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Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse

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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 Hanoi

Authors:

Health assessments
Dr Mirko Winkler
MSc Samuel Fuhrimann
Dr Phuc Pham Duc
Prof Dr Guéladio Cissé

Environmental assessments
MSc Lars Schoebitz
Prof. Dr. Viet-Anh Nguyen
Dr Linda Stande

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Basel and Dübendorf, Switzerland

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Developing Countries

Contacts

Health assessments

Swiss TPH Swiss Tropical and Public Health Institute Schweizerisches Tropen- und Public Health-Institut Institut Tropical et de Santé Publique Suisse Associated Institute of the University of Basel		TRƯỜNG ĐẠI HỌC Y TẾ CÔNG CỘNG HANOI SCHOOL OF PUBLIC HEALTH
Swiss Tropical and Public Health Institute Socinstrasse 57 P.O. Box 4002 Basel Switzerland Dr Mirko Winkler MSc Samuel Fuhrimann Prof Dr Guéladio Cissé Department of Epidemiology and Public Health Ecosystem Health Sciences Unit T: +41 61 284 8339 Correspondence to Mirko Winkler: E-mail: mirko.winkler@unibas.ch Website: www.swisstph.ch		Hanoi School of Public Health (HSPH) 138 Giang Vo street Ba Dinh, Hanoi, Vietnam Dr. Phuc Pham Duc Center for Public Health and Ecosystem Research (CENPHER) T: +84 4 62733162, Fax: +84 4 62733172 E-mail: cenpher@hsph.edu.vn Website: http://cenpher.hsph.edu.vn

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Water and Sanitation in
Developing Countries

Environmental assessments

eawag aquatic research **Sandec** Water and Sanitation in Developing Countries		IESE XÂY DỰNG ĐẠI HỌC NUCETECH
Eawag: Swiss Federal Institute of Aquatic Science and Technology Sandec: Department of Water and Sanitation in Developing Countries Ueberlandstrasse 133 P. O. Box 611 8600 Duebendorf Switzerland MSc Lars Schoebitz Dr. Linda Strande Department of Water and Sanitation in Developing Countries T: +41 58 765 5420 Correspondence to Lars Schoebitz E-mail: Lars.Schoebitz@eawag.ch Website: www.sandec.ch/rrr		Institute of Environmental Science and Engineering (IESE), Hanoi University of Civil Engineering (HUCE). IESE, DHXD, 55 Giai Phong Road, Hanoi, Vietnam Viet-Anh Nguyen (Assoc. Prof., PhD.) Tel. +84-4-3869 1604, Fax. +84-4-3869 3714. E-mail: anhnv@nuce.edu.vn vietanhctn@yahoo.com vietanhctn@gmail.com Website: www.epe.edu.vn www.nuce.edu.vn

Executive summary health assessments

Introduction and methodology

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 Hanoi. The magnitude of potential impacts was determined by means of a semi-quantitative impact assessment. The feasibility studies in Hanoi were oriented towards 11 BMs that were selected due to their potential in the given context. These BMs are:

- Model 1a: Dry fuel manufacturing: agro-industrial waste to briquettes
- Model 2a: Energy service companies at scale: agro-waste to energy (electricity)
- Model 4: Onsite energy generation by sanitation service providers
- Model 6: Manure to power
- Model 8: Beyond cost recovery: the aquaculture example
- Model 9: On cost savings and recovery
- Model 15: Large-scale composting for revenue generation
- Model 16: Subsidy-free community based composting
- Model 17: High value fertilizer production for profit
- Model 18: Urine and struvite use at scale
- Model 19: Compost production for sanitation service Delivery

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 six existing RRR cases were investigated in Hanoi area:

- Case 1: Nam Son landfill
- Case 2: Cau Dien composting plant
- Case 3: Co Dong livestock service cooperative Son Tay town, Hanoi

- Case 4: Kieu Ky waste treatment plant (landfill)
- Case 5: Wastewater treatment and management by the Hanoi Sewerage and Drainage Limited Company (HSDC)
- Case 6: Wastewater reuse in the peri-urban area of Hanoi (Thanh Tri district)

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 six existing RRR cases, the city of Hanoi benefited from a complementary in-depth survey in the frame of a PhD study project, which focused on environmental and health risks related to the reuse of wastewater for agriculture. The in-depth study focused on the To Lich River (one of the city's main open drainage channels which was also selected as a SSP testing site). With the aim to generate evidence on the exposure risk along the wastewater chains in Hanoi, a cross-sectional survey was carried out to assess and map the existing exposure risks due to wastewater. A total of 675 individuals participated in the study, representing different exposure groups: Workers at HSDC (n=128); farmer (n=278); community members (n=269). The cross-sectional survey comprised two components: (i) a questionnaire study to obtain self-reported data on health risks and health outcomes (e.g. diarrhoeal episodes and skin and eye disease) related to the exposure to wastewater and faecal sludge; and (ii) the collection of stool samples to determine the prevalence and the intensity of parasitic infections. The stool samples were analysed for helminth infections by means of the Kato-Katz technique. As a quality control measure, one stool sample was subjected to duplicate Kato-Katz thick smear. Protozoa infections were assessed with the formalin-ether concentration technique (FECT). In the environmental sampling component of the in-depth study, a total of 230 water samples were collected over a period of 8 weeks (April to June 2014). Samples were tested for the following indicators: coliform forming units (CFU) of (i) faecal coliform bacteria and (ii) E. coli; Salmonella spp.; and (iv) helminth eggs.

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

According to health statistics from rural, peri-urban and urban areas of Hanoi, specific diarrhoea diseases, flu, shigellosis, dengue fever and varicella (chickenpox), all of which are communicable diseases, were the leading causes of morbidity at health facilities in urban, peri-urban and rural settings of Hanoi in 2007 and 2011. The most striking difference between different environments is the high number of dengue fever cases reported at the urban health facilities when compared to the peri-urban and rural health facilities.

With regard to access to sanitation facilities, the 2009 Vietnam population and housing census found that 46% use non-improved toilet facilities (61% in rural areas and 12.2% in urban areas), while 10.2% of the households in rural Vietnam have no toilet facilities. In Hanoi water supply is managed by Hanoi Water Work Authority under the Hanoi Party Comity. In general the public water supply is characterised by low pressure, frequent interruptions and occasional contamination.

