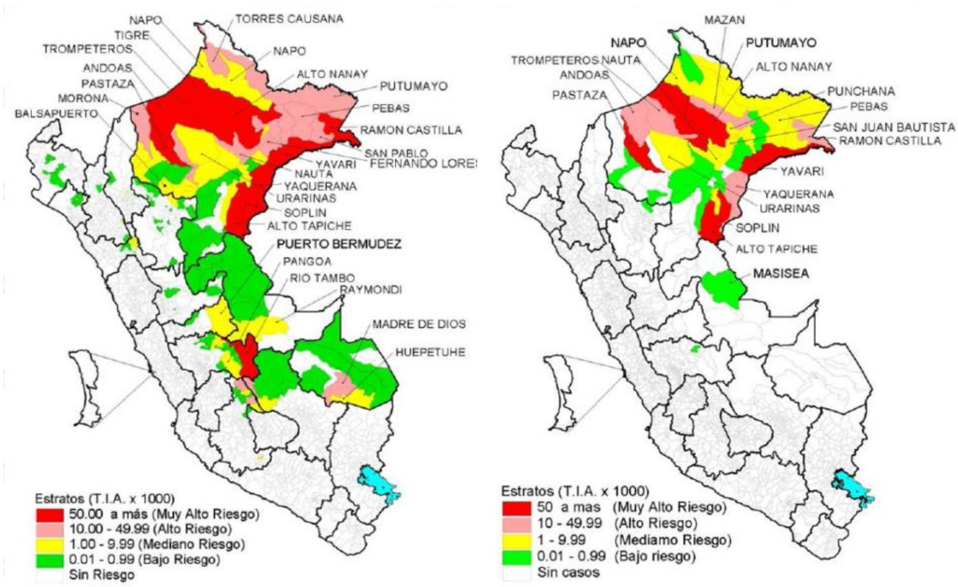

Figure 10 – Incidence of *P. vivax* and *P. falciparum* malaria in Peru (2013) [14]

3.1.3.3 *Leishmaniasis and Chagas diseases*

Leishmaniasis and Chagas diseases are two other vector-borne diseases that are a major public health concern in Peru. The Leishmaniases are diseases caused by protozoan parasites from more than 20 *Leishmania* species that are transmitted to humans by the bites of infected female *Phlebotomine* sandflies. Chagas disease, also known as American trypanosomiasis, is a potentially life-threatening illness caused by the protozoan parasite *Trypanosoma cruzi*. It is found mainly in endemic areas of 21 Latin American countries, where it is mostly transmitted humans by contact with faeces of *triatomine* bugs (also known as 'kissing bugs').

In 2013, a total of 5'122 cases of leishmaniasis were registered in Peru. While no locally transmitted cases of leishmaniasis have been reported for Lima city, incidence of the disease in surrounding districts ranges between 0.01 and 33.6 cases per 100'000 individuals [14]. No transmission of Chagas disease occurs in Lima. Distribution of leishmaniasis and Chagas disease in Peru is shown in Figure 11 [14].

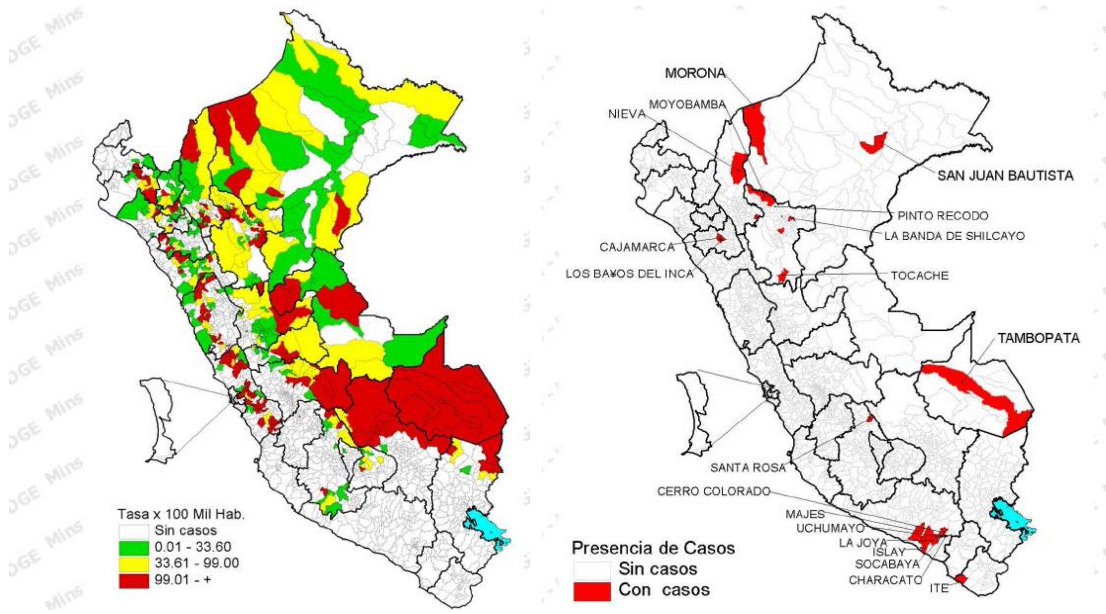

Figure 11 – Distribution of leishmaniasis and Chagas disease in Peru (2013) [14]

3.2 Environmental parameters

Exposure to noise, air pollution, contaminated drinking water, contaminated surfaces and contaminated food products are important environmental determinants of health. For the HRIA of the RRR Project, a sound understanding of potential contaminants of surface waters and waste waters, as well as potential agricultural soils is needed. For example, river water can be polluted with heavy metals due to up-stream industrial activities, which has implications for the use of the river water for irrigation of agricultural surfaces but it will also influence water quality of waste water streams in Lima. This example can be illustrated with heavy metal monitoring data of Rimac River (see Figure 12)[21]. The data show contamination with various heavy metals of which lead and arsenic were above thresholds set by the National Water Resources Act, though not every year. Hence, fluctuations in heavy metal concentrations are evident. Also contamination of the river with faecal coliform bacteria was shown by the same data set, with concentrations of up to 10^8 faecal coliform bacteria per 100 mL (2001-2004), making it unsuitable for irrigation purposes without previous treatment.

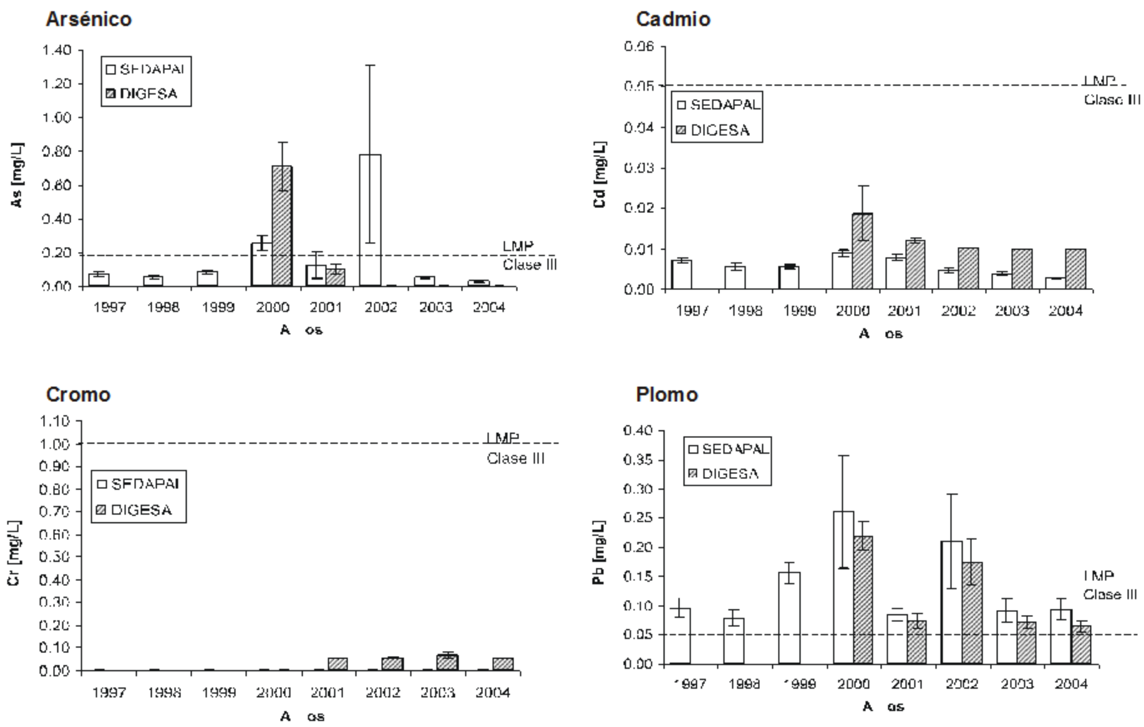

Figure 12 – Concentrations of As, Cd, Cr and Pb in the Rimac River [21]

In the frame of the pre-testing of the Sanitation Safety Planning (SSP) manual in Lima, in-depth studies on the concentration of heavy metals, protozoa and helminth eggs were carried out at two study sites, namely in an agricultural area in Cone Este and the Huascar Parque in Lima city, where treated wastewater is used for the irrigation of the park. Since environmental parameters are likely to have changed considerably in the past decade, the data collected by the SSP trial make an important contribution to the evidence-base for the HRA and HIA. Key data from the trials are presented in the subsequent chapters. A detailed description of the study sites and environmental determinants is available in the respective reports [2, 3].

3.2.1 Environmental sampling at Cono Este study site

At the Cone Este study site of the SSP trials, the Managing Committee and the Technical Working Group (hereafter referred to as 'SSP team') carried out an assessment of the quality of water, grass and vegetables irrigated with water from the river and treatment ponds, as well as fish farmed in those treatment ponds.

A total of 71 samples were collected at three different sites (Universidad Peruana Unión (UPeU) (n=28); Agricultural parcels Carapongo area (n=24); and Agricultural parcels Nievería area (n=19)) on three sampling dates: 21 October, 11 November and 9 December 2013. The sampling plan included the following parameters [2]:

- Elements: river and reservoir water, soil from areas planted with grass and vegetables, grass from irrigated green spaces, vegetables irrigated with water from irrigation canals and reservoirs and fish farmed in the reservoirs.
- Chemical parameters for water: Suspended solids (SS), biochemical oxygen demand (BOD5), N-total, P-Phosphates, salinity and heavy metals (As, Cd, Cr, Pb and Hg).
- Sanitary parameters for water: thermo-tolerant (faecal) coliform bacteria (TTC), nematodes and human protozoan parasites.
- Physical-chemical parameters for soil: pH, organic material, nitrogen, phosphorus, potassium and salinity, and heavy metals (As, Cd, Cr, Pb and Hg).
- Sanitary parameters for soil: TTC, nematodes and human protozoan parasites.
- Chemical parameters for soil: heavy metals (As, Cd, Cr, Pb and Hg).
- Sanitary parameters for grass and vegetables: TTC, nematodes and human protozoan parasites.
- Sanitary parameters for fish: aerobic mesophilic bacteria, *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus* and human parasites

The findings of the environmental sampling at the Cono Este study site are presented in Table 10 and Table 11 [2] and can be summarised as follows:

- Water samples: none of the average values for heavy metals exceeded the national threshold. Protozoa concentrations above the national limit of 0 protozoa per 1 L were detected in water samples from each sampling site. Also helminth eggs were detected in most samples, though the average concentration did not exceed the national limit of ≤1 helminth egg per 1 L.
- Soil samples: concentrations of arsenic and led exceeded national limits at two of the three sampling sites. Cadmium was above the national threshold at one study site.
- Grass samples at UPeU: helminth eggs (A*. Lumbricoides* and *Strongyloides* sp.) were detected on grass surfaces irrigated with wastewater.
- Vegetable samples collected at Carapongo: all the vegetable samples showed contamination with protozoa eggs. Helminth eggs are less of an issue.
- Fish: fish cultivated at the Nievería site showed concentrations of TTC exceeding the national limit of 100 TTC/g (maximum). The maximum concentration of TTC of fish cultivated at the Carapongo site was 3.3 TTC/g.

Table 10 – Environmental parameters in water samples from Cono Este study site

Código	Parámetro	Punto de muestreo	Muestreo			Metales						Protozoos					Helmintos			
				SS	DBO	Cadmio	Cromo	Plomo	Arsenico	Mercurio	Coliformes termo tolarantes	Blastocystis hominis	Endolimax nana	Entamoeba coli	Giardia lamblia	Iodamoeba butsschlii	Ascaris lumbricoides	Hymenolepis nana	Strongyloides sp.	Uncinarias
	Unidad			mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	NMP/100 mL	org./L	org./L	org./L	org./L	org./L	org./L	org./L	org./L	org./L
	Lugar/componente																			
NA	Universidad Peruana Unión de Ñaña:																			
NA-A1	Agua de canal	Garita 1 - puerta principal	M1	99	7.4	0.002	0.003	0.052	43.4	0.2	4.9E+05	5	8	20	15	0	3	0	1	0
			M2	15	5.1	<0.001	<0.002	0.009	17.3	0.1	3.3E+02	3	11	24	9	0	2	0	1	1
			M3	13	8.7	<0.001	<0.002	0.011	31.1	<0.1	1.3E+05	2	3	13	7	0	0	0	1	1
NA-A2	Agua de reservorio	Riego espalda Fam. Mamani	M1	21	5.9	<0.001	<0.002	0.010	32.0	0.1	1.7E+03	0	0	4	0	0	0	0	0	0
			M2	18	6.2	<0.001	<0.002	0.009	21.6	0.1	1.3E+01	0	1	2	0	0	0	0	0	0
			M3	19	3.9	<0.001	<0.002	0.009	20.9	<0.1	1.3E+03	0	1	2	1	0	0	0	0	0
CA	Parcelas agrícolas de Carapongo:																			
CA-A1	Agua de canal	Parcela Raymundo Yaulis	M1	32	2	0.001	<0.002	0.023	32.5	<0.1	3.3E+04	5	8	9	2	0	0	0	1	1
			M2	51	7.5	<0.001	<0.002	0.009	25.7	<0.1	7.0E+05	3	6	11	3	0	0	0	0	1
			M3	36	3.0	0.002	<0.002	0.093	37.4	0.2	7.0E+04	2	3	6	5	0	0	0	0	1
CA-A2	Agua de reservorio	Reservorio Raymundo Yaulis	M1	48	14.6	<0.001	<0.002	0.009	22.3	<0.1	2.2E+02	0	3	0	0	0	0	0	1	0
			M2	150	20.8	<0.001	<0.002	0.034	48.0	<0.1	6.8E+00	5	5	10	0	0	0	0	0	0
			M3	25	16.0	<0.001	<0.002	0.010	26.2	<0.1	4.6E+01	3	0	9	0	0	0	0	0	0
NI	Parcelas agrícolas de Nievería:																			
NI-A1	Agua de canal	Parcela Sr. Serna	M1	18	11.8	<0.001	<0.002	0.012	24.9	<0.1	3.3E+05	9	15	30	11	0	1	1	2	1
			M2	33	13.8	<0.001	<0.002	0.010	25.5	<0.1	8.0E+05	2	8	20	7	0	1	0	0	2
NI-A2	Agua de reservorio	Reservorio Sr. Serna	M1	66	22.6	<0.001	<0.002	<0.009	30.2	<0.1	1.3E+03	3	0	9	0	0	0	0	0	0
			M2	49	20.0	<0.001	<0.002	0.009	26.6	<0.1	7.9E+01	1	0	3	0	0	0	0	0	0
			M3	56	17.4	<0.001	<0.002	0.009	22.1	<0.1	3.3E+04	0	0	4	0	0	0	0	0	0
Ecas de Calidad Ambiental para Agua (DS 002-2008-MINAM):																				
Categoría 3 - Riego de vegetales					15	0.005	0.100	0.050	50	1		0					<1			
		Tallo Alto									2.0E+03									
		Tallo bajo									1.0E+03									

Table 11 – Environmental parameters in soil samples from Cono Este study site

Codigo	Parámetro	Punto de muestreo	Muestreo							Coliformes termo tolarantes	Helmintos			
				Bario	Cadmio	Cromo	Plomo	Arsenico	Mercurio		Ascaris lumbricoides	Hymenolepis nana	Strongyloides sp.	Uncinarias
	Unidad			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	NMP/100 g	H/g	H/g	H/g	H/g
	Lugar/componente													
NA	UPEU:													
NA-S1	Suelo regado con canal	Frontis colegio	M1	199	3.0	18	170	81	<5	3.0E+00	0	0	0	0
			M2	140	2.0	14	120	70	<5	2.3E+03	0	0	0	0
			M3	240	3.0	14	211	98	<5	9.0E+02	0	0	0	0
NA-S2	Suelo regado con reservorio	Área verde espalda Fam. Mamani	M1	156	3.0	13	170	114	<5	3.0E+00	0	0	0	0
			M2	152	3.0	11	149	84	<5	3.0E+00	0	0	0	0
			M3	160	3.0	11	159	98	<5	3.0E+02	0	0	0	0
CA	Parcelas agrícolas de Carapongo:													
CA-S1	Suelo regado con canal	Parcela vecino Yaulis	M1	136	2.0	11	145	81	<5	2.0E+04	0	0	0	0
			M2	145	3.0	10	153	84	<5	2.3E+04	0	0	Larvas	0
			M3	154	2.0	10	147	78	<5	9.0E+03	0	0	Larvas	0
CA-S2	Suelo regado con reservorio	Parcela Raymundo Yaulis	M1	186	3.0	12	149	93	<5	2.3E+02	0	0	0	0
			M2	174	3.0	10	144	87	<5	4.0E+03	0	0	Larvas	0
			M3	210	3.0	11	183	103	<5	1.5E+04	0	0	0	0
NI	Parcelas agrícolas de Nievería:													
NI-S2	Suelo regado con reservorio	Parcela Sr. Serna	M1	84	0.7	13	19	13	<5	2.3E+02	0	0	0	0
			M2	96	0.8	10	19	12	<5	2.3E+04	0	0	Larvas	0
			M3	90	0.7	8	16	9	<5	4.0E+03	0	0	Larvas	0
ECAS de Calidad Ambiental para suelos (DS 002-2013-MINAM)														
Suelo agrícola				750	1.4	0.4	70	50	6.6					
Residencial/Parques				500	10.0	0.4	140	50	6.6					

3.2.2 Environmental sampling at the Parque Huascar study site

At the Parque Huascar study site of the SSP trials, the SSP team carried out an assessment of the quality of water (raw, point of irrigation and boating lak), grass (grass and vegetable beds) and irrigated green spaces (grass).

A total of 40 water, soil and grass samples were collected on three sampling dates: 22 October, 12 November and 10 December 2013. The sampling plan included the following parameters [3]:

- Elements: water (raw, point of irrigation and boating lake), soil (grass and vegetable beds) and irrigated green spaces (grass).
- Chemical parameters for water: Suspended solids (SS), biochemical oxygen demand (BOD5), N-total, P-phosphates, salinity and heavy metals (As, Cd, Cr, Pb and Hg).
- Sanitary parameters for water: thermo-tolerant (faecal) coliform bacteria (TTC), nematodes and human protozoan parasites.
- Physical-chemical parameters for soil: pH, organic material, nitrogen, phosphorus, potassium and salinity, and heavy metals (As, Cd, Cr, Pb and Hg).
- Sanitary parameters for soil: TTC, nematodes and human protozoan parasites.
- Chemical parameters for soil: heavy metals (As, Cd, Cr, Pb and Hg).
- Sanitary parameters for grass: TTC, nematodes and human protozoan parasites.
-

The findings of the environmental sampling at the Parque Huascar study site are presented in Table 12, Table 13 and Table 14 [3] and can be summarised as follows:

- Water samples: none of the average values for heavy metals exceeded the national threshold. The crude water from the waste water treatment plant (WWTP) showed protozoa concentrations above the national limit of 0 protozoa per 1 L and also high concentrations in TTC (up to $7x10^7$ TTC/100mL). Also helminth eggs were detected in all crude water samples. All the samples taken from the Park's storage tank, a spray irrigation point and the boating lake were free of protozoa and helminth eggs and TTC were not exceeding national limits.
- Soil samples: concentrations of chrome exceeded national limits in soil of the green areas and agricultural surfaces of Parque Huascar. Larvae of *Ascaris* spp. and *Strongyloides* spp. were detected in soil samples of the green areas. It is, however, not known whether the detected *Ascaris* spp. and *Strongyloides* spp. larvae are human pathogens.
- Grass samples: as for the soil samples, helminth larvae (*Ascaris* spp. and *Strongyloides* spp.) were detected on grass surfaces irrigated with wastewater. No protozoa were found in grass samples. Interestingly, very high concentrations of TTC were measured on grass samples (up to $2x10^5$ TTC/g). In view of the acceptable concentrations of TTC in the irrigation water, the SSP team concluded that therefore must be another source of TTC contaminating the grass in Huascar Parque.