Against this background, it is not surprising that all major STH species are endemic and of public health importance in Hanoi. In our own in-depth study, the most common STH infection was hookworm with a prevalence of 15.5% in local farmers. Prevalence of intestinal protozoa was found to be very low, i.e. ≤1.0% and differences between exposure groups were not at statistically significant levels. In Vietnam, both fish-borne zoonotic trematodes that infect the liver and the intestines are common, with prevalences up to 50%. Skin disease among farmers using wastewater is a common reported health outcome in Vietnam. A study in Nam Dinh, northern Vietnam could show that exposure to wastewater was a major risk factor for skin disease with a relative risk (RR) of 1.89.

Acute respiratory diseases, particularly flu, are a major public health concern in Hanoi (second leading cause of consultations at health facilities). This clearly shows that a lot of transmission is taking place, with poor personal hygiene and weak sanitation system as important determinants. Also the burden of chronic respiratory diseases and cardiovascular diseases is high, accounting for 7% and 33% of total mortality (all ages, both sexes), respectively, in Vietnam.

Various vector-borne diseases are endemic and of major public health relevance in Vietnam (e.g. malaria, dengue and Japanese encephalitis). There is, however, great geographical variation in the frequency of transmission in vector-borne diseases. Due to climatic and environmental factors, Hanoi city is not considered a risk area for Malaria transmission, with rare cases being reported by Hanoi's health system. In contrast, annual reported cases of Dengue fever varied between 500 and 16,000 in Hanoi in 2009-2011.

With regard to environmental parameters, the water quality monitoring data in the four main rivers and lakes in Hanoi have clearly shown that the water quality of rivers, lakes and ponds is worsening due to the discharge of untreated industrial wastewater, which contains toxic substances, inorganic substances and high organic content. Averagely, concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), heavy metals and coliform in To Lich, Lu, Set and Nhue rivers are 3–4 times higher than target values. In our in-depth study, bacteria concentration was found highest in Nhue and Red River with up to 6.5 log CFU total faecal coliform. Helminth egg concentration where all below 1 egg/L and hence below WHO thresholds for wastewater reuse in agriculture. Only 5 and 7 samples were found positive for *A. lumbricoides* and *T. Trichiura*, respectively.

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 as proposed by the World Health Organization's 'Guidelines for the Safe Use of Wastewater, Excreta and Greywater' and other standards, 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 Hanoi area shows variation in heavy metal concentration, often exceeding national and international thresholds. Besides the soil and water samples, also Cd, Cr, Cu, Ni, Pb, and Zn in the vegetables exceeded the Vietnamese standards. This clearly indicates that irrigation with wastewater is of concern in Hanoi 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.

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 Hanoi 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. Model 15 and 17, both 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 Hanoi 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 8 (beyond cost recovery: the aquaculture example) has 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 that is used for aquaculture is compliant with national and international quality requirements regarding toxic chemicals. Also Model 9 (treated wastewater for irrigation/fertilizer/energy: on cost savings and recovery) has considerable potential for resulting in positive health impacts at community level. Model 1a – Dry fuel manufacturing: agro-waste to briquettes – bears the risk to result in a moderate negative impact by replacing more clean cooking fuels such as gas and electricity with briquettes.

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 1a – Dry fuel manufacturing: agro-waste to briquettes	One percent of the population in Hanoi will use briquettes from the BM as cooking fuel	Impact 1: increase in chronic respiratory disease and cancer	**Moderate negative impact (-560)**
Model 2a – Energy service companies at scale: agro-waste to energy (electricity)	50 villages in rural and peri-urban areas of Hanoi will implement the BM	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (75)**
		Impact 2: changes in health status due to access to electricity	**Insignificant (0)**
Model 4 – Onsite energy generation in enterprises providing sanitation services	30 villages in rural and peri-urban areas of Hanoi will implement the BM	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (90)**
		Impact 2: changes in health status due to access to electricity	**Insignificant (0)**
Model 6 – Manure to power	10 villages in rural and peri-urban areas of Hanoi will implement the BM	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (27)**
		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	Wastewater treatment plant with 500 farmers and 10'000 community	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (545)**

	members benefitting from the treated wastewater	Impact 2: reduction in exposure to toxic chemicals (e.g. heavy metals)	**Minor positive impact (325)**
		Impact 3: access to electricity	**Insignificant (0)**
Model 15 – Large-scale composting for revenue generation	Two centralised co-composting plants are installed in Hanoi, serving 2'000 households each	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (90)**
		Impact 2: indirect health benefits due to reduced MSW loads on landfills	**Minor positive impact (12.5)**
Model 16 – Subsidy-free community based composting	The waste volume of 10,000 households will be collected by the business	Impact 2: indirect health benefits due to reduced MSW loads on landfills	**Minor positive impact (12.5)**
Model 17 – High value fertilizer production for profit	Two centralised co-composting plants are installed in Hanoi, serving 2'000 households each	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (90)**
		Impact 2: indirect health benefits due to reduced MSW loads on landfills	**Minor positive impact (12.5)**
Model 18 – Urine and struvite use at scale	No health impacts at community, farmer or consumer level are anticipated for this model		**Insignificant (0)**
Model 19 – Compost production for sanitation service Delivery	30 villages in rural and peri-urban areas of Hanoi will implement the BM	Impact 1: reduction in respiratory, diarrhoeal and intestinal diseases	**Moderate positive impact (90)**

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.

BM	Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
1a	• MSW • AIW	• Briquettes	• Carbonized - low pressure • Raw - mechanized high pressure • Carbonized - mechanized	• Briquetting	• Hazardous air emissions • Accumulated inorganic waste • Process water	• Air emission control technologies (e.g. activated carbon, scrubbers) • Proximate and ultimate analyses • Post-treatment of process water
2a	• 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	• 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

6	• AM	• Biogas -> Electricity	• Single stage • Multi-stage • Batch • Biogas conversion technologies	• Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Solid residue (digestate) • Liquid effluent	• Maintenance of anaerobic digester • Air emission control technologies • 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
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
16	• MSW	• Soil Conditioner	• Windrow (static/turned) • In-Vessel • Inclined step grades • Vermi-composting	• Compo-sting	• Accumulated inorganic waste • Leachate from composting	• Storage/transport/ disposal (sanitary landfill) • Moisture control • Leachate treatment
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

18	• Urine	• Diluted urine	• UDDTs	• Urine collection and storage	• Ammonia intoxication • Ammonia oxidization	• Urine dilution with water
19	• Urine • Feces	• Stored urine • Soil conditioner	• UDDTs • Co-composting	• Urine application • Co-com-posting	• Ammonia intoxication • Ammonia oxidization • Insufficient pathogen inactivation • Leachate from co- composting	• Urine dilution with water • Moisture control • Leachate treatment • Temperature control (compost heap)

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Abbreviations

AIDS	Acquired Immune Deficiency Syndrome
ARI	Acute Respiratory Infections
BOD	Biochemical Oxygen Demand
BM	Business Model
CCP	Critical Control Points
Cd	Cadmium
CFU	Coliform Forming Units
CI	Confidence Interval
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
COPD	Chronic Obstructive Pulmonary Disease
Cr	Chromium
Cu	Copper
dB	Decibel
EIA	Environmental Impact Assessment
Fe	Iron
FECT	Formalin-Ether Concentration Technique
FGD	Focus Group Discussion
Hanoi PC	Hanoi City People's Committee
HIA	Health Impact Assessment
HRA	Health Risk Assessment
HRIA	Health Risk and Impact Assessment
HSDC	Hanoi Sewerage and Drainage Limited Company
IL	Impact Level
KII	Key Informant Interviews
LF	Lympahtic Filariasis
LoF	Likelihood or Frequency
LPG	Liquefied Petroleum Gas
MICS	Multiple Indicator Cluster Survey
MSW	Municipal Solid Waste
NO_x	Nitrogen Oxides
NPK	Nitrogen, Phosphorus and Potassium
PA	People Affected
Pb	Lead
PM	Particulate Matter
PPE	Personal Protective Equipment

RRR	Resource, Recovery and Reuse
RR	Relative Risk
RS	Risk Score
SO_x	Sulphur Oxides
SSP	Sanitation Safety Planning
STH	Soil-transmitted helminth
SW	Solid waste
URENCO	Hanoi Urban Environment One Member Limited Company
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
YLL	Years Live Lost
WW	Wastewater

Annexes

Annex I – HRIA Methodology and tools for feasibility studies in Hanoi

Annex II – HRIA Hanoi case studies

Annex III – PPE Guide

Annex IV – Health based targets and threshold values

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 Hanoi 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 [2], which comprises an extensive literature review on technologies for resource recovery also identifying potential environmental hazards and measures of mitigation.

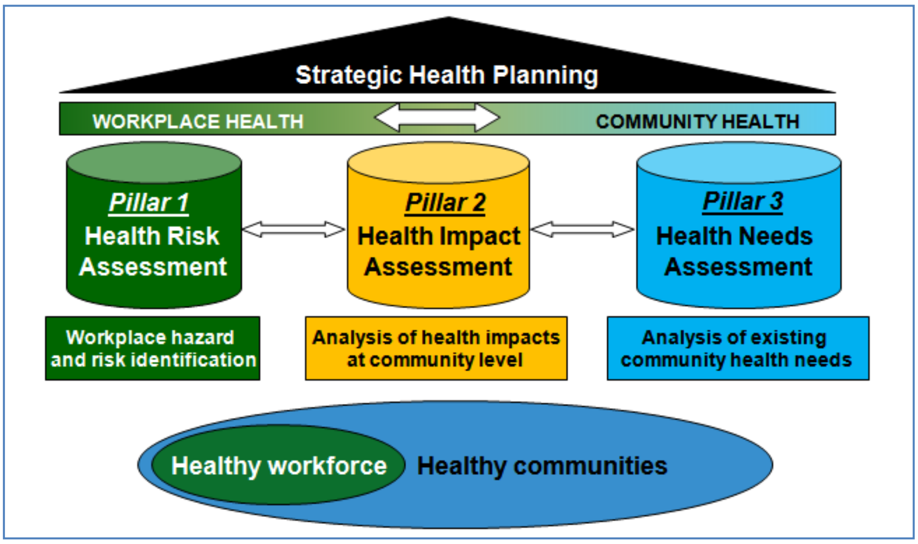

Figure 1 – Different types of health assessments and their interlinkages

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 Hanoi
- To identify common occupational and community health risks associated with existing RRR activities in Hanoi
- To evaluate the acceptability of control measures to mitigate health risk in Hanoi
- To define control measures required for safeguarding occupational health and ensuring safe products for each of the BMs proposed for Hanoi
- 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 Hanoi 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 Hanoi. 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 bacteria and helminth eggs were carried out in the frame of the pre-testing of the Sanitation Safety Planning (SSP) manual in Hanoi.

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.

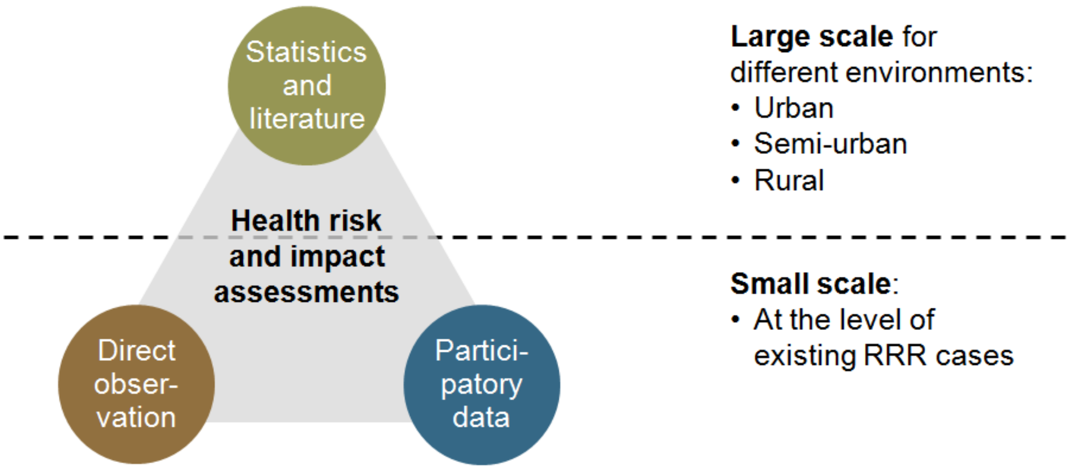

Figure 2 – Methodological triangulation for the health risk and impact assessments

2.1 Baseline data collection activities

The description of the epidemiological profile, environmental parameters and other contextual information of Hanoi 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 Hanoi, 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 Hanoi. In total, six existing RRR cases were analysed:

- Case 1: Nam Son landfill
- Case 2: Cau Dien composting plant
- Case 3: Co Dong livestock service cooperative Son Tay town, Hanoi
- Case 4: Kieu Ky waste treatment plant (landfill)
- Case 5: Wastewater treatment and management by the Hanoi Sewerage and Drainage Limited Company (HSDC)
- Case 6: Wastewater reuse in the peri-urban area of Hanoi (Thanh Tri district)