Table 12 – Environmental parameters in water samples from Huascar Parque study site

Código	Parámetro	Punto de muestreo	Muestreo			Metales					Coliformes termo tolarantes	Protozoos					Helmintos			
				SS	DBO	Cadmio	Cromo	Plomo	Arsenico	Mercurio		Blastocystis hominis	Endolimax nana	Entamoeba coli	Giardia lamblia	Iodamoeba butsschlii	Ascaris lumbricoides	Hymenolepis nana	Strongyloides sp.	Uncinarias
	Unidad			mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	NMP/100 mL	org./L	org./L	org./L	org./L	org./L	org./L	org./L	org./L	org./L
HU	Componente																			
HU-A1	Agua residual cruda	PTAR Sedapal	M1	420	432	<0.001	0.004	0.010	5.5	<0.1	3.3E+07	90	145	195	210	25	3	2	1	2
			M2	565	610	<0.001	0.008	0.011	5.4	<0.1	3.3E+07	70	180	210	160	45	4	4	1	2
			M3	453	563	<0.001	0.011	0.012	5.1	<0.1	7.0E+07	24	72	180	96	24	1	3	1	2
HU-A2	iente PTAR almacen	Cisterna del Parque	M1	50	29.8	<0.001	0.002	<0.009	3.3	<0.1	7.9E+02	0	0	0	0	0	0	0	0	0
			M2	36	28.6	<0.001	0.002	<0.009	3.0	<0.1	4.5E+00	0	0	0	0	0	0	0	0	0
			M3	50	48.2	<0.001	0.004	<0.009	3.4	<0.1	4.6E+01	0	0	0	0	0	0	0	0	0
HU-A3	a de riego (AR trata	Riego área verde principal	M1	35	26.1	<0.001	0.002	<0.009	3.3	<0.1	7.9E+02	0	0	0	0	0	0	0	0	0
			M2	17	18.6	<0.001	0.002	<0.009	3.0	<0.1	7.8E+00	0	0	0	0	0	0	0	0	0
HU-A4	de laguna (agua po	Bomba de agua	M1	48	10.4	<0.001	0.002	<0.009	5.2	<0.1	3.3E+02	0	0	0	0	0	0	0	0	0
			M2	38	8.4	<0.001	0.002	<0.009	3.9	<0.1	1.7E+02	0	0	0	0	0	0	0	0	0
			M3	106	14.6	<0.001	0.004	<0.009	6.0	<0.1	6.8E+01	0	0	0	0	0	0	0	0	0
Ecas de Calidad Ambiental para Agua (DS 002-2008-MINAM):																				
Categoría 1 - Recreacional, B2 - contacto secundario					10						1.0E+03				0					
Categoría 3 - Riego de vegetales					15	0.005	0.100	0.050	50	1		0					<1			
		Tallo Alto									2.0E+03									
		Tallo bajo									1.0E+03									

Table 13 – Environmental parameters in soil samples from Huascar Parque study site

Codigo	Parámetro	Punto de muestreo	Muestreo	Bario	Cadmio	Cromo	Plomo	Arsenico	Mercurio	Coliformes termo tolarantes	Helmintos: Ascaris lumbricoides	Helmintos: Hymenolepis nana	Helmintos: Strongyloides sp.	Helmintos: Uncinarias
	Unidad			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	NMP/100 g	H/g	H/g	H/g	H/g
HU	Componente													
HU-S1	Suelo de área verde	Área verde principal	M1	56	0.9	17	25	6.0	<5	3.0E+00	0	0	0	0
			M2	29	0.6	11	20	7.0	<5	9.0E+02	Larvas	0	Larvas	0
			M3	65	0.5	9	13	10.0	<5	3.0E+00	Larvas	0	0	0
HU-S2	Suelo de área agrícola	Huerto	M1	70	0.6	11	15	12.0	<5	3.0E+00	0	0	0	0
			M2	85	0.6	8	16	13.0	<5	3.0E+00	0	0	0	0
			M3	40	0.7	15	17	6.0	<5	3.0E+00	0	0	0	0
ECAS de Calidad Ambiental para suelos (DS 002-2013-MINAM)														
Suelo agrícola				750	1.4	0.4	70	50	6.6					
Residencial/Parques				500	10	0.4	140	50	6.6					

Table 14 – Environmental parameters in grass samples from Huascar Parque study site

Codigo	Parámetro	Punto de muestreo	Muestreo	Coliformes termo tolarantes	Protozoos: Blastocystis hominis	Protozoos: Endolimax nana	Protozoos: Entamoeba coli	Protozoos: Giardia lamblia	Protozoos: Iodamoeba butsschlii	Helmintos: Ascaris lumbricoides	Helmintos: Hymenolepis nana	Helmintos: Strongyloides sp.	Helmintos: Uncinarias
	Unidad			NMP/g	A ó P/100 g	A ó P/100 g	A ó P/100 g	A ó P/100 g	A ó P/100 g	A ó P/100 g	A ó P/100 g	A ó P/100 g	A ó P/100 g
HU	Componente												
HU-C1	Cesped regado 1	Área verde principal zona juegos	M1	4.0E+02	A	A	A	A	A	L	A	L	A
			M2	9.0E+01	A	A	A	A	A	L	A	L	A
			M3	1.5E+04	A	A	A	A	A	L	A	L	A
HU-C2	Cesped regado 2	Área verde camping-parrilla	M1	4.0E+01	A	A	A	A	A	L	A	L	A
			M2	4.0E+04	A	A	A	A	A	L	A	L	A
			M3	2.0E+05	A	A	A	A	A	L	A	L	A

3.3 Self-reported health issues by workers of reuse cases

In the frame of the questionnaire survey that was carried out at the level of existing RRR cases in Lima, 46 workers (31% female) were asked what kind of health complaints they have experiences within the past two weeks. Results are presented in Figure 13 and can be summarized as follows:

More than 1 in 3 workers (>29%) reported to have experienced some form of musculoskeletal pain (back, joint, and/or muscle pain) in the two weeks preceding the survey. Musculoskeletal conditions were followed by headache (34%), eye irritation (31.9%), acute coughing (23.4%) and abdominal pain (23.4%). Also skin irritation, fever, nausea and lesion were reported by more than 13% of all workers. Diarrhoea, which is often declared as one of the major health outcomes when handling waste, was only reported by 10.6% of the respondents.

Moreover, the majority of the workers completed secondary school (55.3%) and only 3% of them never attended school. 21.3% of the workers undertake regular health check-ups and work in average 5.5 days per week and 33% work at least 10 extra hours per week.

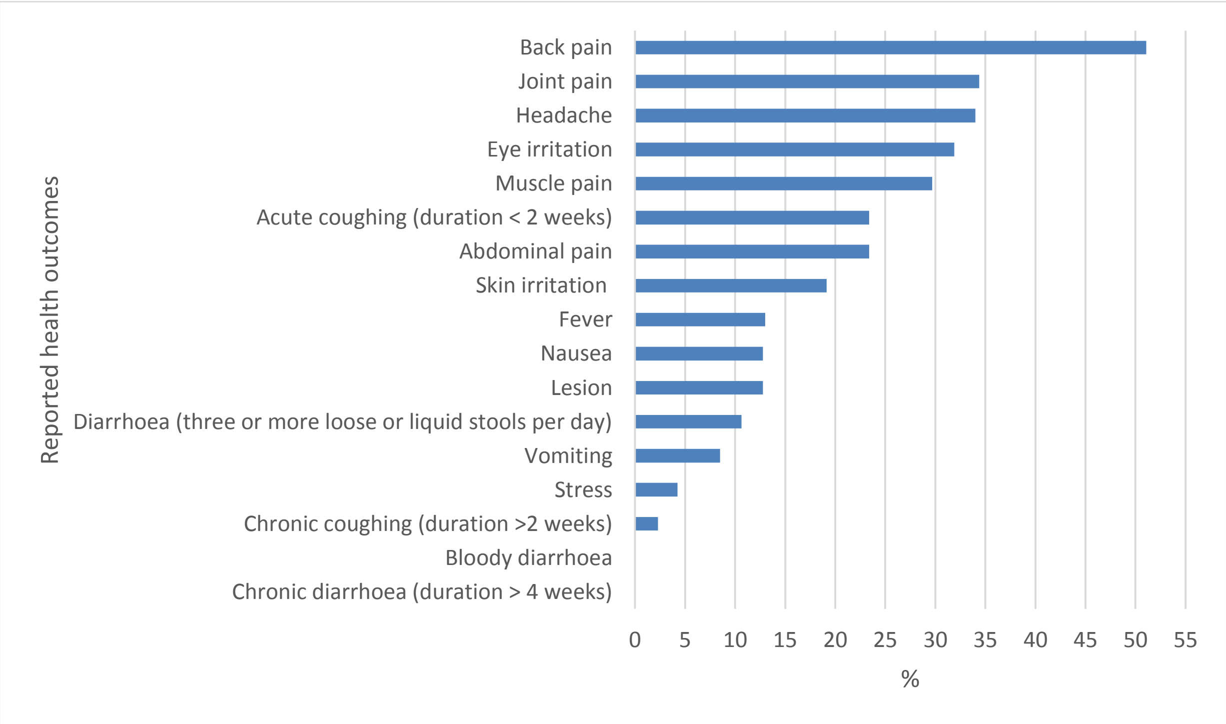

Figure 13 – Health issues reported by workers of RRR cases in Lima area (n=46)

3.4 Acceptability and use of personal protective equipment

The acceptability and use of a total of 11 different types of PPE to protect head, eyes, ears, airways, whole body, hand, legs and feet were assessed at the level of existing RRR businesses in Lima area. A total of 46 workers participated in the study.

First, the health risk assessors from UPCH pre-selected different type of PPE consider as necessary for preventing occupational health hazards at the level of each RRR case according to their expert opinion after a site visit and the key informant interview with the business operators. Overall, uniforms/overalls, rubber gloves, rubber boots were considered as appropriate for most of the workers (>85%). This was followed by safety glasses (78.7%), rain jackets (61.7%) and simple face masks (36.2%). High visibility clothing, safety boots, hard hat and ear plugs were only seen as appropriate for 29.8%, 23.4%, 14.9% and 14.9% of all workers, respectively.

Second, whenever a PPE option was considered relevant for the given tasks of a worker, he was asked whether the worker actually uses the PPE. If this was not the case, it was assessed, which of three options is the primary reason for not wearing the PPE: (i) no need, (ii) not available; or (iii) do not like it. In general most workers were equipped with the necessary PPE, in case the PPE was not available 'no need' was the most common reason for not wearing a specific PPE, followed by 'not available'. Only few workers reported not to like wearing a PPE which would be appropriate for his tasks. Overall, the vast majority of the workers clearly stated that they are willing to wear the indicated PPE if it is available. Details of the study on the use and acceptability of PPE at the level of RRR cases in Lima area are available in Table 15 and Figure 14.

Third, workers were asked whether, besides PPE, they see additional measures/controls that could improve their safety during work. While half of workers did not have any suggestion, the following proposals were made: provide better quality and more comfortable PPE (47.8%; n=22), training and awareness raising programs for workers (26.1%; n=12 each); improvements of the work place infrastructure to prevent exposure to hazardous material (17.4%; n=8), provide milk for workers, institutional support for company, improve worker hygiene, provide health insurance for workforce (n=4 each).

Table 15 – Use, acceptability and willingness to pay for PPE at RRR cases in Lima

Personal protective equipment (PPE)	Head				Eyes		Ear		Airway		Whole body						Hand		Foot			
	Hard hat		Soft hat		Safety glasses		Ear plugs		Simple face		Uniform /		High-visibility		Rain jacket		Rubber gloves		Rubber		Safety	
	No	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*	*No*	*%*
Relevant for RRR case	7	14.9	41	87.2	37	78.7	7	14.9	17	36.2	40	85.1	14	29.8	29	61.7	41	87.2	40	85.11	11	23.4
Worker wear PPE	7	100	39	95.1	27	73.0	6	85.7	13	76.5	39	97.5	14	100	19	65.5	36	87.8	39	97.5	6	54.5
Worker bought PPE	0	0	16	41.0	5	18.5	0	0	1	7.7	10	25.6	8	57.1	3	15.8	4	11.1	5	12.82	3	50.0
Worker not wear PPE	0	0	2	4.9	7	18.9	1	14.3	4	23.5	1	2.5	0	0	10	34.5	5	12.2	1	2.5	5	45.5
Do not like (%)	0	0	0	0	3	42.9	1	100	2	50	1	100	0	0	1	10.0	3	60	0	0	2	40
No need for (%)	0	0	0	0	2	28.6	0	0	1	25	0	0	0	0	6	60.0	2	40	0	0	0	0
Not available (%)	0	0	1	50	2	28.6	0	0	1	25	0	0	0	0	3	30.0	0	0	1	100	3	60
Wear PPE if avalable	0	0	0	0	2	100	0	0	0	0	0	0	0	0	3	100.0	0	0	1	100	3	100
Buy PPE by himselve	0	0	0	0	2	100	0	0	0	0	0	0	0	0	3	100.0	0	0	1	100	3	100

Figure 14 – Percentage of workers wearing PPE considered relevant for the given task

4 Health risk and impact assessment

In this chapter, potential health risks and impacts are outlined after a brief introduction of the BM and respective inputs and outputs. For each of the outputs, quality/safety requirements are listed, which can then also be used as operational and verification monitoring indicators during operation. Peruvian quality standards as defined by the national legislation are listed and reference to the source document is provided. Where no national thresholds exist, quality standards, pathogen reduction rates and threshold values as defined by the WHO 2006 Guidelines on the safe use of wastewater, excreta and graywater are recommended [6]. The full set of national and international quality standards is provided in Annex IV.

For the HRA, the data collected at the level of existing RRR cases in Lima served as important information source in combination with epidemiological and environmental indicators summarized in the previous chapters. For each case a comprehensive risk assessment matrix was completed, which are available in Appendix I. These tables include a risk assessment of each process and list potential hazards, hazardous events, exposure routes, indicated control measures and a risk assessment. A summary of indicated control measures is provided for each BM under the respective chapter. The risk assessment of each BM concludes with an analysis of residual risks. This covers all the risks classified as moderate to very high by the risk assessment (with the proposed control measure in place). For this purpose, the concerned processes (as per flow diagram) are listed and the issues of concern are discussed. In case the control measures at hand for mitigating the risk at the level of the BM are not sufficient, down-stream control measures (e.g. at consumer level) are proposed.

The HIA provides an analysis on how the proposed BM might impact on community health if implemented at scale. The anticipated scale of the business is indicated for each BM. Based on the assumption that the control measures recommended under the risk assessment are implemented, potential impact pathways are described. Finally, the magnitude of each impact is determined by means of a semi-quantitative risk assessment.

For Lima, a total of nine BMs were selected to be assessed in the frame of the feasibility studies:

- Model 2b: Energy service companies at scale: MSW to energy (electricity)
- Model 3: Energy generation from own agro-industrial waste
- Model 4: Onsite energy generation by sanitation service providers
- Model 8: Beyond cost recovery: the aquaculture example
- Model 9: On cost savings and recovery
- Model 13: Informal to formal trajectory in wastewater Irrigation: sale/auctioning wastewater for irrigation
- Model 15: Large-scale composting for revenue generation
- Model 17: High value fertilizer production for profit
- Model 21: Partially subsidized composting at district level

4.1 Model 2b – Energy service companies at scale: MSW to energy (electricity)

Model 2b aims at producing electricity through the processing of MSW. Electricity will be generated in two ways: (i) a gas-based generator will be run with the biogas from anaerobic digestion; and (ii) through the burning of refuse-derived fuel, a steam fed generator will be operated. Soil conditioner is an additional output option, which is depending on the setup of the post-treatment of the sludge and effluent of the anaerobic digestion. Since the post-treatment is not clearly defined as per the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario and context.

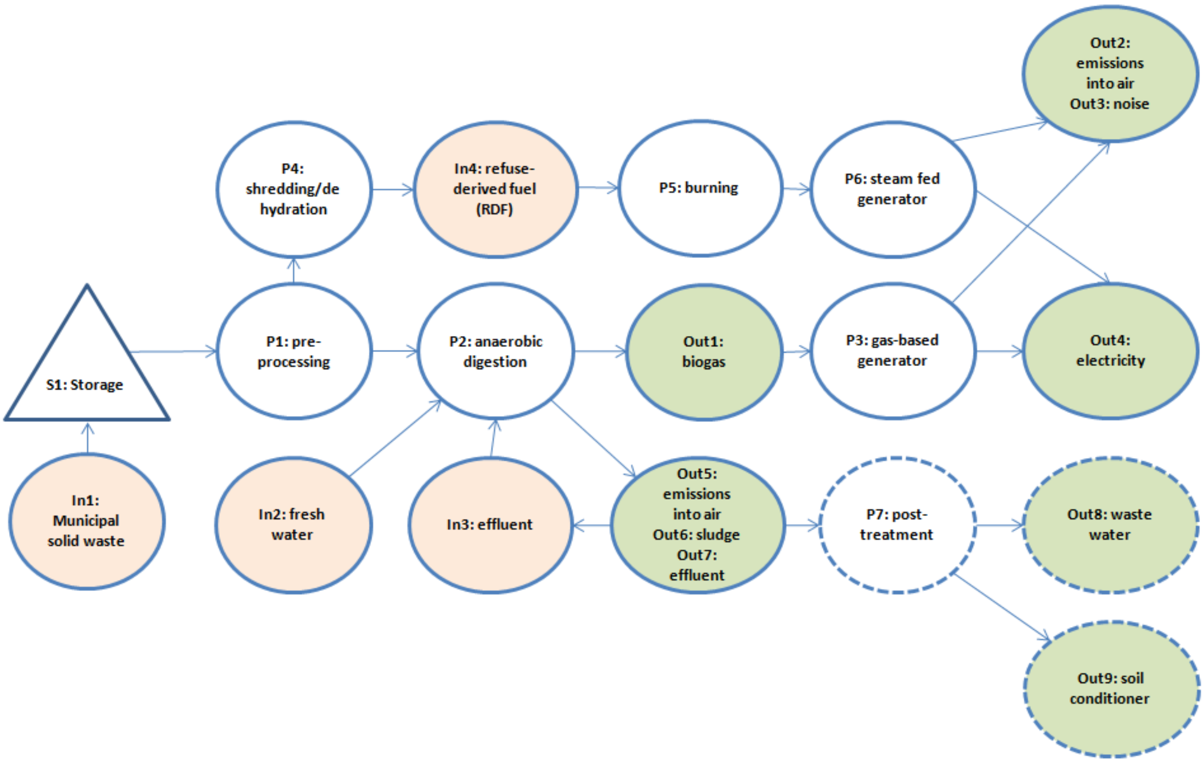

Figure 15 – Model 2b: system flow diagram

4.1.1 Health risk assessment

MSW is usually contaminated with pathogens deriving from human (e.g. diapers) and potentially animal waste. Viruses and bacteria are of primary concern. These will not be fully eliminated during anaerobic digestion (mesophilic digestion at >35°C for >9 days only results in 1 log reduction in *E. coli* and 0 log reduction in helminth eggs). Hence, appropriate disposal or post-treatment of the sludge and effluent is required. In addition, sharp objects (e.g. razor blades), chemical waste (e.g. batteries) or even medical waste may be included in MSW.

Besides the health hazards associated with the inputs, the burning of refuse-derived fuel and the operation of a steam- and gas-fed generator are associated with heat, emissions into the air, noise and toxic burning-residuals. These need to be managed at the level of the plant and an appropriate buffer zone to community houses needs to be established. In order to avoid electric shock of workers or users, intrinsically safe electrical installations, non-sparking tools and proper grounding need to be assured. Potential vector breeding at waste-storage sites and along the cooling water circuit of the plants has to be controlled. There is considerable risk for injury to the body when operating the burning plant and generators. Hence, safety infrastructure, PPE and education of workers are crucial. A fire fire/explosion response plan needs to be developed and implemented.