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 presented 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 were implemented in Hanoi which focused on the To Lich River (one of the city's main open drainage channels which was also selected as a SSP testing site) as our primary study system. We identified processes, transport systems and exposure groups along this system and specifically selected 4 'hotspots' along the channel. Further, we draw the system boundaries as follow: (i) the city wastewater management and maintenance system operated by HSDC; (ii) wastewater reuse in agriculture in the south of Hanoi city (Thanh Tri and Hoang Mai district); (iii) communities which are exposed due to flooding events and consumption of wastewater irrigated vegetables (no clear geographical boundary); and (vi) finally a control system (Duyen Ha commune) where farmers using water from Red River and ground water (considered as clean/safe) Figure 3 shows the flow chart of the wastewater chain in Hanoi. Critical control points (CCP) and the respective important exposure groups at each CCP along the To Lich River system are indicated.

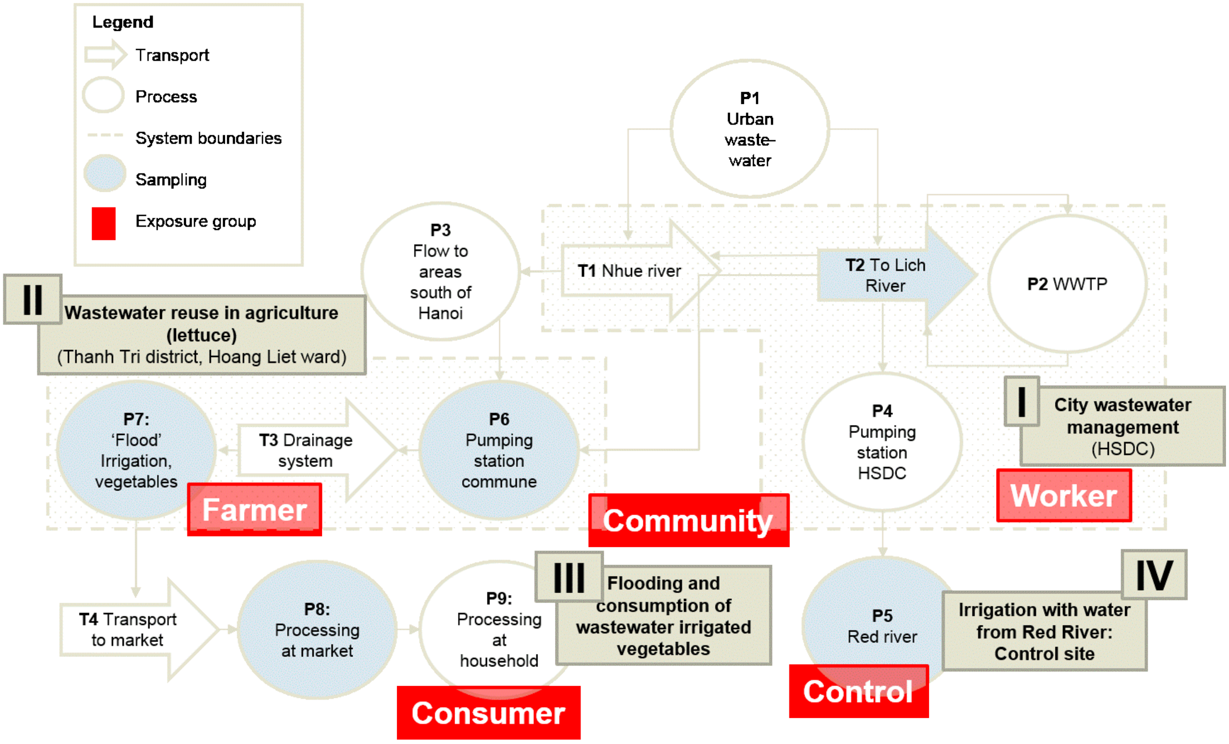

Figure 3 – Flow chart of the wastewater chain in Hanoi

The study was led by Samuel Fuhrimann; a PhD student of Swiss TPH. Samuel's study had following two elements:

The first study element had the goal to generate evidence on the exposure risk along the wastewater chains in the perspective of potential promotion of the safe recovery and reuse of wastewater in the context of Hanoi city. For this purpose, a cross-sectional survey was carried out to assess and map the existing exposure risks due to wastewater. A total of 675 individuals participated in the study, representing different exposure groups: Workers at HSDC (n=128); farmer (n=278); community members (n=269). The cross-sectional survey comprised two components: (i) a questionnaire study to obtain self-reported data on health risks and health outcomes (e.g. diarrhoeal episodes and skin and eye disease) related to the exposure to wastewater and faecal sludge; and (ii) the collection of stool samples to determine the prevalence and the intensity of parasitic infections. The stool samples were analysed for helminth infections by means of the Kato-Katz technique. As a quality control measure, one stool sample was subjected to duplicate Kato-Katz thick smear. Protozoa infections were assessed with the formalin-ether concentration technique (FECT).

The second study element aimed at filling important data gaps in the knowledge on the environmental pollution of the wastewater at different locations (wastewater channels, wastewater drainage at farm level, in the agriculture field and in Red River). A sampling framework was developed in close collaboration with local partners. For the duration of eight weeks, water, was collected in different areas along the wastewater reuse chain. The samples were analyzed for bacteria (total faecal coliform, *Escherichia Coli* and *Salmonella* spp.) and helminth eggs. Additionally, physiochemical parameters and meteorological and geographical information were obtained for each sample. The microbial analysis was conducted according to the recommended methods by the World Health Organization (WHO).

The key findings of the in-depth studies are presented in Chapter 3. The full studies are presented elsewhere.

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 Hanoi.

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 Hanoi. For the outputs of the BM, quality requirements were determined. Since the institutional analysis for Hanoi does not include specific health-related threshold values for different outputs of RRR BM, WHO thresholds are apply for the present report. If such do not exist, values from the United States Environmental Protection Agency (USEPA) or the European Union are cited.

2.2.2 Identification of potential health hazards linked to specific processes

In consideration of the epidemiological and environmental baseline data for Hanoi, 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). The resulting value was 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’) [3] 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 2006 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 2. 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 4. The entire rating was based on a modified Delphi approach (Rowe and Wright, 1999); 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 2 – Definition of impact level, and likelihood for the HRA (adapted from [4])

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 4 – Semi-quantitative assessment matrix (adapted from [4])

2.3 Health impact assessment

The objective of the HIA was to assess potential health impacts at community level of proposed BMs for Hanoi 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 Hanoi.