Table 16 – Model 2b: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: municipal solid waste	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste
In3: fresh water	None
In4: liquid effluent	N.a. (within system
In4: refuse-derived fuel (RDF)	N.a. (within system

Table 17 – Model 2b: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: biogas	N.a. (within system)

Out2 and Out5: emissions into air	Ambient air quality standards[a]:
	• Total hydrocarbons (HC): 100 µ/m^3 24-hour mean
	• Benzene: 2 µ/m^3 24-hour mean
	• $PM_{2.5}$: 25 µ/m^3 24-hour mean; 25 µ/m^3 annual mean
	• H_2S: 150 µ/m^3 24-hour mean; 50 µ/m^3 annual mean
	• SO_x: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean
	Indoor air quality standards[b]
	• Carbon monoxide (CO):
	  • 15 minutes – 100 mg/m3
	  • 1 hour – 35 mg/m3
	  • 8 hours – 10 mg/m3
	  • 24 hours – 7 mg/m3
	• Nitrogen dioxide
	  • 200 µg/m3 – 1 hour average
	  • 40 µg/m3 – annual average

Out3: noise	Occupational noise exposure limits[c]: **Noise level (dB)** – **Exposure time** 82 – 16 h / day 85 – 8 h / day 88 – 4 h / day 91 – 1.5 h / day 94 – 1 h / day

<table>
<tr><td></td><td><table><tr><td>97</td><td>0.5 h / day</td></tr><tr><td>97</td><td>15 min / day</td></tr></table>
• Maximum level (short duration): 140 dB(A)
<u>Community noise exposure limits[d]:</u>
<table><tr><th>Zone</th><th>Day time (dB)</th><th>Night time (dB)</th></tr><tr><td>Protected zone</td><td>50</td><td>40</td></tr><tr><td>Residential zone</td><td>60</td><td>50</td></tr><tr><td>Commercial zone</td><td>70</td><td>60</td></tr><tr><td>Industrial zone</td><td>80</td><td>70</td></tr></table></td></tr>
<tr><td>Out4: electricity</td><td>Intrinsically safe electrical installations and proper grounding</td></tr>
<tr><td>Out6: sludge</td><td>N.a. (within the system)</td></tr>
<tr><td>Out7: liquid effluent</td><td>N.a. (within the system)</td></tr>
<tr><td>Out8: treated effluent</td><td>Unrestricted irrigation
<u>Root crops:</u>
• $<10^3$ E. coli per litre and ≤1 helminth egg per litre
<u>Leave crops:</u>
• $<10^4$ E. coli per litre and ≤1 helminth egg per litre
<u>Drip irrigation of high-growing crops:</u>
• $<10^5$ E. coli per litre and ≤1 helminth egg per litre
<u>Drip irrigation of low-growing crops:</u>
• $<10^3$ E. coli per litre and ≤1 helminth egg per litre

Restricted irrigation
<u>Labour intensive agriculture:</u>
• $<10^4$ E. coli per litre and ≤1 helminth egg per litre
<u>Highly mechanized agriculture:</u>
• $<10^5$ E. coli per litre and ≤1 helminth egg per litre

➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV</td></tr>
<tr><td>Out9: soil conditioner</td><td><u>For agricultural use:</u>
• <1 helminth egg per 1 gram total solids; and $<10^3$ E. coli per gram total solids</td></tr>
</table>

[a] Decreto Supremo N° 009-2008-MINAM
[b] WHO (2010). Guidelines for indoor air quality: selected pollutants. Geneva: World Health Organization
[c] Manual de salud ocupacional, MINSA, DIGESA, PAHO (2005)
[d] Decreto Supremo N° 085-2003-PMC

4.1.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material need to wear appropriate PPE and use tools (e.g. shovels)
  - Workers that are directly exposed to fumes of the burning plant or exhausts of the gas-based generator need to be equipped with gas mask respirators
  - Workers that are exposed to heat need to wear appropriate PPE
  - Workers that are exposed to high levels of noise need to wear hearing protection and occupational noise exposure limits need to be respected (see Table 17)

- Processes
  - The pre-processing of the MSW to include: (i) separation of any faecally contaminated components/fractions for being transferred into the drying beds; and (ii) separation and discharge of any inorganic contaminants, including sharp objects
  - Mesophilic anaerobic digestion is recommended at >35°C for >9 days (1 log reduction *E. coli* and 0 log reduction in helminth eggs)
- Infrastructure
  - Assure good ventilation of working areas where MSW is stored/processed
  - Install heat shields on hot parts that may be touched by individuals
  - Install handrails and fences at dangerous areas for preventing injuries
  - In case the burning plant and/or steam- and gas-fed generator are located in a closed environment: install CO monitors; ensure that exhausts are released to the outside
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 17). The actual distance is depending on the level of emissions
  - For removing the residuals in the burning plant, installation of a bin/tank to collect and treat the toxic scrubbing water
  - At the electricity outlet of the gas-based generator, use intrinsically safe electrical installations, non-sparking tools and proper grounding
  - Prevent gas-leakage at the anaerobic digestion plant and install CO monitors in case the anaerobic digestion takes place in a closed environment
  - Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed:

    <u>Off-site (i.e. discharge):</u>
    - ➢ Drain/transfer effluent to the influent of existing and existing wastewater treatment plant if within load capacity, co-manage sludge/solids handling with existing wastewater of faecal sludge treatment plant

    <u>On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)):</u>
    - ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
    - ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
    - ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
    - ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs)
    - ➢ Planted gravel Filter
    - ➢ Unplanted gravel Filter
    - ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)
- Behavioural aspects and prevention

- Develop a fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)
- Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites and cooling water cycles
- Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
- Protect workers from long term exposure to sunlight
- Restrict access to the operations
- Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.1.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 2b can be reduced to **low, moderate and high levels**. The residual moderate risks are linked to the following processes:

- S1: storage: exposure of the workforce and community members to malodours is of concern related to the storage of MSW. PPE, good ventilation of the storage area and to respect a buffer zone between operations and community infrastructure are essential
- P3: gas-based generator; P5: burning; and P6: steam-fed generator: exposure to toxic gas and noise emissions is of concern for both workers and the community. However, these risks can be controlled with appropriate equipment, a good design of the operation and by respecting a buffer zone between the plant and community infrastructure. Also fire and explosion are major risks related to the burning plant and the electricity generators. This issue must primarily be taken into account when engineering of the plant. At the operational level a fire/explosion response plan needs to be developed and implemented. Finally, toxic residuals of the plant need to be handled and disposed of with care
- Electric shock and fire/explosion are high risks that need to be managed accordingly
- P7: post-treatment: sharps ending up in the soil conditioner pose a moderate risk to users. Soil conditioner must be sieved before packaging and users need to be sensitised about the potential presence of sharp objects and pathogens in the soil conditioner. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.
- **Medical waste must be collected separately for keeping it out of the BM**

4.1.2 Health impact assessment

The burning of MSW for energy production has the potential to indirectly impact people who are currently exposed to landfills (waste pickers or surrounding communities) as it will reduce the load of MSW ending up on landfills. But since Lima is disposing of a well functioning

MSW collection and processing system, with a minimal number of people being exposed to landfills, no health impacts through a reduction of MSW ending up in landfills is anticipated. A second potential health impact is linked to changes in socio-economic status and wellbeing through increased access to electricity.

- **Scale of the BM:** the impact assessment of Model 2b is based on the assumption that 2 plants as proposed by the business model will implement in Lima area

4.1.2.1 Impact 1: changes in health status due to access to electricity

The impact of electricity on the health status of receiving populations is marginal and the direction of health impact (i.e. positive or negative) is not obvious. For example, an improved socio-economic status often impacts positively on access to health care but is also negatively associated with life style related diseases such as obesity and diabetes. However, in Lima 98.8% of the households had access to electricity in 2011 [15]. Therefore it is very unlikely that small-scale provision of electricity to communities in peri-urban areas of Lima will result in any health impacts.

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** The additional electricity supply generated by the plant will not result in an increased number of households that have access to electricity in Lima.
- **Likelihood:** It is very unlikely that access to electricity impacts on the health of people

Table 18 – Model 2b, impact 1: changes in health status due to access to electricity

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Population	Very unlikely	**Insignificant**
Score	0.0	0	0.05	**0**

4.1.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) hazardous air emissions, such as volatile organic compounds, carbon monoxide, polycyclic aromatic hydrocarbons, methane and nitrous oxide, which are created during the gasification process and/or the conversion of biogas into electricity, (2) residuals from the gasification process (i.e. tar, char, oil) that are disposed of or used improperly, (3) solid residue from the anaerobic digestion process (digestate), which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations and (4) liquid effluent from the anaerobic digestion process disposed of or used improperly, which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) air emission control technologies, such as activated carbon or scrubbers, (2) collection/storage/disposal of residuals at an appropriate location, (3) solid residue (digestate) post-treatment, and (4) liquid effluent post-treatment. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of dewatered and appropriately treated sludge (digestate) and liquid effluent from post-treatment. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 19 – Model 2b: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasifi-cation • Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Residuals (tar, char, oil) • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Collection/Storage/ Disposal at appropriate location • Solid/liquid residue post-treatment

4.2 Model 3 – Energy generation from own agro-industrial waste

Model 3 aims at transforming agro-waste from a main product processing plant (e.g. sugar production from sugarcane has bagasse and molasses as by-product) and animal manure and into electricity and ethanol (see Figure 16). Technologies applied for processing agro-industrial waste include a co-generation unit to produce electricity, a distillery unit to produce ethanol/alcohol and biogas unit to produce heat and electricity. An additional output option is treated effluent and soil conditioner, which is depending on the setup of the post-treatment of the sludge and effluent of the anaerobic digestion. Since the post-treatment is not clearly defined as per the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario and context.

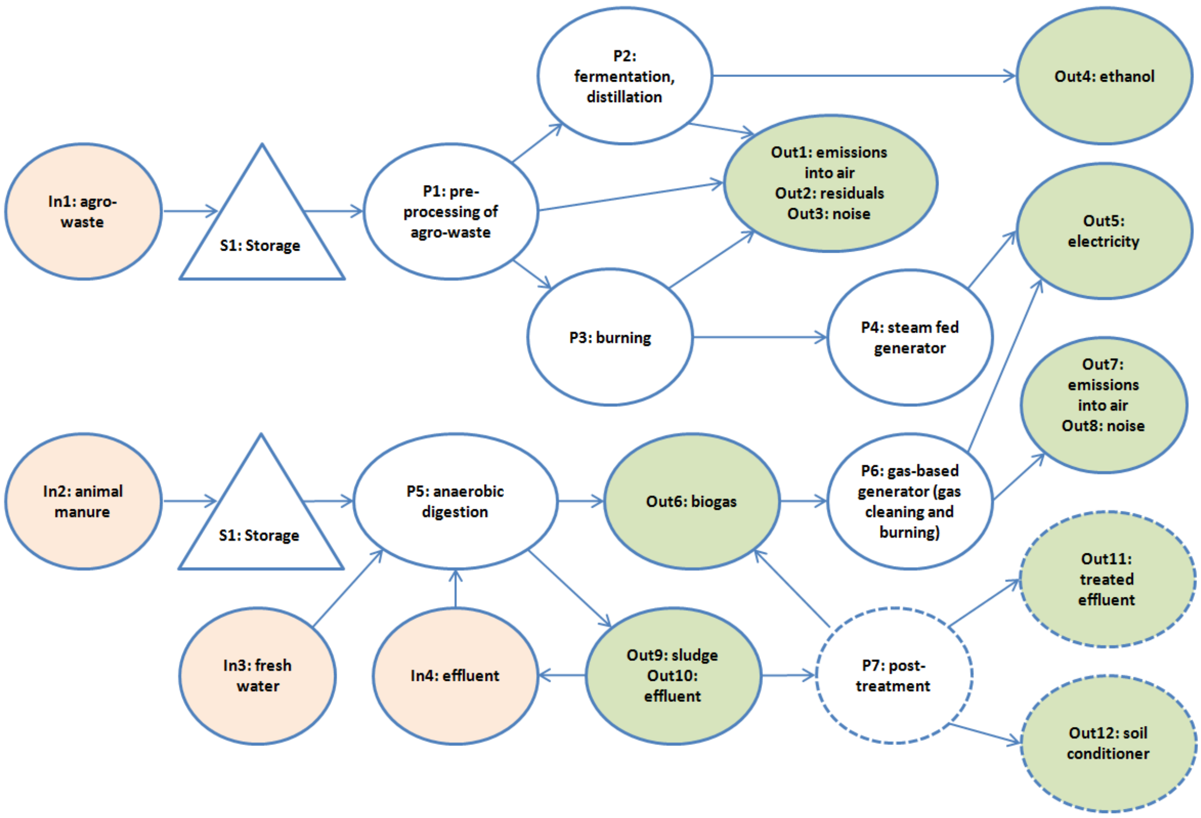

Figure 16 – Model 3: system flow diagram

Table 20 – Model 3: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: agro-waste	Faecal contamination (pathogens)
	Contamination with MSW (inorganic; sharp objects)
In2: animal manure	Pathogens
	Contamination with MSW (inorganic; sharp objects)
In3: fresh water	None
In4: liquid effluent	N.a. (within system)

Table 21 – Model 3: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1, Out4 and Out8: emissions into air	Ambient air quality standards[a]: • Total hydrocarbons (HC): 100 μ/m^3 24-hour mean • Benzene: 2 μ/m^3 24-hour mean • $PM_{2.5}$: 25 μ/m^3 24-hour mean; 25 μ/m^3 annual mean • H_2S: 150 μ/m^3 24-hour mean; 50 μ/m^3 annual mean • SO_x: 20 μ/m^3 24-hour mean; 50 μ/m^3 annual mean
Out2: residuals	None since considered as waste
Out3 and Out5: noise	Occupational noise exposure limits[b]: Noise level (dB) / Exposure time: 82 — 16 h / day 85 — 8 h / day 88 — 4 h / day

<table>
<tr><td></td><td>
<table>
<tr><td>91</td><td>1.5 h / day</td></tr>
<tr><td>94</td><td>1 h / day</td></tr>
<tr><td>97</td><td>0.5 h / day</td></tr>
<tr><td>97</td><td>15 min / day</td></tr>
</table>
Maximum level (short duration): 140 dB(A)
<u>Community noise exposure limits[c]:</u>
<table>
<tr><th>Zone</th><th>Day time (dB)</th><th>Night time (dB)</th></tr>
<tr><td>Protected zone</td><td>50</td><td>40</td></tr>
<tr><td>Residential zone</td><td>60</td><td>50</td></tr>
<tr><td>Commercial zone</td><td>70</td><td>60</td></tr>
<tr><td>Industrial zone</td><td>80</td><td>70</td></tr>
</table>
</td></tr>
<tr><td>Out6: biogas</td><td>N.a. (within system)</td></tr>
<tr><td>Out7: electricity</td><td>Intrinsically safe electrical installations and proper grounding</td></tr>
<tr><td>Out9: sludge</td><td>N.a. (within the system)</td></tr>
<tr><td>Out10: effluent</td><td>N.a. (within the system)</td></tr>
<tr><td>Out11: treated effluent</td><td>
Unrestricted irrigation
<u>Root crops:</u>
$<10^3$ E. coli per litre and ≤1 helminth egg per litre
<u>Leave crops:</u>
$<10^4$ E. coli per litre and ≤1 helminth egg per litre
<u>Drip irrigation of high-growing crops:</u>
$<10^5$ E. coli per litre and ≤1 helminth egg per litre
<u>Drip irrigation of low-growing crops:</u>
$<10^3$ E. coli per litre and ≤1 helminth egg per litre
Restricted irrigation
<u>Labour intensive agriculture:</u>
$<10^4$ E. coli per litre and ≤1 helminth egg per litre
<u>Highly mechanized agriculture:</u>
$<10^5$ E. coli per litre and ≤1 helminth egg per litre
➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV
</td></tr>
<tr><td>Out12: soil conditioner</td><td>
<u>For agricultural use:</u>
<1 helminth egg per 1 gram total solids; and $<10^3$ E. coli per gram total solids
</td></tr>
</table>

[a] Decreto Supremo N° 009-2008-MINAM
[b] Manual de salud ocupacional, MINSA, DIGESA, PAHO (2005)
[c] Decreto Supremo N° 085-2003-PMC

4.2.1 Health risk assessment

Important health hazards linked to this BM relate to the pathogens bound in the animal manure, which will not be fully eliminated during anaerobic digestion (mesophilic digestion at >35°C for >9 days only results in 1 log reduction in *E. coli* and 0 log reduction in helminth eggs). Therefore, appropriate discharge or post-treatment of the sludge (digestate) and effluent from anaerobic digestion is required. The conversion of sugarcane bagasse is a process that includes lots of different chemical reactions. Those reactions are not considered in detail by the HRIA and it is assumed that potential associated environmental and health risks are addressed by the technical and environmental impact assessments.

Operation of a steam-fed and a gas-based generator are associated with heat, emissions into the air, noise and toxic burning-residuals. These need to be managed at the level of the plant and an appropriate buffer zone to community houses needs to be established. In order to avoid electric shock of workers or users, intrinsically safe electrical installations, non-sparking tools and proper grounding need to be assured. Potential vector breeding at waste-storage sites and along the cooling water circuit of the generators has to be controlled. Finally, there is considerable risk for injury to the body when operating the plants or the gas-based generator. Hence, safety infrastructure, PPE and education of workers are crucial. Finally, a fire fire/explosion response plan needs to be developed and implemented.

4.2.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
    - Workers handling any raw material (e.g. agro-waste or animal manure) need to wear appropriate PPE and use tools (e.g. shovels)
    - Workers that are directly exposed to emissions from the fermentation and distillation processes or exhausts of the electricity generators need to be equipped with gas mask respirators
    - Workers that are exposed to heat need to wear appropriate PPE
    - Workers that are exposed to high levels of noise (e.g. operating the generator; 85 dB permanent or 140 dB short duration) need to wear hearing protection
- Processes
    - Mesophilic anaerobic digestion is recommended at >35°C for >9 days (1 log reduction *E. coli* and 0 log reduction in helminth eggs)
- Infrastructure
    - Assure good ventilation of working areas where animal-manure is stored/processed
    - Install heat shields on hot parts that may be touched by individuals
    - Install handrails and fences at dangerous areas for preventing injuries
    - In case the burning plant, steam-fed generator, gas-based generator or fermentation distillation processes are located in a closed environment: install CO monitors; ensure that exhausts are released to the outside
    - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 21). The actual distance is depending on the level of emissions
    - For removing the residuals in the burning plant, installation of a bin/tank to collect and treat the toxic scrubbing water
    - At the electricity outlet of the gas-based generator, use intrinsically safe electrical installations, non-sparking tools and proper grounding
    - Prevent gas-leakage at the anaerobic digestion plant and install CO monitors in case the anaerobic digestion takes place in a closed environment
    - In order to prevent consumption of ethanol of inferior quality, denature the ethanol produced by the plant
    - Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed:

        <u>Off-site (i.e. discharge):</u>

- Drain/transfer effluents/sludge into an existing wastewater treatment plant (WWTP) for co-treatment
- Discharge sludge on landfill

On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)):

- Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
- Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
- Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs)
- Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs)
- Planted gravel Filter
- Unplanted gravel Filter
- Planted/unplanted drying beds (1-3 log reduction in helminth eggs)

- Behavioural aspects and prevention
    - Develop a fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)
    - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
    - Rodent and vector-control (e.g. screening or use of larvicides, insecticides) at waste-storage sites, drying beds and cooling water cycle.
    - Protect workers from long term exposure to sunlight
    - Restrict access to the operations
    - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.2.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 2a can be reduced to **low, moderate and high levels**. The residual moderate risks are linked to the following processes:

- S1: storage: exposure of the workforce and community members to malodours is of concern related to the storage of animal manure. PPE, good ventilation of the storage area and to respect a buffer zone between operations and community infrastructure are essential
- P2: fermentation, distillation; P3: burning; and P4: steam fed generator: exposure to toxic gas and noise emissions are of concern for both workers and the community. However, these risks can be controlled with appropriate equipment, a good design of the operation and by respecting a buffer zone between the plant and community

infrastructure. Also fire and explosion are major risks related to the burning plant and the electricity generators. This issue must primarily be taken into account when engineering of the plant. At the operational level a fire/explosion response plan needs to be developed and implemented. Finally, toxic residuals of the plant need to be handled and disposed of with care

- Electric shock and fire/explosion are high risks that need to be managed accordingly

4.2.2 Health impact assessment

The production of power by using agro-waste and animal manure has an impact on community health in two ways. First, it has the potential to reduce exposure of community members to pathogens deriving from animal manure, and thus lower the incidence of respiratory, diarrhoeal and intestinal diseases. Second, the provision of electricity can impact socio-economic status and wellbeing, both of which have a strong link to community health.

- **Scale of the BM:** the impact assessment of Model 3 is based on the assumption that 2 plants as proposed by the business model will implement in Lima area

4.2.2.1 Impact 1: changes in health status due to access to electricity

➔ For the impact definition, see Model 3, impact 1 (section 4.1.2.1).