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 2). <u>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 Hanoi area. The assumption was clearly stated at the end of the introduction of the HIA of each BM</u>.

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 5). As for the HRA, the rating for the HIA was based on a modified Delphi approach (Rowe and Wright, 1999).

Table 3 – Definition of impact level and likelihood for the HIA (adapted from [5])

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

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IMPACT LEVEL (IL)		PEOPLE AFFECTED (PA): Individual cases 1	Specific population 100	Medium population group 1,000	Large population group 10,000	Major population 100,000
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
LIKELIHOOD or FREQUENCY (LoF)		0.05 Very unlikely	0.3 Unlikely	0.5 Possible	0.7 Likely	0.95 Almost certain

Figure 5 – Impact assessment matrix (adapted from [5])

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 [2]. 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

Vietnam made the transmission from a low to a middle income country over the past years and with it the health situation changed drastically. Communicable diseases typically for low income population such as diarrheal diseases or tuberculosis are not any more the major contributor to overall years live lost (YLL) as it was recorded in 1990. In 2010 the WHO reported that non-communicable diseases such as stroke, liver cancer or injuries, e.g. as road injuries are the leading cause of YLL (Figure 6). Along with this change life expectancy reached for males 70.2 years and for females it was 75.6 years [6]

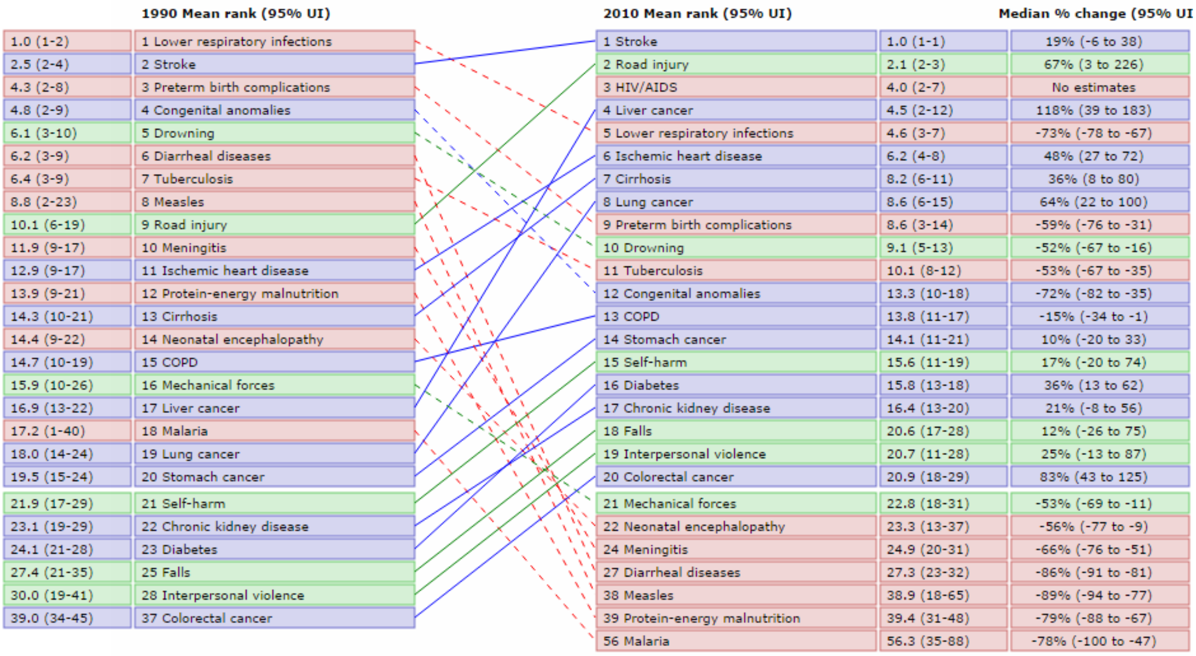

Figure 6 – Ranks for top 25 causes of YLLs 1990-2010, Vietnam [7]

Specific diarrhoea diseases, flu, shigellosis, dengue fever and varicella (chickenpox), all of which are communicable diseases, were the leading causes of morbidity at health facilities in urban, peri-urban and rural settings of Hanoi in 2007 and 2011. These were followed by hepatitis B, H1N1 and mumps. Moreover, in 2010, 233 cases of cholera were reported in urban Hanoi Table 4.

The most striking difference between different environments is the high number of dengue fever cases reported at the urban health facilities when compared to the peri-urban and rural health facilities. However, this data may be biased since diagnostic tests for dengue fever are not routinely done at peripheral health facilities. Moreover, sporadic cases of Japanese encephalitis, Rabies, Foot and Mouth disease and Tetanus were reported for 2007-2010. The occurrence of these diseases need to be considered when working within proximity to water ponds and/or in close contact with animals. In 2011 there were 547 cases of *Entamoeba histolytica* reported mainly occurring in peri-urban and rural Hanoi. Thus, it is important to note that due to limited diagnostics at health facilities (indicated by the fact that the leading causes are unspecific diarrheal diseases and flu) and underreporting of certain disease, these statistics have distinct limitations. Nevertheless, such data provide a comprehensive overview of potential disease patterns in Hanoi area and are an important information source for the description of the baseline health status and risk assessment.

Table 4 – Reported disease for urban, peri-urban and rural Hanoi, 2007-2010

2011

Disease reported	Hanoi Total	Urban	Peri-urban	Rural
Diarrhoea	6'974	1'968	2'883	2'123
Flu	5'596	42	2'400	3'154
Entamoeba histolytica	547	12	290	245
Dengue fever	494	445	35	14
Foot and mouth disease	326	167	82	77
Mumps	223	5	147	71
Varicella	170	4	31	135
Hepatitis B	32	15	5	12
Pertussis	2	-	1	1

2010

Disease reported	Hanoi Total	Urban	Peri-urban	Rural
Diarrhoea	106'845	41'405	31'518	33'922
Flu	75'905	5'499	18'896	51'510
Shigellosis	15'275	3'624	4'329	7'322
Dengue fever	3'155	2'337	420	398
Varicella	3'069	429	669	1'971
Mumps	2'421	104	662	1'655
Hepatitis B	465	225	99	141
Cholera	233	193	27	13
H1N1	27	23	2	2
Bệnh TCM	25	10	15	0
Measles	20	9	2	9
Newborn tetanus	18	5	5	8
Streptococcus	15	2	6	7
Other tetanus	13	4	5	4
Japanese encephalitis	7	2	2	3
Rabies	7	1	0	6
Encephalomyelitis	1	1	0	0
H5N1	1	0	1	0