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** The additional electricity supply generated by the plant will not result in an increased number of households that have access to electricity in Lima.
- **Likelihood:** It is very unlikely that access to electricity impacts on the health of people

Table 22 – Model 3, impact 1: changes in health status due to access to electricity

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Population	Very unlikely	**Insignificant**
Score	0.0	0	0.05	**0**

4.2.2.2 Impact 2: reduction in respiratory, diarrhoeal and intestinal diseases

Unsafe discharge of animal manure into the environment poses health risk to communities. For example, pathogens from animal manure may end-up in surface waters, which are used for irrigation purposes. As a result, unsafe disposal of animal manure into the environment is likely to contribute to the incidence of respiratory and diarrhoeal diseases, as well as helminth infections. Hence, the recycling of animal manure has the potential to reduce the incidence of those diseases.

According to the waste supply analysis for Lima, there is an existing market for some type of animal manure (e.g. chicken), while others are mostly disposed into the environment (e.g. pig). This makes it difficult to estimate the number of people that are exposed to animal manure that is exposed into the environment. However, since almost all households are connected to the sewerage system and limited exposure to surface waters occurs, a reduction of animal manure that is disposed into the environment might benefit only a few people.

Impact 2, assumptions:

- **Impact level:** pathogens in animal manure generally cause disease of short duration and/or minor disability
- **People affected:** an estimated number of 500 people would benefit from reduced disposal of animal manure into the environment
- **Likelihood:** of those exposed, 1 in 5 would develop some form of clinical infection

Table 23 – Model 3, impact 2: reduction in respiratory, diarrhoeal and intestinal diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Medium population group	Possible	**Minor positive impact**
Score	0.1	500	0.3	**15**

4.2.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) hazardous air emissions during the fermentation and distillation process, such as particulate matter, volatile organic compounds and hazardous air pollutants, (2) solid residue from the anaerobic digestion process (digestate) which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations, and (3) liquid effluent from the anaerobic digestion process, which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) air emission control technologies, such as activated carbon or scrubbers, (2) solid residue (digestate) post-treatment, and (3) liquid effluent post-treatment. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of dewatered and appropriately treated sludge (digestate) and liquid effluent from post-treatment. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 24 – Model 3: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• AIW • AM	• Ethanol • Electricity	• Fermentation, Distillation Technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Fermen-tation • Distillation • Biogas to electricity conversion	• Hazardous air emissions • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Solid/liquid residue post-treatment

4.3 Model 4 – Onsite energy generation by sanitation service providers

The primary goal of BM 4 is to provide sanitation service to underserved communities who lack access to toilets. In addition, the business transforms black and brown water into electricity and soil conditioner to be sold to communities. The quality of the soil conditioner, and resulting end-use options, depend on the setup of the post-treatment of the sludge (digestate) and liquid effluent of the anaerobic digestion process. Since the post-treatment is not clearly defined as per the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario.

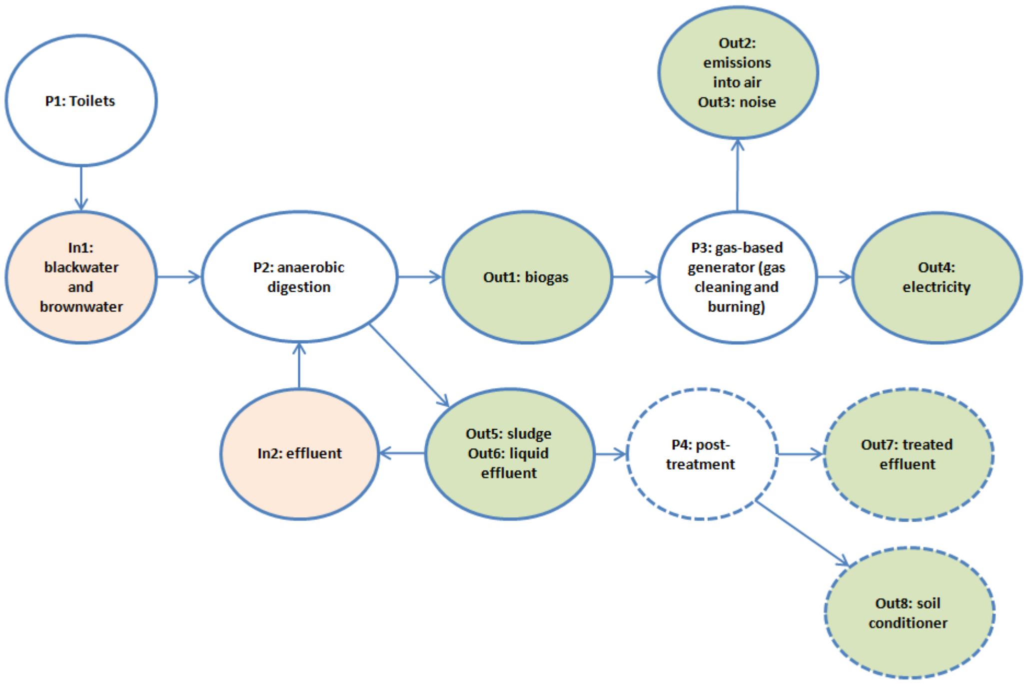

Figure 17 – Model 4: system flow diagram

Table 25 – Model 4: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: blackwater and brownwater	Pathogens
	Contamination with sharp objects and inorganic waste
In2: effluent	Pathogens

Table 26 – Model 4: Quality/safety requirements for outputs

<table>
<tr><th>Outputs of health relevance</th><th>Quality/safety requirements</th></tr>
<tr><td>Out1: biogas</td><td>N.a. (within the system)</td></tr>
<tr><td>Out2: emissions into air</td><td>Ambient air quality standards[a]:
• Total hydrocarbons (HC): 100 µ/m^3 24-hour mean
• Benzene: 2 µ/m^3 24-hour mean
• $PM_{2.5}$: 25 µ/m^3 24-hour mean; 25 µ/m^3 annual mean
• H_2S: 150 µ/m^3 24-hour mean; 50 µ/m^3 annual mean
• SO_x: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean</td></tr>
<tr><td>Out3: noise</td><td>Occupational noise exposure limits[b]:
<table>
<tr><th>Noise level (dB)</th><th>Exposure time</th></tr>
<tr><td>82</td><td>16 h / day</td></tr>
<tr><td>85</td><td>8 h / day</td></tr>
<tr><td>88</td><td>4 h / day</td></tr>
<tr><td>91</td><td>1.5 h / day</td></tr>
<tr><td>94</td><td>1 h / day</td></tr>
<tr><td>97</td><td>0.5 h / day</td></tr>
<tr><td>97</td><td>15 min / day</td></tr>
</table>
Community noise exposure limits[c]:
<table>
<tr><th>Zone</th><th>Day time (dB)</th><th>Night time (dB)</th></tr>
<tr><td>Protected zone</td><td>50</td><td>40</td></tr>
<tr><td>Residential zone</td><td>60</td><td>50</td></tr>
<tr><td>Commercial zone</td><td>70</td><td>60</td></tr>
<tr><td>Industrial zone</td><td>80</td><td>70</td></tr>
</table></td></tr>
<tr><td>Out4: electricity</td><td>Intrinsically safe electrical installations and proper grounding</td></tr>
<tr><td>Out5: sludge</td><td>Considered as waste or within the system (in the case of post-treatment)</td></tr>
<tr><td>Out6: effluent</td><td>Considered as waste or within the system (in the case of post-treatment)</td></tr>
<tr><td>Out7: treated effluent (optional)</td><td>Unrestricted irrigation
Root crops:
• <10^3 E. coli per litre and ≤1 helminth egg per litre
Leave crops:
• <10^4 E. coli per litre and ≤1 helminth egg per litre
Drip irrigation of high-growing crops:
• <10^5 E. coli per litre and ≤1 helminth egg per litre
Drip irrigation of low-growing crops:
• <10^3 E. coli per litre and ≤1 helminth egg per litre
Restricted irrigation
Labour intensive agriculture:
• <10^4 E. coli per litre and ≤1 helminth egg per litre</td></tr>
</table>

	Highly mechanized agriculture: • <10^5 *E. coli* per litre and ≤1 helminth egg per litre ➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV
Out8: soil conditioner (optional)	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids

[a] Decreto Supremo N° 009-2008-MINAM
[b] Manual de salud ocupacional, MINSA, DIGESA, PAHO (2005)
[c] Decreto Supremo N° 085-2003-PMC

4.3.1 Health risk assessment

Black and brownwater pose two main health hazards: pathogens and sharp objects such as razor blades. The faecal pathogens will not be fully eliminated during anaerobic digestion (mesophilic digestion at >35°C for >9 days only results in 1 log reduction in *E. coli* and 0 log reduction in helminth eggs). Therefore, appropriate discharge or post-treatment of the sludge (digestate) and effluent from anaerobic digestion is required. Sharp objects that will be placed in the brownwater may end up in the soil conditioner and are thus a health hazard that needs to be controlled. The operation of a gas-based generator is associated with heat, emissions into the air, noise and toxic burning-residuals. These need to be managed at the level of the plant and an appropriate buffer zone to community houses needs to be established. In order to avoid electric shock of workers or users, intrinsically safe electrical installations, non-sparking tools and proper grounding need to be assured. There is risk for injury to the body when operating the gas-based generator. Hence, safety infrastructure, PPE and education of workers are crucial. Finally, a fire fire/explosion response plan needs to be developed and implemented.

4.3.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material (i.e. black and brown water) need to wear PPE and use tools (e.g. shovels)
  - Workers that are directly exposed to exhausts of the gas-based generator need to be equipped with gas mask respirators
  - Workers that are exposed to heat need to wear appropriate PPE
  - Workers that are exposed to high levels of noise (e.g. operating the generator; 85 dB permanent or 140 dB short duration) need to wear hearing protection
- Processes
  - Mesophilic anaerobic digestion is recommended at >35°C for >9 days (1 log reduction *E. coli* and 0 log reduction in helminth eggs)
- Infrastructure
  - Place clearly visible signs on toilets that prohibit disposal of any sharp object and inorganic waste into the toilet
  - Provide trash bins for disposal of sharp objects and inorganic waste components in each toilet

  - Install facilities where the dried anaerobic sludge or soil conditioner can be sieved carefully for removing any sharp objects
  - Install heat shields on hot parts that may be touched by individuals
  - In case the gas-based generator is located in a closed environment: install CO monitors and ensure that exhausts are released to the outside
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 21). The actual distance is depending on the level of emissions
  - At the electricity outlet of the gas-based generator, use intrinsically safe electrical installations, non-sparking tools and proper grounding
  - Prevent gas-leakage at the anaerobic digestion plant and install CO monitors in case the anaerobic digestion takes place in a closed environment
  - Depending on the further use of the outputs of the post-treatment, off-site and on-site post-treatment options are available (see section 4.1.1.1)
- Behavioural aspects and prevention
  - Develop and implement a fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)
  - Place clearly visible danger signs on the packaging, indicating the risk of sharp objects and that users need to wear gloves and boots when applying the product
  - Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
  - Restrict access to the anaerobic digestion plant and the generator
  - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE, ergonomic hazards, etc.)

4.3.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 4 can be reduced to **low, moderate and high levels**. The residual moderate risks are linked to the following processes:

- P1: toilet and P4: post-treatment: sharps ending up in the soil conditioner pose a moderate risk to users. Therefore it is crucial to sensitize users of the toilets to the issue and rigorously implement different control measures for preventing (e.g. trash bins) or removing (i.e. sieving) any sharp objects in the solid fraction of the anaerobic sludge
- P3: gas-based generator: exposure to toxic gas and noise emissions are of concern for both workers and the community. However, these risks can be controlled with appropriate equipment, a good design of the operation and by respecting a buffer zone between the plant and community infrastructure. Also fire and explosion are major risks related to the generator. This issue must primarily be taken into account

by the engineering of the plant. At the operational level a fire/explosion response plan needs to be developed and implemented

- Electric shock and fire/explosion are high risks that need to be managed accordingly

4.3.2 Health impact assessment

The provision of sanitation services to underserved communities is likely to reduce incidence of diarrhoeal diseases, ARI and helminth infections. In addition, the provision of electricity can impact socio-economic status and wellbeing, both of which have a strong link to community health.

- **Scale of the BM:** the impact assessment of Model 4 is based on the assumption that 10 villages in peri-urban areas of Lima, with a population of 1,000 people each, will implement the BM

4.3.2.1 Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

According to resent estimates by MINSA, over 90% of the households in Lima have some form of toilets and are connected to the sewerage system [13]. This has two consequences. First, there are only few communities that are underserved in terms of sanitation services and thus demand in the business model may be low. Second, there are relatively few people that practice unsafe sanitation practices in Lima. This reduces environmental disposal of human excreta and limits the burden of diseases linked to unsafe sanitation practices [28]. The situation in peri-urban areas of Lima is, however, different. For example, in Lurigacho Chosica district located in the valley of the Rimac River, only 39% of households are connected to the sewerage system, 27% use a black hole or latrine and 19% use a septic tank. Hence, in these communities the business has some potential to reduce the burden of diarrhoeal diseases and infection with protozoa or helminth infections in Lima.

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would be rolled out to 10 villages (average size 1’000 people) where 1 in 10 people would use the public toilets (10x1’000x0.1=1’000)
- **Likelihood:** it is unlikely (odds: 5–40%) that the business positively impacts on diarrhoeal diseases and helminth infections

Table 27 – Model 4, impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Large population group	Likely	**Moderate positive impact**
Score	0.1	1’000	0.3	**30**

For maximizing the health benefits of the business, it is recommended:

- to keep the fee for the usage of the toilets at a minimum;
- to provide free access to the toilet facilities to children;
- to target communities with particularly low access to sanitation for the implementation of the business; and
- to promote hand washing practice at the exit of the facility.

4.3.2.2 Impact 2: changes in health status due to access to electricity

➔ For the impact definition, see Model 3, impact 1 (section 4.1.2.1).

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 10 villages with an average of 300 individuals profits from the BM
- **Likelihood:** It is very unlikely that access to electricity impacts on the health of people

Table 28 – Model 4, impact 2: changes in health status due to access to electricity

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Medium population	Very unlikely	**Insignificant**
Score	0.0	3’000	0.05	**0**

4.3.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) air emissions from the anaerobic digester if not controlled properly or in case of failure, (2) solid residue from the anaerobic digestion process (digestate), which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations and (3) liquid effluent from the anaerobic digestion process which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) regular maintenance of the anaerobic digester to prevent leakages, and (2) and (3) solid and liquid residue post-treatment of the solid residue (digestate) and liquid effluent from the anaerobic digestion process. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of dewatered and appropriately treated sludge (digestate) and liquid effluent from post-treatment. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 29 – Model 4: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• Feces • Urine • FS	• Biogas -> Cooking fuel	• Single stage • Multi-stage • Batch	• Anaerobic digestion	• Air emissions • Solid residue (digestate) • Liquid effluent	• Maintenance of anaerobic digester • Solid/liquid residue post-treatment

4.4 Model 8 – Beyond cost recovery: the aquaculture example

Model 8 employs a wastewater-duckweed-fish rearing system on a small to medium scale. The products are: (i) treated wastewater; (ii) fish; and (iii) co-crops for consumption. The business has the potential to reduce environmental contamination and improve irrigation water quality.

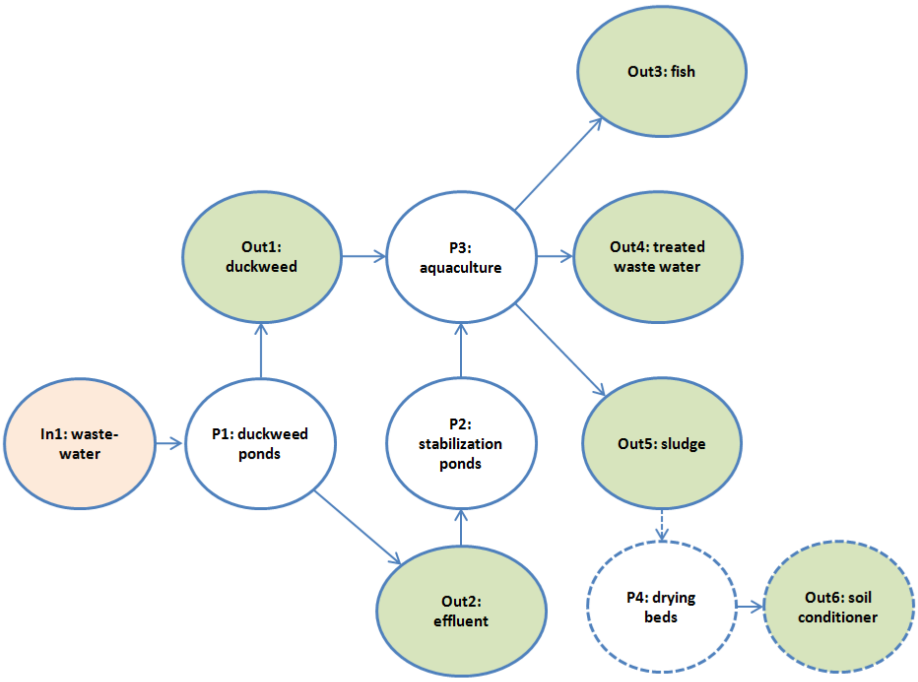

Figure 18 – Model 8: system flow diagram

Table 30 – Model 8: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: wastewater	Viruses, bacteria
	Protozoa
	Soil-transmitted helminths
	Trematodes
	Skin irritants
	Disease vectors
	Chemicals others than heavy metals

	Heavy metals

Table 31 – Model 8: Quality/safety requirements for outputs

<table>
<tr><th>Outputs of health relevance</th><th>Quality/safety requirements</th></tr>
<tr><td>Out1: duck week</td><td>N.a. (within system)</td></tr>
<tr><td>Out2: effluent</td><td>N.a. (within system)</td></tr>
<tr><td>Out3: fish</td><td>
<table>
<tr><th>Parameter[a]</th><th>Unit</th><th>Mean limit</th><th>Max. limit</th></tr>
<tr><td>Aerobic mesophiles (30°C)</td><td>UFC/g</td><td>5E+05</td><td>10^6</td></tr>
<tr><td>Escherichia coli</td><td>UFC/g</td><td>10</td><td>100</td></tr>
<tr><td>Staphylococcus aureus</td><td>UFC/g</td><td>100</td><td>1000</td></tr>
<tr><td>Salmonella spp.</td><td>P or A /25 g</td><td>Absence</td><td></td></tr>
<tr><td>Vibrio cholerae</td><td>P or A /25 g</td><td>Absence</td><td></td></tr>
<tr><td>Vibrio parahemolyticus</td><td>NMP/g</td><td><3</td><td></td></tr>
</table>
</td></tr>
<tr><td>Out4: treated wastewater</td><td>
Unrestricted irrigation
<u>Root crops:</u>
• $<10^3$ E. coli per litre and ≤1 helminth egg per litre
<u>Leave crops:</u>
• $<10^4$ E. coli per litre and ≤1 helminth egg per litre
<u>Drip irrigation of high-growing crops:</u>
• $<10^5$ E. coli per litre and ≤1 helminth egg per litre
<u>Drip irrigation of low-growing crops:</u>
• $<10^3$ E. coli per litre and ≤1 helminth egg per litre
Restricted irrigation
<u>Labour intensive agriculture:</u>
• $<10^4$ E. coli per litre and ≤1 helminth egg per litre
<u>Highly mechanized agriculture:</u>
• $<10^5$ E. coli per litre and ≤1 helminth egg per litre
➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV
</td></tr>
<tr><td>Out5: wastewater sludge</td><td>➔ Reuse of WWTP sludge is prohibited in Peru</td></tr>
<tr><td>Out6: soil conditioner</td><td>➔ Reuse of WWTP sludge is prohibited in Peru</td></tr>
</table>

[a] Instituto Tecnológico de Producción (ITP) and National Fishing Hygiene Service (SANIPES) (2010)

4.4.1 Health risk assessment

Risks associated with the business derive from the various potential hazards contained in wastewater such as pathogens and toxic chemicals (i.e. elements such as heavy metals as well as various hazardous organic compounds (see WHO 2006 guidelines; Volume II, Chapter 4.6). Phyto-remediative wastewater treatment has the potential to remove pathogens but its treatment efficiency regarding toxic chemicals is limited.

The environmental sampling in the frame of the SSP trial at the Cone Este study site found acceptable concentrations of heavy metals in the Rimac River water, as well as in water samples taken in agricultural irrigation channels. Therefore, phyto-remediative wastewater treatment and aquaculture appears feasible in the Cone Este area. On the other hand, concentration of heavy metals can show considerable fluctuations linked to environmental factors and intermittent industrial pollution. **These findings suggest that, from a health perspective, wastewater fed agriculture in Lima needs to be promoted with care , also since the concentration of heavy metals is likely to further increase over time due to accumulation in the soils.**

No recent data was identified on chemical parameter other than heavy metals. For identifying settings suitable for aquaculture in Lima, environmental sampling is required. With regard to irrigation with wastewater, the WHO 2006 Guidelines only define maximum tolerable soil concentrations of various toxic chemicals but not concentrations in the wastewater *per se*. Hence, national threshold values for toxic chemicals in wastewater apply.

Where phyto-remediative wastewater treatment and aquaculture seem feasible in terms of the concentration of toxic chemicals in wastewater and receiving soils, a series of stabilization ponds will be needed in order to assure the required pathogen reduction rates: 1. anaerobic stabilisation pond (retention time: 1–3 days); 2. facultative pond (retention time: 4-10 days); and 3. aquaculture (i.e. fish pond, P3). This setup is also important for producing fish that meets quality standards. By having two stabilisation ponds prior to the fish pond, the concentration of pathogen will be reduced.

It also has to be noted that according to the institutional analysis, the reuse of sludge is prohibited in Peru. Therefore, the reuse of the sludge from the phyto-remediative treatment process as proposed by Model 8 is currently not an option. However, since there is the possibility that the legislation will change in the future, the risk assessment is nevertheless covering all processes of the BM under the assumption that the sludge would be treated according to future national standards.

4.4.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material (e.g. wastewater, sewage sludge or inorganic contaminants) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Mechanical screening of the wastewater before entering the duck-week pond
  - In locations where the concentration of toxic chemicals such as metals in wastewater and/or receiving agricultural soils exceed national and international standards (see Annex IV), source reduction and/or physico-chemical removal processes (e.g. absorption) need to be applied.
  - Three stabilization ponds are needed: 1. anaerobic stabilisation pond (retention time: 1–3 days); 2. facultative pond (retention time: 4-10 days); and 3. fish pond (retention time: 4-10 days) (i.e. aquaculture, P3). The final retention times depend on ambient temperature and pathogen loads of the wastewater. For calculating the days needed, check WHO 2006 Guidelines, Volume III, Annex 1).

    - Store duckweed for at least 30 days under dry conditions prior to addition to the fish pond
    - Depuration of fish before harvesting by moving fish to a clean pond for at least 2-3 weeks
    - Harvest fish at young age in order to avoid accumulation of toxic chemicals
    - Currently, the reuse of sludge is prohibited in Peru. If this changes in the future, the sludge needs to be compliant with national standards. Otherwise the sludge must not be further processed for producing fertilizer. For pathogen removal, the sludge needs to be dewatered and put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
    - Sieving of the soil conditioner prior to packaging for discharging any remaining inorganic contamination or sharp objects
- Infrastructure
    - Install handrails and fence dangerous areas for preventing injuries and drowning
- Behavioural aspects and prevention
    - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
    - Protect workers from long term exposure to sunlight
    - Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
    - Restrict access to the operations
    - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.4.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 4 can be reduced to **low and moderate levels**. The residual moderate risks are linked to the following processes:

- P1: duckweed ponds: in settings where the concentration of toxic chemicals in wastewater and/or receiving soils exceed national and WHO Guidelines threshold values (see annex IV), the treated wastewater is not suitable for irrigation. Consequently, source reduction and/or physico-chemical removal processes have to be applied. If not, there is a very high risk for adverse health impacts (e.g. chronic disease or even cancer linked to consumption of products that are contaminated with heavy metals and potentially other toxic chemicals) linked to wastewater-fed agriculture in Lima.
- P2: stabilisation ponds: the pathogen load of the wastewater needs to be monitored on a regular basis for adapting the retention times in the stabilisation ponds. If monitoring of pathogen loads is not an option, 3 days in the anaerobic pond and 10 days in the facultative pond should be applied

- P3: aquaculture: for reducing contamination of fish with pathogens to a minimum, duck-weed needs to be stored under dry conditions for 30 days prior to addition to the fish pond and the fish needs to be purified in a clean water pond for 2-3 weeks prior to harvesting
- P4: composting: in order to avoid exposure of consumers to pathogens in the soil conditioner, it will be crucial to respect the temperature and duration indicated for the drying of the sludge

4.4.2 Health impact assessment

In settings where the concentration of toxic chemicals of wastewater and agricultural soils are compliant with national and international threshold values, or source reduction and treatment processes are applied as per risk assessment, Model 8 has the potential to positively impact on health linked to the treatment of wastewater. Hence, farmers and consumers may benefit from the business.

- **Scale of the BM:** the impact assessment of Model 8 is assuming that 3 operations serving 500 farmers with safe irrigation water will be implemented. The products irrigated with safe irrigation water and safe fish from the aquaculture will be consumed by 150’000 consumers (i.e. 3x50’000 consumers; similar ration as found in the Cone Este area). In view of the size of the operation, the general downstream population is not considered for the impact assessment since no effect is anticipated

4.4.2.1 Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

Untreated wastewater negatively impacts on the health of populations, be it through direct contact, ingestion or the consumption of contaminated products. Clearly, diarrhoeal diseases and respiratory infections are important public health issues in Lima. Farmers are particularly exposed to risks related to untreated wastewater and besides intestinal and respiratory diseases they also suffer often from skin diseases. Hence, by replacing untreated wastewater with treated wastewater for irrigation is likely to reduce incidence of disease in farmers. One well known source of bacterial, viral and protozoa infection, besides poor hygiene practices, is through the consumption of contaminated food. Thus, the replacement of untreated wastewater with treated wastewater for irrigation can have a considerable impact on diseases incidence of consumers. The same applies for safe fish from the aquaculture. As those consumers might also consume products from other areas and may, in addition, carefully wash the products before consumption, the likelihood of the impact on consumers is set at unlikely.

Impact 1, assumptions:

- **Impact level:** pathogens in untreated wastewater generally cause disease of short duration and/or minor disability
- **People affected:** 1’500 farmers (3x500) and 150’000 consumers (3x50’000) would benefit from the business
- **Likelihood:** farmers: likely; and consumers: unlikely

Table 32 – Model 8, impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Specific/large population groups	Likely Unlikely	**Major positive impact**
Score: farmers	0.1	500	0.7	35
Score: consumers	0.1	150,000	0.3	4'500
			TOTAL	**4'535**

4.4.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) heavy metals in effluent and/or sludge from wastewater treatment, which when disposed of or treated inadequately can have a negative impact, and (2) solid residue (accumulated sludge from WW treatment) which when disposed of or treated inadequately can have a negative impact. Mitigation measures to avoid negative impacts include: (1.a) upstream monitoring to ensure influent meets guidelines for heavy metal concentrations, (1.b) monitoring of effluent and solids to ensure concentrations of heavy metals do not exceed regulations, and (2) post-treatment of the solid residue (accumulated sludge from WW treatment), to ensure that it is appropriately treated for the intended end-use. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated sludge (accumulated sludge from WW treatment). If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 33 – Model 8: potential environmental hazards and proposed mitigation measures

Waste stream	**End-product**	**Technologies**	**Process**	**Pot. Env. Hazard**	**Mitigation measures**
• WW	• Fish • Treated WW	• Duckweed • Aquaculture	• Pond treatment	• Heavy metals in effluent and/or sludge from WW treatment • Solid residue (sludge from WW treatment)	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treatment

4.5 Model 9 – On cost savings and recovery

This business model aims at cost recovery of wastewater treatment through the following value propositions: two revenue streams (treated wastewater sales and soil conditioner sales), and a cost-saving mechanism using the treatment processes to capture biogas and converting it to electricity that is subsequently used to (partially) power the plant. Wastewater needs to be treated to a quality that is accepted by Peru's regulation for irrigated farming (see Decreto Supremo N° 002-2008-MINAM). Since the wastewater treatment is not clearly defined as per the business model, the risk assessment does not go into the details of the wastewater treatment plant or the production of electricity. However, it is anticipated that for the construction of a 1.5-230 million US$ wastewater treatment plant (as per business model description) a detailed occupational health management plant would be developed. Therefore, the HRIA of Model 9 is primarily focusing on down-stream issues.

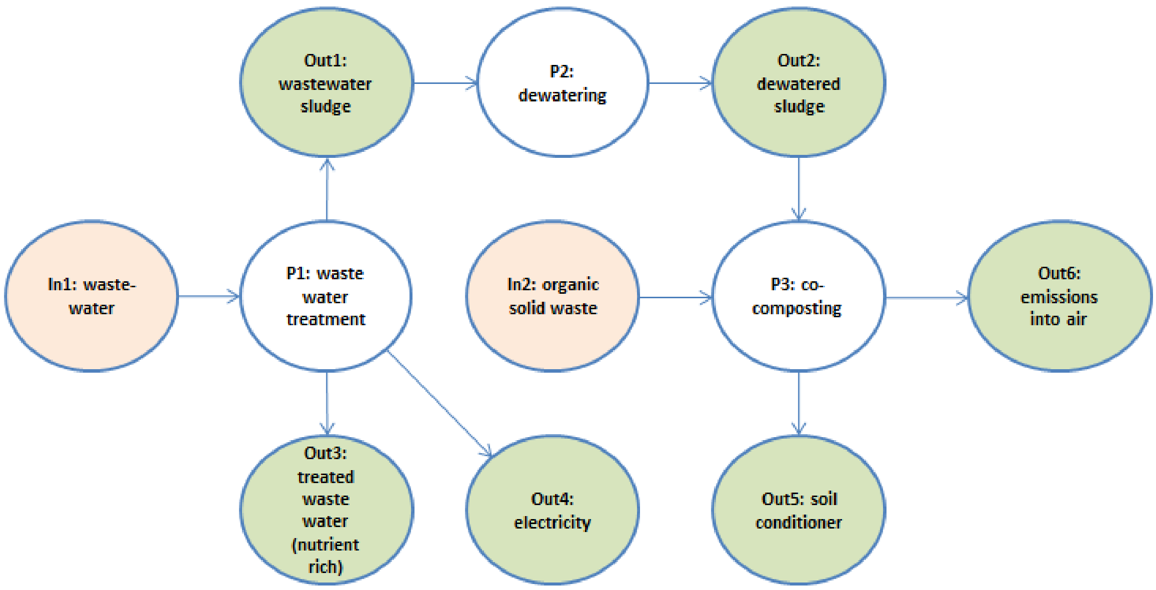

Figure 19 – Model 9: system flow diagram

Table 34 – Model 9: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: wastewater	Viruses, bacteria
	Protozoa
	Soil-transmitted helminths
	Trematodes
	Skin irritants
	Disease vectors
	Chemicals others than heavy metals
	Heavy metals
In2: organic solid waste	Pathogens
	Sharps
	Inorganic waste components

Table 35 – Model 9: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: wastewater sludge	Maximum heavy metals concentration of wastewater sludge for composting (unit: mg/kg dried matter): Cd: 3.0; Cr_{tot}: 300; Cu 500; Hg: 5.0; Ni: 100; Pb: 200; and Zn: 2,000[a]
Out2: dewatered sludge	N.a. (inside system)
Out3: treated wastewater	**Unrestricted irrigation** Root crops: • $<10^3$ *E. coli* per litre and ≤1 helminth egg per litre Leave crops: • $<10^4$ *E. coli* per litre and ≤1 helminth egg per litre Drip irrigation of high-growing crops: • $<10^5$ *E. coli* per litre and ≤1 helminth egg per litre Drip irrigation of low-growing crops: • $<10^3$ *E. coli* per litre and ≤1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • $<10^4$ *E. coli* per litre and ≤1 helminth egg per litre Highly mechanized agriculture: • $<10^5$ *E. coli* per litre and ≤1 helminth egg per litre ➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV
Out4: electricity	Intrinsically safe electrical installations and proper grounding
Out5: soil conditioner	➔ **Reuse of WWTP sludge is prohibited in Peru**
Out6: emissions into air	Ambient air quality standards[a]: • Total hydrocarbons (HC): 100 μ/m^3 24-hour mean • Benzene: 2 μ/m^3 24-hour mean • $PM_{2.5}$: 25 μ/m^3 24-hour mean; 25 μ/m^3 annual mean • H_2S: 150 μ/m^3 24-hour mean; 50 μ/m^3 annual mean • SO_x: 20 μ/m^3 24-hour mean; 50 μ/m^3 annual mean

[a] Decreto Supremo N° 009-2008-MINAM

4.5.1 *Health risk assessment*

Risks associated with the business derive from the various potential hazards contained in wastewater as outlined in section 3.2. It is well known, that accordingly designed and operated wastewater treatment plants allow for removing pathogens to acceptable levels. The removal of heavy metals, however, is more complex and cost intensive, which makes them a great concern from an economic, health and environmental perspective. Ideally, heavy metals are kept out of wastewater streams by reducing and controlling potential sources.

The environmental sampling in the frame of the SSP trial found acceptable concentrations of heavy metals in the effluent of the Huascar Wastewater Treatment Plant (PTAR), although the plant does not apply any physico-chemical removal processes. This is a positive finding. On the other hand, concentration of heavy metals can show considerable fluctuations linked to environmental factors and intermittent industrial pollution. **These findings suggest that, from a health perspective, wastewater fed agriculture in Lima needs to be promoted with care, also since the concentration of heavy metals is likely to further increase over time due to accumulation in the soils.**

It also has to be noted that according to the institutional analysis, the reuse of sludge is prohibited in Peru. Therefore, the reuse of the sludge as proposed by Model 9 is currently not an option. However, since there is the possibility that the legislation will change in the future, the risk assessment is nevertheless covering all processes of the BM under the assumption that the sludge would be treated according to future national standards.

4.5.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material (e.g. wastewater, sewage sludge or inorganic contaminants) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Primary, secondary and tertiary treatment has to be applied for reducing pathogens. Different options can be combined for reaching a minimum of 7 log reduction in bacterial indicators (e.g. *E. coli*) and 3 log reductions in helminth eggs
  - In locations where the concentration of toxic chemicals such as metals in wastewater and/or receiving agricultural soils exceed national and international standards (see Annex IV), source reduction and/or physico-chemical removal processes (e.g. absorption) need to be applied.
  - Currently, the reuse of sludge is prohibited in Peru. If this changes in the future, the sludge needs to be compliant with national standards. Otherwise the sludge must not be further processed for producing fertilizer. For pathogen removal, the sludge needs to be dewatered and put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
  - A temperature of ≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter) should be maintained for the co-composting
  - Moisture of co-composting material should be above 40% for reducing bio-aerosol emission
  - Sieving of the soil conditioner prior to packaging for discharging any remaining inorganic contamination or sharp objects
- Infrastructure
  - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
  - Install handrails and fence dangerous areas for preventing injuries and drowning
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded. The actual distance is depending on the level of emissions
- Behavioural aspects and prevention
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices

- Rodent and vector-control (e.g. screening or use of larvicides, insecticides) at waste-storage sites and treatment ponds
- Protect workers from long term exposure to sunlight
- Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
- Restrict access to the operations
- Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.5.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 4 can be reduced to **low, moderate and high levels**. The residual moderate and high risks are linked to the following processes:

- P1: wastewater treatment plant: in settings where the concentration of toxic chemicals in wastewater and/or receiving soils exceed national and WHO Guidelines threshold values (see annex IV), the treated wastewater is not suitable for irrigation. Consequently, source reduction and/or physico-chemical removal processes have to be applied. If not, there is a very high risk for adverse health impacts (e.g. chronic disease or even cancer linked to consumption of products that are contaminated with heavy metals and potentially other toxic chemicals) linked to wastewater fed agriculture in Lima.
- P2: dewatering and P3: co-composting: in order to avoid exposure of consumers to pathogens in the soil conditioner, it will be crucial to respect the temperature and duration indicated for the drying of the sludge and the co-composting
- P3: co-composting: sharps ending up in the soil conditioner pose a moderate risk to users. Therefore it is important carefully sieve the soil conditioner before packaging and also users need to be sensitised on the potential contamination with sharp objects. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.
- P3: co-composting: to ensure that workers are protected with respirators is important when handling the waste materials for the co-composting process. Otherwise pathogens, fungi and dust affect their respiratory system

4.5.2 Health impact assessment

The health benefits of a modern wastewater treatment plant in an environment like Lima primarily relate to down-stream issues like reduced exposure to pathogens and potentially also toxic chemicals.

- **Scale of the BM:** the impact assessment of Model 9 is assuming that an area like the agricultural areas of Cono Este would be served by the treatment plant. According to the SSP trial at Cono Este, population groups that would be impacted by such a

WWTP are 5,600 farmers, 700,000 consumers and 22,000 people from the general population [2].

4.5.2.1 Impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

Untreated wastewater negatively impacts on the health of populations, be it through direct contact, ingestion or the consumption of contaminated products. Clearly, diarrhoeal diseases and respiratory infections are important public health issues in Lima. Farmers are particularly exposed to risks related to untreated wastewater and besides intestinal and respiratory diseases they also suffer often from skin diseases. Hence, by replacing untreated wastewater with treated wastewater for irrigation is likely to reduce incidence of disease in farmers. With regard to downstream communities that are currently exposed to untreated wastewater, it is not established to what extent incidence of respiratory, diarrhoeal, intestinal and skin diseases in this population group is linked to exposure to untreated wastewater. One well known source of bacterial, viral and protozoa infection, besides poor hygiene practices, is through the consumption of contaminated food. The SSP trial estimated that about 700,000 people consume products from Cone Este area. Thus, the replacement of untreated wastewater with treated wastewater for irrigation can have a considerable impact on diseases incidence of consumers. As those consumers might also consume products from other areas and may, in addition, carefully wash the products before consumption, the likelihood of the impact on consumers is set at unlikely.

Impact 1, assumptions:

- **Impact level:** pathogens in untreated wastewater generally cause disease of short duration and/or minor disability
- **People affected:** 5,600 farmers, 22,000 community members and 700,000 consumers would benefit from the business
- **Likelihood:** farmers: likely; general population: very unlikely; and consumers: unlikely

Table 36 – Model 9, impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Large population groups	Likely; very unlikely; and unlikely	**Major positive impact**
Farmers	0.1	5,600	0.7	3,920
General population	0.1	22,000	0.05	110
Consumers	0.1	700,000	0.3	21,000
			TOTAL	**25,030**

4.5.2.2 Impact 2: reduction in exposure to toxic chemicals

Long-term exposure to toxic chemicals (e.g. heavy metals) can cause a range of health effects, ranging from neurological damage to poisoning. In general, these effects are difficult to quantify and many knowledge gaps exist. The environmental sampling in the frame of the SSP trial suggests that chemicals and heavy metals are not a major issue in Lima's wastewater. Soils seem to be more important sources of heavy metals than wastewater. In addition, the number of people being directly exposed to untreated wastewater is relatively small.

Under the assumption that the business model will operate in settings with acceptable concentrations of toxic chemicals, or will eliminate these to acceptable levels, a minor positive health effect is anticipated in the farming population. The impact is anticipated to be insignificant at community and consumer level. The likelihood of any effect is very low.

Impact 2, assumptions:

- **Impact level:** health impacts linked to long-term exposure to toxic chemicals is not perceived by most individuals but can result moderate disability. A minor positive effect (0.1) is applied as an average value
- **People affected:** 5,600 farmers, 22,000 community members and 700,000 consumers would benefit from the business
- **Likelihood:** it is unlikely that community members will experience any improvement in their health status due to reduce exposure to toxic chemicals

Table 37 – Model 9, impact 2: reduction in exposure to toxic chemicals

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Large population groups	Very unlikely	**Moderate positive impact**
Farmers	0.1	5,600	0.05	28
General population	0.0	22,000	0.05	0
Consumers	0.0	700,000	0.05	0
			TOTAL	**28**

4.5.2.3 Impact 3: changes in health status due to access to electricity

➔ For the impact definition, see Model 3, impact 1 (section 4.1.2.1).