2009

Disease reported	Hanoi Total	Urban	Peri-urban	Rural
Diarrhoea	104'557	44'184	34'863	25'510
Flu	100'158	11'852	24'077	64'229
Shigellosis	17'422	3'305	6'341	7'776
Dengue fever	16'072	12'112	2'424	1'536
Varicella	2'659	534	765	1'360
Mumps	1'855	466	526	863
H1N1	1'681	1'443	197	41
Measles	742	467	146	129
Other tetanus	118	16	30	72
Hepatitis B	46	21	24	1
Foot and Mouth	28	14	13	1
Rabies	13	2	0	11
Newborn tetanus	9	4	1	4
Japanese encephalitis	6	1	0	5
Pertussis	6	3	0	3
Like dengue fever	4	2	2	0
Encephalomyelitis	1	1	0	0

2008

Disease reported	Hanoi Total	Urban	Peri-urban
Diarrhoea	75'108	42'641	32'467
Flu	20'220	3'312	16'908
Shigellosis	7'734	3'122	4'612
Varicella	2'398	1'162	954
Dengue fever	2'103	1'891	212
Mumps	603	396	249
Hepatitis B	192	147	45
Foot and Mouth	172		353
Measles	87	87	10
Pertussis	6	2	4
Other tetanus	5	0	5
other	5	1	4
Salmonellosis	4	4	0
Japanese encephalitis	1	0	1
Streptococcus	1	0	1
Rabies	0	0	0

2007

Disease reported	Hanoi Total	Urban	Peri-urban
Diarrhoea	68'598	39'169	30'429
Flu	15'260	3'323	11'947
Shigellosis	6'251	2'610	3'641
Varicella	2'365	1'304	1'061
Dengue fever	1'806	1'634	172
Acute Diarrhoea	919	795	124
Mumps	552	382	170
Encephalitis virus	288	173	115
Pneumonia	21	14	7
Foot and Mouth	15	15	0
Salmonellosis	8	6	2
Other tetanus	7	2	5
Streptococcus	5	3	2
Japanese encephalitis	3	0	3
Encephalomyelitis	3	2	1
Pertussis	2	2	0

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 2009 Vietnam population and housing census found that 46% use non-improved toilet facilities (61% in rural areas and 12.2% in urban areas), while 10.2% of the households in rural Vietnam have no toilet facilities [6]. In Table 5 household characteristics (i.e. energy source for lighting, main drinking water source and toilet facility) are listed for urban and rural environments of Vietnam.

Table 5 – Household characteristics in Vietnam for the years 1999 and 2009 [6]

Living conditions	1999			2009		
	Total	Urban	Rural	Total	Urban	Rural
Energy source for lighting	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Electricity network	77.8	95.8	72.1	96.1	99.6	94.6
Other source	22.2	4.2	27.9	3.9	0.4	5.4
Main drinking water source	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Piped water from water treatment plant	13.1	46.9	2.3	25.5	63.5	8.6
Bore well or protected hand-dug well	54.9	41.5	59.1	49.3	30.4	57.8
Rain water	10.1	3.4	12.3	11.9	2.4	16.1
Natural spring or unprotected hand-dug well and other sources	21.9	8.2	26.3	13.3	3.7	17.5
Toilet	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Sanitary toilet	16.4	54.3	4.4	54.0	87.8	39.0
Other toilet	67.7	36.7	77.5	38.2	9.9	50.8
No toilet	15.9	9.0	18.1	7.8	2.3	10.2

In Hanoi water supply is managed by Hanoi Water Work Authority under the Hanoi Party Comity. In general the public water supply is characterised by low pressure, frequent interruptions and occasional contamination. Hence, it is common reality that private households have to store, increase pressure, boil or supply separately water in bottles on individual bases to ensure supply and quality of drinking water [8].

Most of the supplied water is exploited from ground water (between 600,000 and 650,000 m^3/day). Recent studies showed that concentrations of Arsenic (As) in the groundwater ranged from <0.10 to 330 µg/L, with about 40% of tested water samples exceeding WHO drinking water guideline of 10 µg/L. Also, 76% and 12% of groundwater samples had higher concentrations of Manganese (Mn) and Barium (Ba) than WHO drinking water guidelines, respectively. Such increased concentration can be of major public health concerns as they can lead to skin and other cancers [9].

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 [10].

In the 1990s, diarrhoeal diseases were the leading cause of death in Vietnam. In recent years, mortality rate due to diarrhoeal diseases decreased considerably, though, acute diarrhoea still ranks as a leading cause of morbidity at the health facilities in urban, peri-urban and rural Hanoi as shown in Table 4. Due to limited diagnostics at peripheral health facilities, the cause of diarrhoeal disease is generally not determined. For example, Shigellosis, which often leads to acute diarrheal, is reported as one of the major health outcomes in the context of Hanoi, but most cases are not confirmed by laboratory investigations. Moreover, a series of outbreaks of cholera (*Vibrio cholera*) have been reported. In total 8,000 cases of clinical, or symptomatic, cholera, were reported between 2007 and 2010 [11].

In peri-urban context of Hanoi, wastewater contact was detected as the principal risk factor for diarrhoea. As the local economy depends on the use of wastewater for agriculture and aquaculture, it is important to find solutions to mitigate the public health risks associated with this use, in addition to promotions of personal, domestic and food hygiene [12]. The monthly incidence of diarrhoea in 636 persons aged 15–70 years followed for 328,254 days at risk between 2002 and 2004 in Yen So commune, Hanoi, Vietnam, is illustrated in Figure 7.