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** the electricity generated by the plant would serve 3'000 people
- **Likelihood:** It is very unlikely that access to electricity impacts on the health of people

Table 38 – Model 4, impact 2: changes in health status due to access to electricity

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Medium population	Very unlikely	**Insignificant**
Score	0.0	3’000	0.05	**0**

4.5.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) heavy metals in effluent and/or sludge from wastewater treatment, which when disposed of or treated inadequately can have a negative impact, (2) solid residue (accumulated sludge from WW treatment) which when disposed of or treated inadequately can have a negative impact, and (3) air emissions from the anaerobic digester if not controlled properly or in case of failure. Mitigation measures to avoid negative impacts include: (1.a) upstream monitoring to ensure influent meets guidelines for heavy metal concentrations, (1.b) monitoring of effluent and solids to ensure concentration of heavy metals do not exceed regulations, and, (2) solid residue post-treatment of the solid residue (accumulated sludge from WW treatment), which is converted into a soil conditioner for endues in agriculture, and (3) regular maintenance of the anaerobic digester to prevent leakages. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated sludge (accumulated sludge from WW treatment) and in the case of this business model means as a soil conditioner for end-use in agriculture. If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 39 – Model 9: potential environmental hazards and proposed mitigation measures

Waste stream	**End-product**	**Technologies**	**Process**	**Pot. Env. Hazard**	**Mitigation measures**
• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conven-tional WW treatment • Biogas to electricity conversion	• Heavy metals in effluent and/or WW sludge • Solid residue (sludge from WW treatment) • Air emissions	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treament • Maintenance of anaerobic digester

4.6 Model 13 – Informal to formal trajectory in wastewater Irrigation: sale/auctioning wastewater for irrigation

The key feature of Model 13 is a WWTP that mainly receives domestic wastewater. Through partnership with farmer association in the vicinity of the WWTP the treated wastewater would be sold to produce vegetables to meet the diverse demands of a growing population.

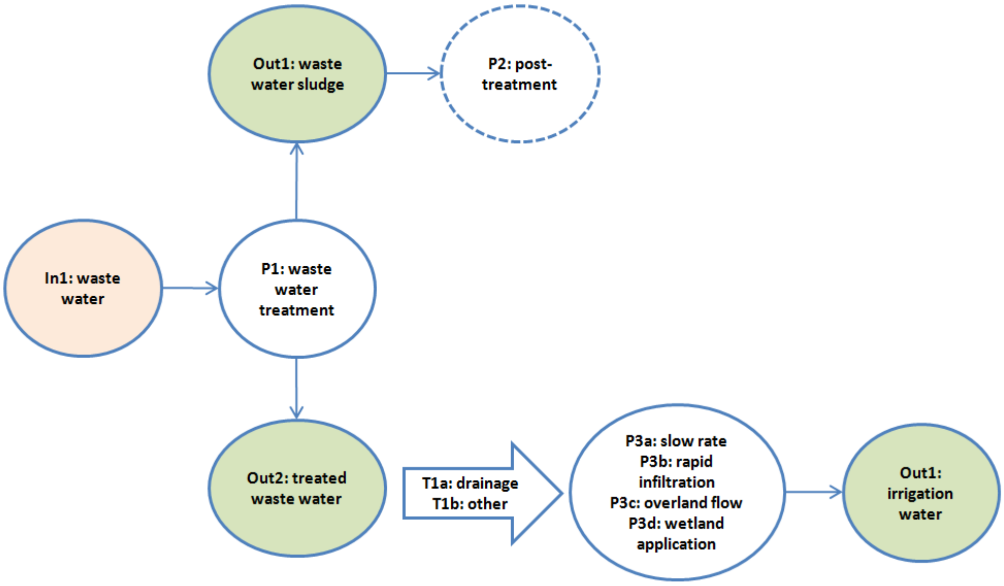

Figure 20 – Model 13: system flow diagram

Table 40 – Model 13: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: untreated wastewater	Viruses, bacteria
	Protozoa
	Soil-transmitted helminths
	Trematodes
	Skin irritants
	Disease vectors
	Chemicals others than heavy metals
	Heavy metals

Table 41 – Model 13: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: waste water sludge	➔ **Reuse of WWTP sludge is prohibited in Peru**
Out2: treated waste water	N.a. (within the system)
Out3: irrigation water	**Unrestricted irrigation** Root crops: • $<10^3$ E. coli per litre and <1 helminth egg per litre Leave crops:

	• $<10^4$ E. coli per litre and <1 helminth egg per litre Drip irrigation of high-growing crops: • $<10^5$ E. coli per litre and <1 helminth egg per litre Drip irrigation of low-growing crops: • $<10^3$ E. coli per litre and <1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • $<10^4$ E. coli per litre and <1 helminth egg per litre Highly mechanized agriculture: • $<10^5$ E. coli per litre and <1 helminth egg per litre ➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV

4.6.1 Health risk assessment

Risks associated with the business derive from the various potential hazards contained in wastewater such as pathogens and toxic chemicals. These issues are discussed in detail under Model 9 (see section 4.5.1).

4.6.1.1 Indicated control measures

The full risk assessment matrix is available in Appendix I. Indicated control measures are as follows:

- Protective equipment
  - Workers handling any raw material (e.g. wastewater, sewage sludge or inorganic contaminants) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Primary, secondary and tertiary treatment has to be applied for reducing pathogens. Different options can be combined for reaching a minimum of 7 log reduction in bacterial indicators (e.g. *E. coli*) and 3 log reductions in helminth eggs
  - In locations where the concentration of toxic chemicals such as metals in wastewater and/or receiving agricultural soils exceed national and international standards (see Annex IV), source reduction and/or physico-chemical removal processes (e.g. absorption) need to be applied.
  - For pathogen removal, the sludge needs to be dewatered and put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
  - Currently, the reuse of sludge is prohibited in Peru. If this changes in the future, the sludge needs to be compliant with national standards. Otherwise the sludge must not be further processed for producing fertilizer
  - The irrigation options depend on the quality of the treated wastewater. According to Peruvian law, the concentration of 100 *E. coli*/mL must not be exceeded if the treated wastewater is used for irrigation. The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV. Of note, the application of infiltration systems would

allow to further reduce pathogen load in irrigation water. More details are available in the WHO 2006 Guidelines.

- Infrastructure
    - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
    - Install handrails and fence dangerous areas for preventing injuries and drowning
    - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded. The actual distance is depending on the level of emissions
- Behavioural aspects and prevention
    - Any slow and rapid infiltration system requires a hydrology study in order to exclude any contamination of drinking water sources
    - The drainage system needs to be complemented with a pre-treatment facility (e.g. screening and grease traps) for preventing backups and overflows. In addition, regular cleaning of the drainage system is necessary for preventing clogging and overflow.
    - Advice farmers who apply the wastewater to wear boots and gloves when working in the irrigated fields.
    - Advice farmers who apply the wastewater to respect 2 days between last irrigation and harvesting.
    - Advice farmers who apply the wastewater to wash harvested crops with fresh water
    - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
    - Vector-control (e.g. screening or use of larvicides, insecticides) at treatment ponds where indicated
    - Protect workers from long term exposure to sunlight
    - Restrict access to the operations
    - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.6.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 4 can be reduced to **low, moderate and high levels**. The residual moderate and high risks are linked to the following processes:

- P1: wastewater treatment plant: in settings where the concentration of toxic chemicals in wastewater and/or receiving soils exceed national and WHO Guidelines threshold values (see annex IV), the treated wastewater is not suitable for irrigation. Consequently, source reduction and/or physico-chemical removal processes have to be applied. If not, there is a very high risk for adverse health impacts (e.g. chronic disease or even cancer linked to consumption of products that are contaminated with heavy metals and potentially other toxic chemicals) linked to wastewater fed agriculture in Lima

- P2: dewatering: in order to avoid potential future exposure of consumers to pathogens in the soil conditioner (**currently, the reuse of WWTP sludge is prohibited in Peru**), it will be crucial to respect the temperature and duration indicated for the drying of the sludge

4.6.2 Health impact assessment

➔ Same as for Model 9 (section 4.5.2)

4.6.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) groundwater contamination with heavy metals and/or pathogens, due to inadequately treated wastewater (2) contamination of irrigated crops with heavy metals and/or pathogens, due to heavy metal being present in incoming wastewater and (3) solid residue (accumulated sludge from WW treatment), which when disposed of or treated inadequately can have a negative impact. Mitigation measures to avoid negative impacts include: (1.a) upstream monitoring to ensure influent meets guidelines for heavy metal concentrations, (1.b) monitoring of effluent and solids to ensure concentration of heavy metals do not exceed regulations, (2) adhering to appropriate levels of multiple barrier protection, such as the WHO "Guidelines for the safe use of Wastewater, Excreta and Greywater, 2006", which extensively describe the limitations, and environmental and health concerns for this type of application, and (3) post-treatment of the solid residue (accumulated sludge from WW treatment), to ensure that it is appropriately treated for the intended end-use. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated sludge (accumulated sludge from WW treatment). If for some reason this is not feasible, only then should disposal of solids at sanitary landfills be considered. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 42 – Model 13: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• WW	• Water (for reclamation)	• Conventional WW treatment with limited nutrient removal • Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Conventional WW treatment • Land application	• Groundwater contamination (heavy metals/pathogens) • Contamination of irrigated crops • Solid residue (sludge from WW treatment)	• Crop selection • Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • 2006 WHO guidelines • Solid residue (sludge from WW treatment) post-treatment

4.7 Model 15 – Large-scale composting for revenue generation

This business model is a small to medium scale production that aims at (i) reducing greenhouse gas emission through processing of municipal solid waste; and (ii) collecting and treating MSW and night soil from the city for producing organic fertilizer. The business would be implemented in urban Lima linked to the increased availability of MSW.

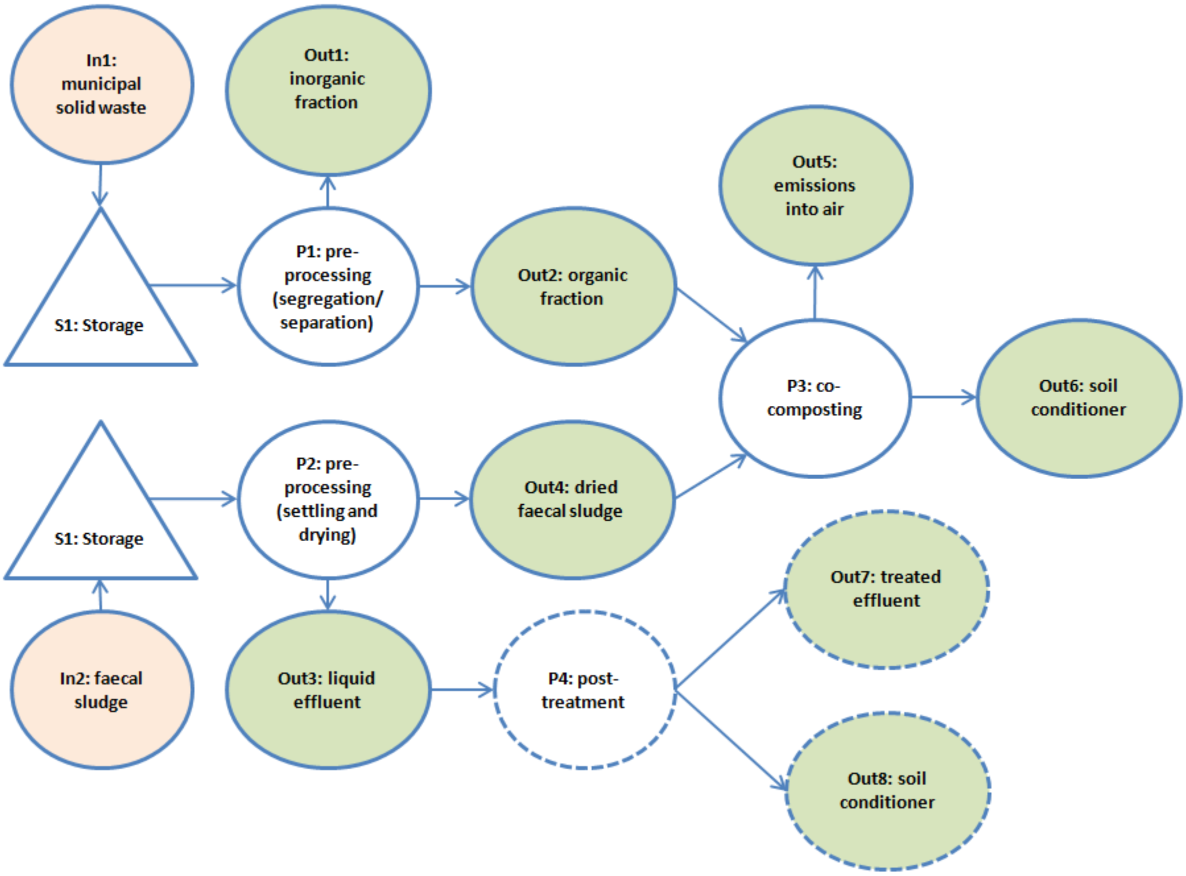

Figure 21 – Model 15: system flow diagram

Table 43 – Model 15: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: municipal solid waste	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste
In2: faecal sludge	Pathogens
	Contamination with sharp objects and inorganic waste

Table 44 – Model 15: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: inorganic fraction	None since considered as waste → appropriate disposal/recycling
Out2: organic fraction	N.a. (within the system)
Out3: liquid effluent	N.a. (within the system)
Out4: dried sludge	N.a. (within the system)
Out5: emissions into air	Ambient air quality standards[a]: • Total hydrocarbons (HC): 100 µ/m^3 24-hour mean • Benzene: 2 µ/m^3 24-hour mean • $PM_{2.5}$: 25 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • H_2S: 150 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • SO_x: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean
Out7: treated effluent	**Unrestricted irrigation** Root crops: • <10^3 *E. coli* per litre and ≤1 helminth egg per litre Leave crops: • <10^4 *E. coli* per litre and ≤1 helminth egg per litre Drip irrigation of high-growing crops: • <10^5 *E. coli* per litre and ≤1 helminth egg per litre Drip irrigation of low-growing crops: • <10^3 *E. coli* per litre and ≤1 helminth egg per litre **Restricted irrigation** Labour intensive agriculture: • <10^4 *E. coli* per litre and ≤1 helminth egg per litre Highly mechanized agriculture: • <10^5 *E. coli* per litre and ≤1 helminth egg per litre ➔ The full list of biological and chemical threshold values of irrigation water and receiving soils is available in Annex IV
Out8: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids

[a] Decreto Supremo N° 009-2008-MINAM

4.7.1 Health risk assessment

Health risks of this business are associated with the two types of inputs. MSW is usually contaminated with pathogens deriving from human (e.g. diapers) and potentially animal waste. Viruses and bacteria are of primary concern. In addition, sharp objects (e.g. razor blades), chemical waste (e.g. batteries) or even medical waste may be included in MSW. Pathogens are the primary hazard of the second input, faecal sludge, as well as potential contamination thereof with sharp object (e.g. razor blades). Besides the health hazards associated with the inputs, the operation of a co-composting plant involves emissions into the air such as malodours, thermophilic fungi and dust. Also the liquid effluents need to be treated appropriately. However, since the post-treatment of the liquid effluent is not clearly defined by the business model, the risk assessment is limited to the description of the efficiency of different post-treatment options but does not define which combination has to be selected. For the impact assessment it is assumed that the sludge and effluent of the anaerobic digestion are disposed of safely, i.e. appropriate disposal in case of no onsite post-treatment or treated effluent and soil conditioner that are compliant with quality/safety requirements as per the given scenario.

4.7.1.1 Indicated control measures

- Protective equipment
    - Workers handling any raw material (e.g. MSW and faecal matter) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
    - Separation of any components that are contaminated with biological (e.g. human waste such as diapers or sanitary products), chemical (e.g. batteries) or inorganic (e.g. sharp objects such as razor blades) wastes. To be discharged into the inorganic fraction and disposed of appropriately
    - For pathogen removal, the faecal sludge needs to be put on drying beds for: (i) 1.5-2 years at 2-20°C; (ii) >1 years at 20-35°C; or (iii) >6 months by means of alkaline treatment at pH>9, >35°C and moisture <25%
    - Depending on the further use of the outputs of the post-treatment, off-site and on-site post-treatment options are available (see section 4.1.1.1)
    - A temperature of ≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter) should be maintained for the co-composting
    - Moisture of co-composting material should be above 40% for reducing bio-aerosol emission
    - Sieving of the soil conditioner prior to packaging for discharging any remaining inorganic contamination or sharp objects
- Infrastructure
    - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
    - Install handrails and fence dangerous areas for preventing injuries
    - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 44Table 21). The actual distance is depending on the level of emissions
- Behavioural aspects and prevention
    - Assure that MSW is not contaminated with any medical waste
    - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices
    - Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
    - Protect workers from long term exposure to sunlight
    - Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
    - Restrict access to the operations
    - Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.7.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 15 can be reduced to **low and moderate levels**. The residual risks are linked to the following processes:

- P1: pre-processing of MSW: rigorous discharging of any human, animal or chemical waste, as well as sharp objects is essential for assuring quality and safety of the organic fraction
- P2: settling and drying, and P3: co-composting: in order to avoid exposure of consumers to pathogens in the soil conditioner, it will be crucial to respect the temperature and duration indicated for the drying of the sludge and the co-composting
- P3: co-composting: to ensure that workers are protected with respirators is important when handling the waste materials for the co-composting process. Otherwise pathogens, fungi and dust affect their respiratory system
- P3: co-composting and P4: post-treatment: sharps ending up in the soil conditioner pose a moderate risk to users. Soil conditioner must be sieved before packaging and users need to be sensitised about the potential presence of sharp objects and pathogens in the soil conditioner. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.
- **Medical waste must be collected separately for keeping it out of the BM**

4.7.2 Health impact assessment

By collecting and processing faecal sludge, the business is a purification process. Consequently, there is the potential that the business' activity will result in a reduction of unsafe disposal of faecal matter into the environment and thus exposure to pathogens may be reduced.

- **Scale of the BM:** the impact assessment of Model 15 is assuming that two centralised co-composting plants are installed in Lima, each collecting faeces from 2'000 households

4.7.2.1 Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases

The business entails safe collection and disposal of faecal sludge. Consequently, there is the potential that the business' activity will result in a reduction of unsafe disposal of faecal matter into the environment. In Lima, over 90% of the households are connected to the sewerage system. In peri-urban areas of Lima, where about half of the households rely on onsite sanitation systems, Model 15 may be an interesting option. However, also in these settings open defecation very rare. Against this background, it is highly unlikely that the business will lead to considerable reduction in diarrhoeal diseases, ARI and helminth infections.

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** in total, faeces would be collected from 4,000 households with an average size of 5 people
- **Likelihood:** it is very unlikely that the business will make a difference in disease incidence

Table 45 – Model 15, impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Medium population group	Very unlikely	**Minor positive impact**
Score	0.1	4,000	0.01	**4**

4.7.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) accumulated waste resulting from separation of inorganic fractions from MSW prior to composting and disposed of or used improperly (2) leachate from the composting process, which if moisture is not well controlled can leach into the environment, (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) liquid effluent from FS treatment, which when leaching into the environment can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), (2) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, (3) temperature control of the compost heap to ensure sufficient pathogen inactivation, and (4) post-treatment of the liquid effluent from FS dewatering processes. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated liquid effluent from post-treatment of liquid effluent from FS dewatering processes. If for some reason this is not feasible, only then should treated liquid effluent from FS dewatering processes get discharged into the environment presuming that it complies with local standards for discharge into the environment. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 46 – Model 15: potential environmental hazards and proposed mitigation measures

Waste stream	**End-product**	**Technologies**	**Process**	**Pot. Env. Hazard**	**Mitigation measures**

• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

4.8 Model 17 – High value fertilizer production for profit

The difference between Model 17 and Model 15 (analysed above) are:

- the input faecal sludge is combined with animal manure; and
- nitrogen (N), phosphorus (P) and potassium (K) (NPK) are added for the co-composting in order to produce branded/certified organic fertilizer

From a health protection and health impact perspective, these two modifications to Model 15 do not make any difference. Therefore, the HRIA of Model 15 also applies to Model 17.

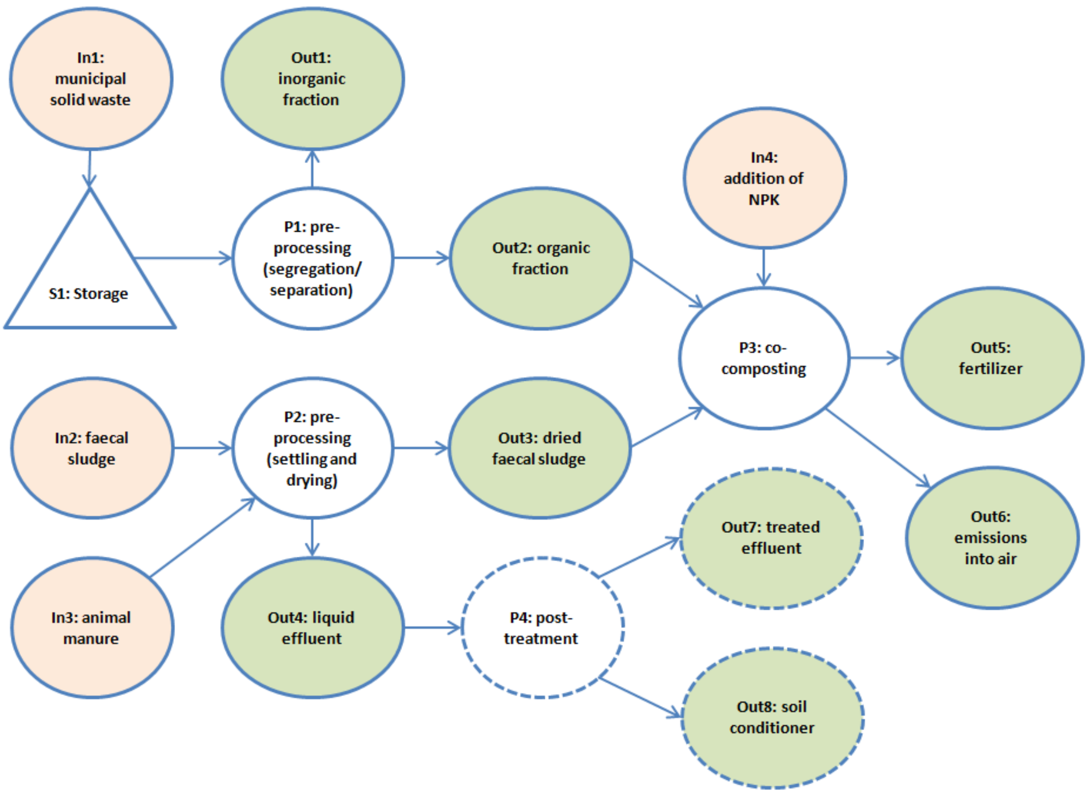

Figure 22 – Model 17: system flow diagram

Table 47 – Model 17: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: municipal solid waste	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste
In2: faecal sludge	Pathogens
	Contamination with sharp objects and inorganic waste
In3: animal manure	Pathogens
In4: addition of NPK	None

4.8.1 Health risk assessment

➔ Same as for Model 15 (section 4.7.1)

4.8.2 Health impact assessment

➔ Same as for Model 15 (section 4.7.2)

4.8.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) accumulated waste resulting from separation of inorganic fractions from MSW prior to composting and disposed of or used improperly (2) leachate from the composting process, which if moisture is not well controlled can leach into the environment, (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) liquid effluent from FS treatment, which when leaching into the environment can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), (2) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, (3) temperature control of the compost heap to ensure sufficient pathogen inactivation, and (4) post-treatment of the liquid effluent from FS dewatering processes. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated liquid effluent from post-treatment of liquid effluent from FS dewatering processes. If for some reason this is not feasible, only then should treated liquid effluent from FS dewatering processes get discharged into the environment presuming that it complies with local standards for discharge into the environment. Further details on technology options are outlined in the “Technology Assessment Report” [1].

Table 48 – Model 17: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • FS	• Fertilizer (NPK added)	• Solid/liquid separation • Drying beds • Co-composting	• Co-com-posting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

4.9 Model 21 – Partially subsidized composting at district level

This business processes MSW into soil conditioner, which will be sold to fertilizer shops and farmers. Inorganic waste fractions are sold to plastic manufacturers and metal-using industry.

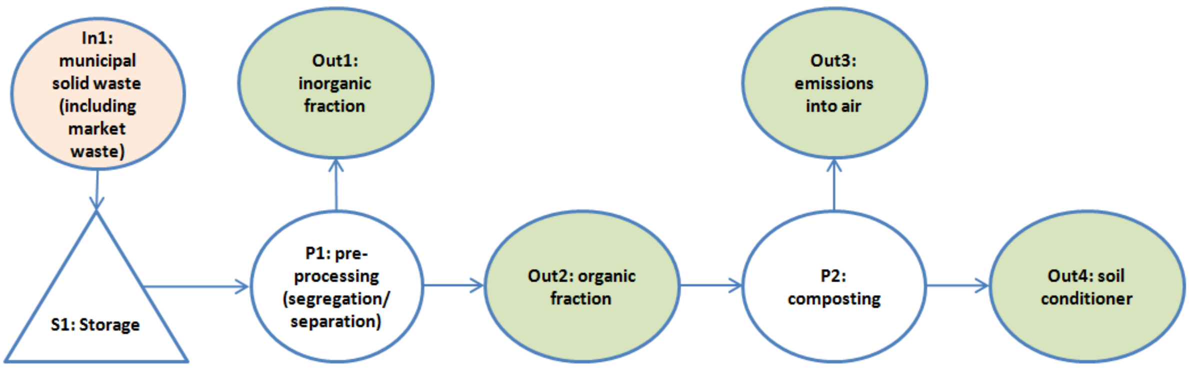

Figure 23 – Model 21: system flow diagram

Table 49 – Model 21: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: municipal solid waste (including market waste)	Contamination with pathogens deriving from human and animal waste (viruses and bacteria are of primary concern)
	Contamination with sharp objects
	Contamination with medical waste
	Contamination with chemical waste

Table 50 – Model 21: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: inorganic fraction	None since considered as waste → appropriate disposal/recycling
Out2: organic fraction	N.a. (within system)

Out3: emissions into air	Ambient air quality standards[a]: • Total hydrocarbons (HC): 100 µ/m^3 24-hour mean • Benzene: 2 µ/m^3 24-hour mean • $PM_{2.5}$: 25 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • H_2S: 150 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • SO_x: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean
Out4: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 E. coli per gram total solids

[a] Decreto Supremo N° 009-2008-MINAM

4.9.1 Health risk assessment

Health risks of this business are associated with the MSW, which can be contaminated with pathogens deriving from human (e.g. diapers) and potentially animal waste. Viruses and bacteria are of primary concern. In addition, sharp objects (e.g. razor blades), chemical waste (e.g. batteries) or even medical waste may be included in MSW. Besides the health hazards associated with the inputs, the operation of a composting plant involves emissions into the air such as malodours, thermophilic fungi and dust.

4.9.1.1 Indicated control measures

- Protective equipment
  - Workers handling any raw material (e.g. MSW or composting material) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Separation of any components that are contaminated with biological (e.g. human waste such as diapers or sanitary products), chemical (e.g. batteries) or inorganic (e.g. sharp objects such as razor blades) wastes. To be discharged into the inorganic fraction and disposed of appropriately
  - A temperature of ≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter) should be maintained for the co-composting
  - Moisture of co-composting material should be above 40% for reducing bio-aerosol emission
  - Sieving of the soil conditioner prior to packaging for discharging any remaining inorganic contamination or sharp objects
- Infrastructure
  - Assure good ventilation of working areas with a high load of malodours or dust (e.g. co-composting facility)
  - Install handrails and fence dangerous areas for preventing injuries
  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 44Table 21). The actual distance is depending on the level of emissions
- Behavioural aspects and prevention
  - Assure that MSW is not contaminated with any medical waste
  - Educate workers on ergonomic hazards and how to avoid musculoskeletal damage or injury due to inappropriate working practices

- Insect vector- and rodent-control (e.g. screening or use of larvicides, insecticides) at storage sites
- Protect workers from long term exposure to sunlight
- Farmers using the soil conditioner should be advised to wear boots and gloves when applying the compost
- Restrict access to the operations
- Implement a worker well-being programme that includes regular sessions (e.g. weekly) where general health concerns are reported and health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards, etc.)

4.9.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 15 can be reduced to **low and moderate levels**. The residual risks are linked to the following processes:

- P1: pre-processing of MSW: rigorous discharging of any human, animal or chemical waste, as well as sharp objects is essential for assuring quality and safety of the organic fraction
- P3: co-composting: to ensure that workers are protected with respirators is important when handling the waste materials for the co-composting process. Otherwise pathogens, fungi and dust affect their respiratory system
- P3: composting: sharps ending up in the soil conditioner pose a moderate risk to users. Soil conditioner must be sieved before packaging and users need to be sensitised about the potential presence of sharp objects and pathogens in the soil conditioner. In addition, users need to be advised to wear boots and gloves when applying the soil conditioner.
- **Medical waste must be collected separately for keeping it out of the BM**

4.9.2 Health impact assessment

Since the business does not reduce or induce any exposure to health hazards, no health impacts are anticipated. **Therefore, the health impact of Model 21 is rated as insignificant**.

4.9.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) accumulated waste resulting from separation of inorganic fractions from MSW prior to composting and disposed of or used improperly (2) leachate from the composting process, which if moisture is not well controlled can leach into the environment, due to high nutrient and organic matter concentrations (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) liquid effluent from FS treatment, which when leaching into the environment can have a negative impact due to high nutrient and organic matter concentrations. Mitigation measures to avoid negative impacts include: (1) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), (2) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, (3) temperature control of the compost heap to ensure sufficient pathogen inactivation, and (4) post-treatment of the liquid effluent from FS dewatering processes. The goal of RRR based businesses should be full resource recovery of all End-products, which implies end-use of appropriately treated liquid effluent from post-treatment of liquid effluent from FS dewatering processes. If for some reason this is not feasible, only then should treated liquid effluent from FS dewatering processes get discharged into the environment presuming that it complies with local standards for discharge into the environment. Further details on technology options are outlined in the "Technology Assessment Report" [1].

Table 51 – Model 21: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

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6 Appendices

6.1 Appendix I – Health risk assessment tables

6.1.1 Model 2b – Energy service companies at scale: MSW to energy (electricity)

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
S1: storage	Biological hazards	Rodents → disease transmission	Rodents attracted by MSW	Hand to mouth, vectors living on rodents	Use of tools	3	3	High	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of storage facility	2	2	Moderate	2	2	**Low risk (4)**
P1: pre-processing (segregation/ separation) P4: shredding/de-hydration	Biological hazards	Pathogens	MSW is contaminated with pathogens deriving from human and animal waste	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
					Separation of any components that are contaminated with human and/or animal waste (e.g. diapers, sanitary products). To be discharged into the inorganic fraction and disposed of appropriately.	2	2	Moderate			
				Inhalation	PPE	3	2	Moderate			
	Chemical	Chemicals	Compost is contaminated	Toxic	Separation of any waste	3	3	High	2	2	**Low risk**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
	hazards		with toxic matter	matter	components that contain (e.g. batteries) or are contaminated with chemicals. To be discharged into the inorganic fraction and disposed of appropriately.						(4)
	Physical hazards	Sharp objects	Skin cuts when handling MSW	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation of any sharp objects (e.g. razor blades). To be discharged into the inorganic fraction and disposed of appropriately.	2	3	Moderate			
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	2	2	Moderate	2	3	**Moderate risk (6)**
					Rapid processing of MSW after arrival	2	2	Moderate			
P2: Anaerobic digestion	Biological hazards	Pathogens	N. a.	N.a.	Anaerobic digestion at >35°C for >9day (1 log reduction *E. coli* and 0 log reduction in helminth eggs) [a]	Since anaerobic digestion is done under mesophilic conditions, it is not considered as a control measure					
			Accidental contact while handling the animal manure/slurry	Hand to mouth	PEE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE	3	2	Medium	4	1	**Low risk (4)**
					Prevent any gas leakage	3	3	High			
					Install CO monitors around the plant	2	2	Medium			
					Assure ventilation of plant	2	3	Medium			
			Inhalation of toxic gases at		Respect a buffer zone	3	2	Medium	4	1	**Low risk**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			community level		between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)						**(4)**
P3: gas-based generator P5: burning P6: steam fed generator	Biological hazards	Disease vectors	Vector breeding sites in stagnant components of cooling water cycle	Vectors	Screening/covering of open water bodies	3	3	High	4	1	**Low risk (4)**
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE (gas mask respirators)	3	2	Moderate	4	3	**Moderate risk (12)**
					Install CO monitors around the plant	2	2	Moderate			
					Assure ventilation of plant	2	3	Moderate			
					Ensure that exhausts are released to the outside	3	3	High			
			Inhalation of toxic gases at community level	Inhalation	Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Moderate	4	3	**Moderate risk (12)**
		Chemicals	Chemicals in scrubbing water	Skin contact or inhalation	Installation of a bin/tank to collect and treat the toxic liquids	3	2	Moderate	4	2	**Moderate risk (8)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
	Physical hazards	Fire/explosion	A fire or explosion occurs due to gas leakage, etc.		Develop fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)	3	3	High	16	1	**High risk (16)**
		Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
					Heat shields	3	3	High			
		Dust/ashes	Exposure to dust when discharging ashes	Inhalation	Water spraying at ash discharge	2	3	Moderate	1	3	**Low risk (3)**
					PPE	3	3	High			
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Medium	4	1	**Low risk (4)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Medium	4	3	**Moderate risk (12)**
			Noise exposure at community level	Air	Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on the noise emitted by the operation and can easily be calculated.	3	2	Medium	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
		Electricity	Electric shock of a worker	Skin contact	Use of intrinsically safe electrical installations; non-sparking tools and proper grounding.	3	3	High	16	1	**High risk (16)**
P4: Anaerobic digestion	Biological hazards	Pathogens	N. a.	N.a.	Anaerobic digestion at >35°C for >9day (1 log reduction *E. coli* and 0 log reduction in helminth eggs) [a]	Since anaerobic digestion is done under mesophilic conditions, it is not considered as a control measure					
			Accidental contact while handling the animal manure/slurry	Hand to mouth	PEE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE	3	2	Medium	4	1	**Low risk (4)**
					Prevent any gas leakage	3	3	High			
					Install CO monitors around the plant	2	2	Medium			
					Assure ventilation of plant	2	3	Medium			
			Inhalation of toxic gases at community level		Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Medium	4	1	**Low risk (4)**

					Control measures				Risk assessment		
Element of the process	**Category**	**Hazard(s)**	**Hazardous event**	**Exposure route**		**TE**	**Acc**	**Mitigation potential**	**IL**	**LoF**	**Residual risk**
P: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: <u>Off-site (i.e. discharge):</u> ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill <u>On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)):</u> ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with pathogens while operating the post-treatment components	Hand-to-mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	2	**Moderate risk (8)**
Generalities	Physical hazard	Radiation	Long-time exposure of workers to direct sunlight	Environmental	Protect workers from long-term exposure to sun light	2	2	Medium	8	1	**Moderate risk (8)**
	Various	Various	Workers are getting ill due to exposure to pathogens and chemical hazards or unhealthy working practices	Various	Implement a worker well-being programme that includes regular sessions where general health concerns are reported and health protection	2	2	Medium	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards etc.)						
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers interfere with processes they are not familiar with and get hurt	Injury to the body	Restrict access to technical processes to workers that are operating the process	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	**Moderate risk (8)**

6.1.2 Model 3 – Energy generation from own agro-industrial waste

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: pre-processing	As the business model requires sugarcane bagasse as the input product, the pre-processing is already covered within the company that utilizes the sugarcane				Not applicable				Not applicable		
S1: storage	Biological hazards	Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Avoid vector breeding in storage areas (e.g. screening or insecticides)	3	2	Moderate	4	1	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	3	2	Moderate	2	4	**Moderate risk (8)**
			Exposure of community to malodours		Assure good ventilation	2	3	Moderate	2	3	**Moderate risk (6)**
					Respect a buffer zone between operation and community infrastructure in order to prevent community annoyance due to malodours	3	2	Moderate	4	3	**Moderate risk (12)**
P2: fermentation, distillation P3: burning P4: steam fed generator	Biological hazards	Disease vectors	Vector breeding sites in stagnant components of cooling water cycle	Vectors	Screening/covering of open water bodies	3	2	Moderate	2	2	**Low risk (4)**
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE (gas mask respirators)	3	2	Moderate	4	3	**Moderate risk (12)**
					Install CO monitors around the plant	2	2	Moderate			
					Assure ventilation of plant	2	3	Moderate			
					Ensure that exhausts are released to the outside	3	3	High			
			Inhalation of toxic gases at community level	Inhalation	Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Moderate	4	3	**Moderate risk (12)**
					Unburnt gases should be flared	3	2	Moderate	2	1	**Low risk (4)**
		Chemicals	Chemicals in scrubbing water	Skin contact or	Installation of a bin/tank to collect and treat the toxic	3	2	Moderate	4	2	**Moderate risk (8)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
				inhalation	liquids						
		Ethanol	Individual drinking ethanol of inferior quality	Ingestion	Denaturing of ethanol for preventing consumption	3	2	Moderate	2	1	**Low risk (2)**
	Physical hazards	Fire/explosion	A fire or explosion occurs due to gas leakage, etc.		Develop fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)	3	3	High	16	1	**High risk (16)**
		Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
					Heat shields	3	3	High			
		Dust/ashes	Exposure to dust when discharging ashes	Inhalation	Water spraying at ash discharge	2	3	Moderate	1	3	**Low risk (3)**
					PPE	3	3	High			
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Medium	4	1	**Low risk (4)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Medium	4	3	**Moderate risk (12)**
			Noise exposure at community level	Air	Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on	3	2	Medium	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
					the noise emitted by the operation and can easily be calculated.						
		Electricity	Electric shock of a worker	Skin contact	Use of intrinsically safe electrical installations; non-sparking tools and proper grounding.	3	3	High	16	1	**High risk (16)**
P5: Anaerobic digestion	Biological hazards	Pathogens	N. a.	N.a.	Anaerobic digestion at >35°C for >9day (1 log reduction E. coli and 0 log reduction in helminth eggs) [a]	Since anaerobic digestion is done under mesophilic conditions, it is not considered as a control measure					
			Accidental contact while handling the animal manure/slurry	Hand to mouth	PEE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE	3	2	Medium	4	1	**Low risk (4)**
					Prevent any gas leakage	3	3	High			
					Install CO monitors around the plant	2	2	Medium			
					Assure ventilation of plant	2	3	Medium			
			Inhalation of toxic gases at community level		Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Medium	4	1	**Low risk (4)**
P6: gas-based generator	Biological hazards	Disease vectors	Vector breeding sites in stagnant components of cooling water cycle	Vectors	Screening/covering of open water bodies	3	3	High	4	1	**Low risk (4)**
	Chemical	Toxic	Inhalation of toxic gases at	Inhalation	PPE (gas mask	3	2	Moderate	4	3	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
	hazards	gases	workplace level		respirators)						**risk (12)**
					Install CO monitors around the plant	2	2	Moderate			
					Assure ventilation of plant	2	3	Moderate			
					Ensure that exhausts are released to the outside	3	3	High			
			Inhalation of toxic gases at community level	Inhalation	Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety requirements for outputs)	3	2	Moderate	4	3	**Moderate risk (12)**
		Chemicals	Chemicals in scrubbing water	Skin contact or inhalation	Installation of a bin/tank to collect and treat the toxic liquids	3	2	Moderate	4	2	**Moderate risk (8)**
	Physical hazards	Fire/explosion	A fire or explosion occurs due to gas leakage, etc.		Develop fire/explosion response plan (e.g. installation of fire detection/suppression equipment; anti-back firing systems; separate fuel storage; escape routes; and purging system with nitrogen)	3	3	High	16	1	**High risk (16)**
		Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
					Heat shields	3	3	High			
		Dust/ashes	Exposure to dust when discharging ashes	Inhalation	Water spraying at ash discharge	2	3	Moderate	1	3	**Low risk (3)**
					PPE	3	3	High			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Medium	4	1	**Low risk (4)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Medium	4	3	**Moderate risk (12)**
			Noise exposure at community level	Air	Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on the noise emitted by the operation and can easily be calculated.	3	2	Medium	4	3	**Moderate risk (12)**
		Electricity	Electric shock of a worker	Skin contact	Use of intrinsically safe electrical installations; non-sparking tools and proper grounding.	3	3	High	16	1	**High risk (16)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P7: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: Off-site (i.e. discharge): ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)): ➢ Septic tank (≥1 log reduction of E. coli and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of E. coli and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of E. coli and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of E. coli and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with pathogens while operating the post-treatment components	Hand-to-mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	4	2	**Moderate risk (8)**
Generalities	Physical hazard	Radiation	Long-time exposure of workers to direct sunlight	Environmental	Protect workers from long-term exposure to sun light	2	2	Medium	8	1	**Moderate risk (8)**
	Various	Various	Workers are getting ill due to exposure to pathogens and chemical hazards or unhealthy working practices	Various	Implement a worker well-being programme that includes regular sessions where general health concerns are reported and	2	2	Medium	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					health protection measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards etc.)						
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers interfere with processes they are not familiar with and get hurt	Injury to the body	Restrict access to technical processes to workers that are operating the process	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	**Moderate risk (8)**