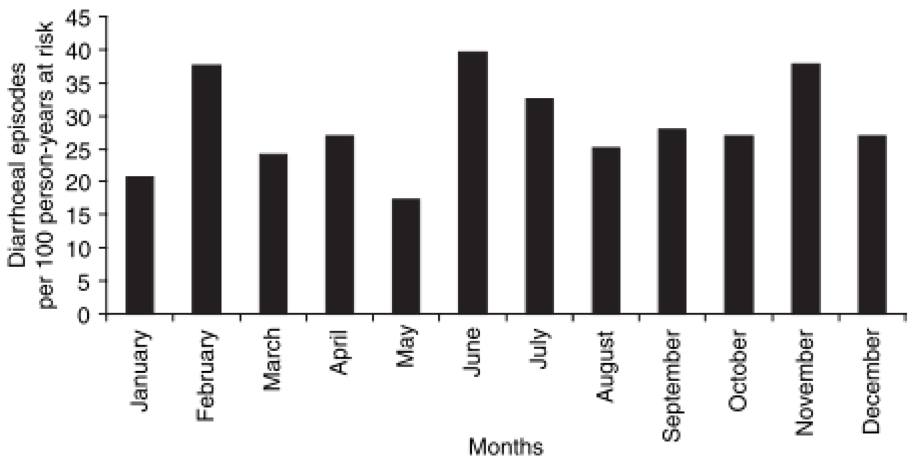

Figure 7 – Monthly incidence of diarrhoea in a at risk cohort, 2002-2004, Hanoi [13]

3.1.1.2 Helminth infections

Soil-transmitted helminth (STH) infections are the most common helminth infections worldwide. In Vietnam, all major STH are endemic and there are estimates that 39.9 million (44.4%) people are infected with *Ascaris lumbricoides*; 17.6 million (23.1%) with *Trichuris trichiura* [14], and 19.8 million (22.1%) with hookworm [15].

The highest prevalence of helminth infection are found in rural areas of northern Vietnam and closely related with the use of excreta as fertiliser in the agriculture. Recent studies around the reuse of wastewater in agriculture in rural settings of Vietnam indicated that direct contact with water from wastewater fed rivers is one of the most important risk factors for Helminth infections (odds ratio [OR]=1.5, 95% confidence interval [CI] 1.1–2.2) [16].

In our own in-depth study carried out in selected exposure groups, the most common STH infection was hookworm with a prevalence of 15.5% in local farmers. More detailed findings on STH infections along the major drainage and wastewater fed channels in Hanoi are available in Table 6.

Table 6 – Helminth prevalence in different exposure groups, Thanh Tri district, 2014

Helminth prevalence	Wastewater treatment plant workers n=128		Farmers n=278		Community n=259		Difference	
	n	%	n	%	n	%	x2	p-value
Hookworm	5	3.9	43	15.5	10	3.9	28.4	<0.001
Trichuris trichiura	9	7.0	11	4.0	11	4.2	2.14	0.341
Ascaris lumbricoides	2	1.6	0	0.0	2	0.8	3.8	0.149

3.1.1.3 Intestinal protozoa

Intestinal protozoa show a worldwide distribution with infection being highest in infants and children. Little information is available on intestinal protozoa infection for Vietnam. In 163 cases of diarrhea reported over a period of one year 9.9% were reported to be positive for *Entamoeba histolytica.* In Ha Nam Province, a rural area 60 km south of Hanoi socio-economic and personal hygiene factors determine infection with *E. histolytica*, rather than exposure to human and animal excreta in agricultural activities [17].

In our own in-depth study, prevalence rates of intestinal protozoa were found to be very low, i.e. ≤1.0% (see Table 7). The differences between exposure groups were not at statistically significant levels.

Table 7 – Intestinal protozoa in different exposure groups, Thanh Tri district, 2014

Intestinal protozoa	Wastewater treatment plant workers n=43		Farmer n=245		Community 1 n=229		Difference	
	n	%	n	%	n	%	x2	p-value
Entamoeba histolytica	0	0	0	0	0	0		
Entamoeba coli	1	0.8	3	1.1	1	0.4	0.93	0.62
Giardia lamblia	1	0.8	0	0.0	1	0.4	1.87	0.387
Balantidium coli	0	0	1	0.4	1	0.4	0.47	0.79
Chilomastix mesnili	0	0	0	0	0	0		
Entamoeba hartmanni	0	0	0	0	0	0		
Iodamoeba buetschlii	0	0	0	0	0	0		

3.1.1.4 Food-borne trematode infections

Food-borne trematode infections (also known as food-borne trematodiases), are a group of parasitic infections caused by trematodes (flatworms or “flukes”) that are acquired through ingestion of food contaminated with the larval stages of the parasite. Transmission is linked to human behaviour patterns related to methods of producing, processing and preparing foods. In particular, dishes containing raw fish, crustaceans and plants are an established dietary tradition of many populations living in countries where these diseases are endemic. Food-borne trematodiases are thus sustained and perpetuated by entrenched cultural practices [18].

In Vietnam, both fishborne zoonotic trematodes that infect the liver and the intestines are common [19]. Of the 615 persons investigated, 64.9% presented with trematode eggs in their stool. In 2005, a cross-sectional survey for faecal trematode eggs was conducted in 2 communes in Nghia Hung District, Nam Dinh Province, Vietnam, southeast of the capital of Hanoi [20]. Infected persons were treated to expel liver and intestinal parasites for specific identification. The liver trematode *Clonorchis sinensis* was recovered from 51.5%. The most numerous were *Haplorchis* spp. (90.4% of all worms recovered). These results demonstrate that fishborne intestinal parasites are an important food safety risk in a Vietnam, particularly in people who have a strong tradition of eating raw fish.

3.1.1.5 Skin and eye infections

Skin disease among farmers using wastewater is a common reported health outcome in Vietnam. A study in Nam Dinh, northern Vietnam could show that exposure to wastewater was a major risk factor for skin disease with a relative risk (RR) of 1.89 [95% confidence interval (CI) 1.39–2.57] [13]. Monthly prevalence (percentage) of self-reported skin disease in My Tan (n = 546) and My Trung (n = 557) communes are presented in Figure 8 (August 2004–July 2005).

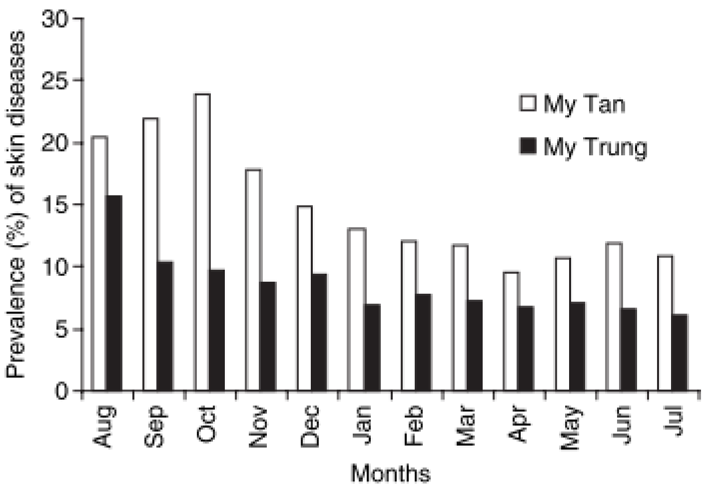

Figure 8 – Monthly prevalence of self-reported skin disease, My Tan and My Trung [13]

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.