6.1.3 *Model 4 – Onsite energy generation by sanitation service providers*

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: Toilets	Physical hazards	Sharp objects	**At consumer level:** Exposure of users of the soil conditioner to sharp object (blades, syringes)	Skin contact	Place clearly visible signs on toilets that prohibit disposal of any sharp object and inorganic waste into the toilet	2	2	Moderate	4	3	**Moderate risk (12)**
					Provide trash bins for disposal of sharp objects and inorganic waste components in each toilet	2	2	Moderate			
P2: anaerobic digestion	Biological hazards	Pathogens	N. a.	N.a.	Anaerobic digestion at >35°C for >9day (1 log reduction *E. coli* and 0 log reduction in helminth eggs) [a]	Since anaerobic digestion is done under mesophilic conditions, it is not considered as a control measure					
			Accidental contact while handling the faecal sludge/slurry	Hand to mouth	PEE	3	3	High	2	2	**Low risk (4)**
					Use of tools	3	3	High			
	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	PPE	3	2	Medium	4	1	**Low risk (4)**
					Prevent gas leakage	3	3	High			
					Install CO monitors around the plant	2	2	Medium			
					Assure ventilation of plant	2	3	Medium			
			Inhalation of toxic gases at community level		Respect a buffer zone between operation and community infrastructure so that ambient air quality standards are not exceeded (see table with quality/safety	3	2	Medium	4	1	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
					requirements for outputs)						
	Physical hazards	Sharp objects	Exposure to sharp objects when handling the anaerobic sludge	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
P3: gas-based generator	Chemical	Toxic gases	Inhalation of toxic gases at workplace level	Inhalation	Ensure that exhausts are released to the outside	3	3	High	4	1	**Low risk (4)**
					Install CO monitors around the plant	2	2	Moderate			
	Physical hazards	Fire/explosion	A fire or explosion occurs due to gas leakage, etc.		Develop and implement fire/explosion response plan	3	3	High	16	1	**High risk (16)**
		Heat	Worker gets in contact with fire or hot surface	Skin contact	PPE	3	3	High	2	2	**Low risk (4)**
					Heat shields	3	3	High			
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Medium	4	1	**Low risk (4)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Medium	4	3	**Moderate risk (12)**
			Noise exposure at community level		Respect a buffer zone between the operation and community houses so that noise levels at community level do not exceed 55dB during the day and 45dB at night. The actual distance is depending on the noise emitted by the operation and can easily be calculated.	3	2	Medium	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
		Electricity	Electric shock of a worker	Skin contact	Use of intrinsically safe electrical installations; non-sparking tools and proper grounding.	3	3	High	16	1	**High risk (16)**
P4: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: Off-site (i.e. discharge): ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)): ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with pathogens while operating the post-treatment components	Hand-to-mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	2	2	**Low risk (4)**
	Physical hazard	Sharp objects	**At consumer level:** Exposure of users of the soil conditioner to sharp	Skin contact	Careful sieving of the sludge/soil conditioner before packaging	2	3	Moderate	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			object (blades, syringes)		Place clearly visible danger signs on the packaging, indicating the risk of sharp objects and that users need to wear gloves and boots when applying the product	2	1	Low			
Generalities	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	8	1	**Moderate risk (8)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	2	2	**Low risk (4)**

6.1.4 Model 8 – Beyond cost recovery: the aquaculture example

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: duckweed pond	Biological hazards	Pathogens	Wastewater contaminated with faeces or urine	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
				Inhalation	PPE	3	2	Moderate			
	Chemical hazards	Chemicals and heavy metals	**Consumer level:** Treated wastewater is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	In case chemical indicators of the wastewater or receiving soils exceed national threshold values (see annex IV), **the treated wastewater is not suitable for irrigation**	**Not a control measure but a pre-condition**					
	Physical hazards	Sharp objects	Skin cuts when handling sludge in subsequent processes	Skin contact	Mechanical screening of the wastewater before entering the duck-week pond	2	3	Moderate	4	1	**Low risk (4)**
					Use of PPE when handling the screened material	3	3	High			
		Inorganic waste	Contamination of sludge with inorganic waste	Environmental hazard	Mechanical screening of the wastewater before entering the duck-week pond	2	3	Moderate	1	3	**Low risk (4)**
P2: Stabilisation ponds	Biological hazards	Bacteria, viruses, protozoa and helminths	**Downstream issue:** Fish is contaminated with pathogens Unsafe wastewater is used for irrigation	Hand to mouth and ingestion	Three stabilization ponds are needed for producing treated wastewater: 1.) Anaerobic stabilisation pond (1-3 days) 2.) Facultative pond (4-10 days) 3.) Aquaculture (→ P3)	3	2	Moderate	4	2	**Moderate risk (8)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P3: aquaculture	Biological hazards	Pathogens	Fish is contaminated with pathogens	Hand to mouth and ingestion	Store duckweed for at least 30 days under dry conditions prior to addition to the fish pond	2	2	Moderate	4	2	**Moderate risk (8)**
					Depuration of fish before harvesting by moving fish to a clean pond for at least 2-3 weeks	2	2	Moderate			
	Chemical hazards	Chemicals	Fish is contaminated with chemicals (e.g. heavy metals)	Ingestion	Harvest fish at young age	3	2	Moderate	2	1	**Low risk (4)**
P4: drying beds	Biological hazards	Pathogens	Pathogens enter the co-composting process and ultimately pose risk to the users of the compost	Hand to mouth	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of drying beds	3	2	Medium	2	2	**Low risk (4)**
	Biological	Vector-borne diseases	Mosquitoes and flies breed in ponds and consequently increase the risk for transmission of vector-borne diseases	Mosquito bites	Prevent mosquito breeding in treatment ponds	2	2	Moderate	4	1	**Low risk (4)**

6.1.5 *Model 9 – On cost savings and recovery*

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: wastewater treatment plant	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent	Acciden-tal ingestion	Primary, secondary and tertiary treatment has to be applied for reducing pathogens. Different options can be combined for reaching a minimum of 7 log reduction in bacterial indicators (e.g. *E. coli*) and 3 log reductions in helminth eggs.	3	3	High	4	1	**Low risk (4)**
		Pathogens	Accidental contact with pathogens while operating the wastewater treatment plant	Hand-to-mouth and inhalation	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	2	2	**Low risk (4)**
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated wastewater is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	In case chemical indicators of the wastewater or receiving soils exceed national threshold values (see annex IV):						
					Option A.) Apply a physico-chemical removal process (e.g. absorption)	3	1	Low	4	2	**Moderate risk (8)**
					Option B.) Do not promote the treated wastewater for irrigation	2	1	Low	4	2	**Moderate risk (8)**
		Heavy metals	**Downstream exposure:** Poor sludge quality results in contaminated fertilizer	Ingestion	The reuse of WWTP sludge is currently prohibited in Peru.	2	1	Low	4	2	**Moderate risk (8)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					If this does change in the future, given standards need to be applied. **Otherwise the sludge must not be further processed for producing soil conditioner**						

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
	Physical hazards	Sharp objects	Workers are hurt or drown during operation of the plant	Injury to the body	PPE	3	3	High	5	1	**Moderate risk (5)**
					Use of tools	3	3	High			
					Installation of handrails and fencing of dangerous areas	3	3	High			
P2: dewatering	Biological hazards	Pathogens	Pathogens enter the co-composting process and ultimately pose risk to the users of the compost	Hand to mouth	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of drying beds	3	2	Medium	2	2	**Low risk (4)**
P3: co-composting	Biological hazards	Pathogens	Sludge and organic-waste is contaminated with pathogens (e.g. chicken waste → campylobacter, salmonella)	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
			Downstream exposure: Those that apply the compost are exposed to pathogens such as *E. coli* and helminth eggs	Hand to mouth and inhalation	≥45°C for ≥5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter)	3	2	Moderate	4	2	**Moderate risk (8)**
					Advice farmers to wear boots and gloves when applying the compost	3	2	Moderate			
		Thermophil	Inhalation of airborne	Inhalation	PPE	3	2	Moderate	4	3	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
		ic fungi and actino-mycetes	spores		Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			**risk (12)**
		Malodours	Exposure to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Good ventilation of working area	2	3	Moderate			
	Physical	Dust	Long-term exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
		Sharp objects and inorganic waste	Skin cuts when handling organic solid waste	Skin contact	Separate and discharge contaminated organic solid waste	2	2	Moderate	4	2	**Moderate risk (8)**
Generalities	Biological	Vector-borne diseases	Mosquitoes breed in ponds and consequently increase the risk for transmission of vector-borne diseases	Mosquito bites	Prevent mosquito breeding in treatment ponds	2	2	Moderate	4	1	**Low risk (4)**
	Physical		Physical injury of workers		Prevent the risk of drowning in ponds by means of PPE, worker education and only employ workers that know how to swim	3	3	High	8	1	**Moderate risk (6)**

6.1.6 Model 13 – Informal to formal trajectory in wastewater Irrigation: sale/auctioning wastewater for irrigation

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: wastewater treatment plant	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent	Acciden-tal ingestion	Primary, secondary and tertiary treatment has to be applied for reducing pathogens. Different options can be combined for reaching a minimum of 7 log reduction in bacterial indicators (e.g. *E. coli*) and 3 log reductions in helminth eggs.	3	3	High	4	1	**Low risk (4)**
		Pathogens	Accidental contact with pathogens while operating the wastewater treatment plant	Hand-to-mouth and inhalation	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	2	2	**Low risk (4)**
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated wastewater is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	In case chemical indicators of the wastewater or receiving soils exceed national threshold values (see annex IV):						
					Option A.) Apply a physico-chemical removal process (e.g. absorption)	3	1	Low	4	2	**Moderate risk (8)**
					Option B.) Do not promote the treated wastewater for irrigation	2	1	Low	4	2	**Moderate risk (8)**
		Heavy metals	**Downstream exposure:** Poor sludge quality results in contaminated fertilizer	Ingestion	The reuse of WWTP sludge is currently prohibited in Peru.	2	1	Low	4	2	**Moderate risk (8)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					If this does change in the future, given standards need to be applied. **Otherwise the sludge must not be further processed for producing soil conditioner**						
	Physical hazards	Sharp objects	Workers are hurt or drown during operation of the plant	Injury to the body	PPE	3	3	High	5	1	**Moderate risk (5)**
					Use of tools	3	3	High			
					Installation of handrails and fencing of dangerous areas	3	3	High			
post-treatment (drying beds)	Biological hazards	Pathogens	Pathogens enter the co-composting process and ultimately pose risk to the users of the compost	Hand to mouth	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of drying beds	3	2	Medium	2	2	**Low risk (4)**
T1a: drainage system T1b: other	Biological hazards	Pathogens	**Downstream exposure**: Flooding event results in exposure to pathogens	Hand to mouth and acciden-tal ingestion	Complement drainage system with a pre-treatment facility (e.g. screening and grease traps) for preventing backups and overflows.	3	3	High	4	1	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					Regular cleaning of the drainage system for preventing clogging and overflow	2	3	Moderate	4	1	**Low risk (4)**
					Regulate the flow of any pumping station for preventing overflowing in subsequent processes	3	3	High	4	1	**Low risk (4)**
P3a: slow rate infiltration P3b: rapid infiltration	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent	Hand to mouth and acciden-tal ingestion	**Monitor biological indicators in effluent of the WWTP, which needs to comply with national standards (see Annex IV)**	2	2	Moderate	4	2	**Moderate risk (8)**
			Groundwater is contaminated by the infiltrated untreated waste water	Ground-water contamin ation	Hydrology study to be done before building an infiltration technology						
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated waste water is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	**Monitor chemical indicators in effluent of the WWTP and receiving soils, which needs to comply with national standards (see Annex IV)**						
			Groundwater is contaminated by the infiltrated untreated waste water	Ground-water contamin ation	Hydrology study to be done before building an infiltration technology						
P3c: overland flow	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated water	Hand to mouth, acciden-	**Monitor biological indicators in effluent of the WWTP, which needs**	2	2	Moderate	4	4	**High risk (16)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent - Skin penetration by pathogens transferred by water - Skin diseases	tal ingestion, skin penetration and skin contact	**to comply with national standards (see Annex IV)** Advice farmers to wear boots and gloves when working in the irrigated fields. Advice farmers to respect 2 days between last irrigation and harvesting. Advise farmers to wash harvested crops with fresh water						
	Chemical hazards	Chemicals, including heavy metals	**Downstream exposure:** Treated waste water is used for irrigation, where heavy metals may impact on soil quality and accumulate in crops	Ingestion	**Monitor chemical indicators in effluent of the WWTP and receiving soils, which needs to comply with national standards (see Annex IV)**						
P3d: wetland application	Biological hazards	Pathogens	**Downstream exposure:** - Accidental intake of contaminated water from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent - Skin penetration by pathogens transferred by water - Skin diseases	Hand to mouth, acciden-tal ingestion, skin penetration and skin contact	**Monitor biological indicators in effluent of the WWTP, which needs to comply with national standards (see Annex IV)** Advice farmers to wear boots and gloves when working in the irrigated fields. Advice farmers to respect 2 days between last irrigation and harvesting.	2	2	Moderate	4	3	**Moderate risk (12)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					Advise farmers to wash harvested crops with fresh water						
Generalities	Biological	Vector-borne diseases	Mosquitoes breed in ponds and consequently increase the risk for transmission of vector-related diseases	Mosquito bites	Prevent mosquito breeding in treatment ponds	2	2	Moderate	2	2	**Low risk (4)**
	Physical		Physical injury of workers		Prevent the risk of drowning in ponds by means of PPE, worker education and only employ workers that know how to swim	3	3	High	8	1	**Moderate risk (8)**

6.1.7 Model 15 – Large-scale composting for revenue generation

6.1.8 Model 17 – High value fertilizer production for profit

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
S1: storage	Biological hazards	Rodents → disease transmission	Rodents attracted by MSW	Hand to mouth, vectors living on rodents	Use of tools	3	3	High	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of storage facility	2	2	Moderate	2	2	**Low risk (4)**
P1: pre-processing (segregation/ separation)	Biological hazards	Pathogens	MSW is contaminated with pathogens deriving from human and animal waste	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
					Separation of any components that are contaminated with human and/or animal waste (e.g. diapers, sanitary products). To be discharged into the inorganic fraction and disposed of appropriately.	2	2	Moderate			
				Inhalation	PPE	3	2	Moderate			
	Chemical hazards	Chemicals	Compost is contaminated with toxic matter	Toxic matter	Separation of any waste components that contain (e.g. batteries) or are contaminated with chemicals. To be discharged into the inorganic fraction and disposed of appropriately.	3	3	High	2	2	**Low risk (4)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
	Physical hazards	Sharp objects	Skin cuts when handling MSW	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation of any sharp objects (e.g. razor blades). To be discharged into the inorganic fraction and disposed of appropriately.	2	3	Moderate			
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	2	2	Moderate	2	3	**Moderate risk (6)**
					Rapid processing of MSW after arrival	2	2	Moderate			
P2: pre-processing (settling and drying)	Biological hazards	Pathogens	High loads of pathogens enters the composting process	Hand to mouth and inhalation	Storage treatment at 2-20°C: 1.5-2 years [a]	3	2	Medium	4	3	**Moderate risk (12)**
					Storage treatment at 20-35°C: >1 years [a]	3	2	Medium			
					Storage treatment at pH>9 (alkaline treatment): >35°C; and moisture <25%: >6 months [a]	3	2	Medium			
			Accidental contact while handling the sludge	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of drying beds	3	2	Medium	2	2	**Low risk (4)**
P3: co-composting	Biological hazards	Thermophilic fungi and actino-mycetes	Inhalation of airborne spores	Inhalation	PPE	3	2	Moderate	4	2	**Moderate risk (8)**
					Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			
		Pathogens	Exposure to pathogens bound in the organic waste	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
			Downstream exposure: Those that apply the compost are exposed to pathogens such as *E. coli* and helminth eggs	Hand to mouth and inhalation	≤45°C for ≤5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter)	3	2	Moderate	4	2	**Moderate risk (8)**
					Advice consumers to wear boots and gloves when applying the compost.	3	2	Moderate			
		Malodours	Exposure to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Good ventilation of working area	2	3	Moderate			
	Physical	Dust	Long-term exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
P4: post-treatment	Biological hazards	Pathogens	Downstream exposure: - Accidental intake of contaminated liquid effluent from the plant - Ingestion of produce that is irrigated with unsafe liquid effluent or fertilized with unsafe soil conditioner	Acciden-tal ingestion	Depending on the further use of the outputs of the post-treatment, the following post-treatment options are proposed: <u>Off-site (i.e. discharge):</u> ➢ Drain/transfer effluents/sludge into an existing WWTP for co-treatment ➢ Discharge sludge on landfill <u>On-site (in case of agricultural reuse of the outputs, a combination of the following options will be required for achieving the required quality standard (see table with quality/safety requirements for outputs)):</u> ➢ Septic tank (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic baffled reactor (≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Anaerobic filter(≥1 log reduction of *E. coli* and ≥2 log reduction in helminth eggs) ➢ Constructed/vertical flow wetland (≥0.5-3 log reduction of *E. coli* and ≥1-3 log reduction in helminth eggs) ➢ Planted gravel Filter ➢ Unplanted gravel Filter ➢ Planted/unplanted drying beds (1-3 log reduction in helminth eggs)						
			Accidental contact with	Hand-to-	PPE	3	3	High	4	2	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			pathogens while operating the post-treatment components	mouth							risk (8)
		Disease vectors	Treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding in ponds	2	2	Moderate	2	2	Low risk (4)
Generalities	Various	Various	Input is contaminated with medical waste		In settings where medical waste is disposed of in MSW, this business model is not an option	3	2	Moderate	8	5	40
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	4	1	Low risk (4)
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	Moderate risk (8)

6.1.9 Model 21 – Partially subsidized composting at district level

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
S1: storage	Biological hazards	Rodents → disease transmission	Rodents attracted by MSW	Hand to mouth, vectors living on rodents	Use of tools	3	3	High	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on faecal matter and transmitting disease	Vectors	Screening of storage facility	2	2	Moderate	2	2	**Low risk (4)**
P1: pre-processing (segregation/ separation)	Biological hazards	Pathogens	MSW is contaminated with pathogens deriving from human and animal waste	Hand to mouth	PPE	3	3	High	4	2	**Moderate risk (8)**
					Use of tools	3	3	High			
					Separation of any components that are contaminated with human and/or animal waste (e.g. diapers, sanitary products). To be discharged into the inorganic fraction and disposed of appropriately.	2	2	Moderate			
				Inhalation	PPE	3	2	Moderate			
	Chemical hazards	Chemicals	Compost is contaminated with toxic matter	Toxic matter	Separation of any waste components that contain (e.g. batteries) or are contaminated with chemicals. To be discharged into the inorganic fraction and disposed of appropriately.	3	3	High	2	2	**Low risk (4)**
	Physical	Sharp	Skin cuts when handling	Skin	PPE	3	3	High	4	1	**Low risk**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
	hazards	objects	MSW	contact	Use of tools	3	3	High			(4)
					Separation of any sharp objects (e.g. razor blades). To be discharged into the inorganic fraction and disposed of appropriately.	2	3	Moderate			
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	2	2	Moderate	2	3	**Moderate risk (6)**
					Rapid processing of MSW after arrival	2	2	Moderate			
P3: composting	Biological hazards	Thermophilic fungi and actino-mycetes	Inhalation of airborne spores	Inhalation	PPE	3	2	Moderate	4	2	**Moderate risk (8)**
					Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			
		Pathogens	Exposure to pathogens bound in the organic waste	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
			Downstream exposure: Those that apply the compost are exposed to pathogens such as E. coli and helminth eggs	Hand to mouth and inhalation	≤45°C for ≤5 days (2 log reductions in bacteria and <1 viable helminth eggs per g dried matter)	3	2	Moderate	4	1	**Low risk (4)**
					Advice consumers to wear boots and gloves when applying the compost.	3	2	Moderate			
		Malodours	Exposure to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Good ventilation of working area	2	3	Moderate			
	Physical	Dust	Long-term exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
Generalities	Various	Various	Input is contaminated with medical waste		In settings where medical waste is disposed of in	3	2	Moderate	8	5	**40**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					MSW, this business model is not an option						
	Various		People from the community access the plant and get hurt, are exposed to pathogens or other hazards	Injury to the body, hand to mouth, inhalation	Restrict access to operations for external individuals	3	3	High	4	1	**Low risk (4)**
	Physical hazard		Workers suffer of musculoskeletal damage due to inappropriate working practices	Injury to the body	Worker education for preventing musculoskeletal damage due to inappropriate working practices	2	2	Medium	4	2	**Moderate risk (8)**