Reported disease outcomes such as H1N1, flue reported in the health centres around Hanoi often go along with acute respiratory tract infections and are therefore a major health concern in the area of Hanoi as shown in Table 4.

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 [21]. 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.

In Vietnam, 23% of the population is smoking and raised blood pressure is estimated at 23.1%. Chronic respiratory diseases and cardiovascular diseases account for 7% and 33% of total mortality (all ages, both sexes), according to estimates of the WHO [22]. Taken together, those two health conditions account for 4 in 10 deaths in Vietnam, which makes exposure to indoor and outdoor air pollution an important public health concern.

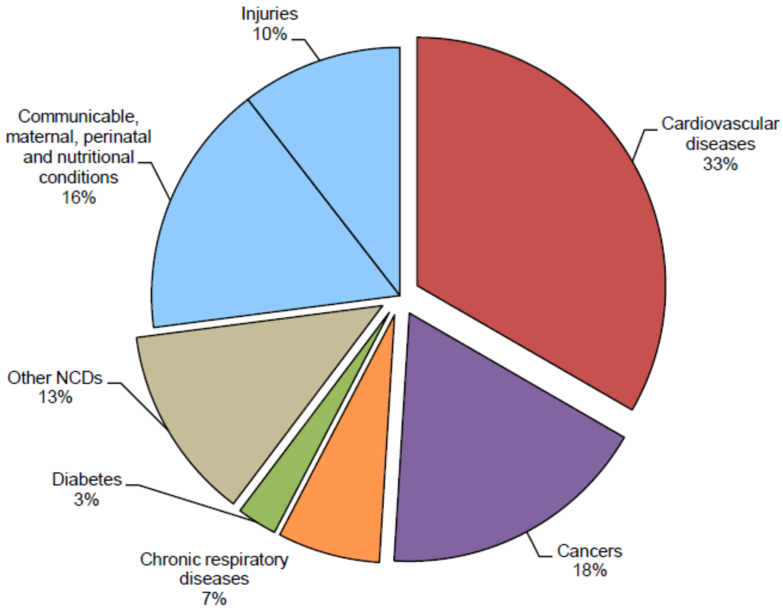

Figure 9 – NCD-related mortality (%), all ages, both sexes, Vietnam (2012) [22]

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 Vietnam. Therefore, various vector-borne diseases are endemic in the country and are of major public health relevance (e.g. dengue fever, malaria, Japanese encephalitis and Chikungunya fever).

3.1.3.1 Malaria

Malaria, a protozoan infection transmitted by anopheline mosquitoes, is the most important parasitic disease in humans. Malaria is a major concern the Mekong area.

Prior to the early 1990s, malaria was a major cause of morbidity and mortality in Vietnam. As the result of improved socio-economic conditions, increased government investment, and community-based monitoring, the malaria burden in Vietnam has been dramatically alleviated in recent years. The number of malaria cases in Vietnam has plunged to merely 11,355 in 2008. Malaria in Vietnam is distributed in the central and southern parts of the country, and malaria occurs mostly in the forests or forest edges. Hence, Hanoi city is not considered a risk area for Malaria transmission as shown in Figure 10 [23].

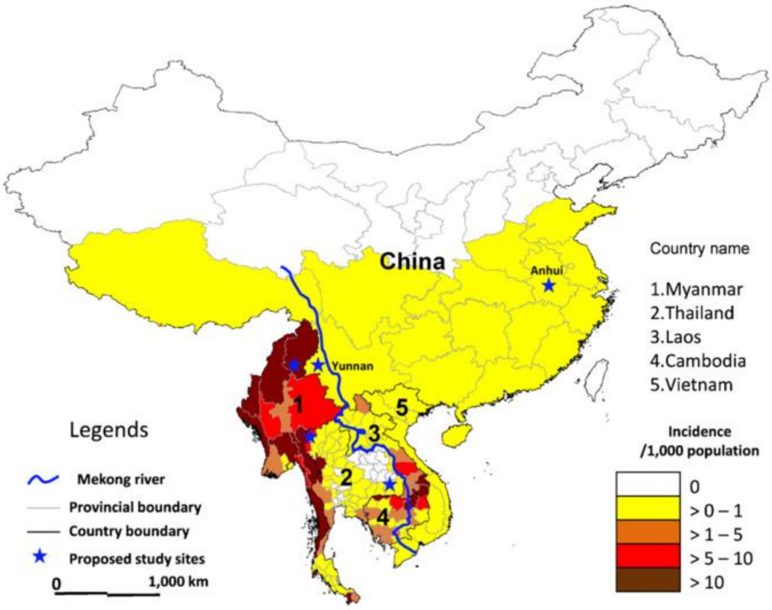

Figure 10 – Malaria incidence in the Greater Mekong sub-Region [23]

3.1.3.2 Dengue fever

Dengue fever is arboviral diseases that involve several species of mosquitoes within the genus *Aedes* and *Culex* in their transmission cycle. These mosquitoes live in close association with man since they breed in any small water collection, including open containers, old tires and tree holes. Both species are endemic in Vietnam and each year many cases of Dengue fever are reported in urban context of Vietnam.

Overall Southeast Asia is considered an epicentre of this global dengue outbreak, accounting for 70% of global dengue morbidity and mortality, and is a region with substantial potential for further expansion. Even though Hanoi is a considered as a low dengue transmission setting, incidence has been increasing since 1999. In 2009, Hanoi experienced its largest ever-recorded outbreak of dengue and is since then under higher surveillance [24]. This is also reflected in the diagnosed Dengue cases at the level of the health facilities Table 4.

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3.1.3.3 Japanese encephalitis

Japanese encephalitis virus is the leading cause of viral encephalitis in Asia and occurs in almost all Asian countries (see Figure 11) [25]. Transmission occurs principally in rural agricultural locations where flooding irrigation is practised – some of which may be near or within urban centres. Transmission is related mainly to the rainy season in south-east Asia but may take place all year round, particularly in tropical climate zones. However, in comparison with the number of reported cases of dengue fever, Japanese encephalitis is less of a concern in Vietnam (see Table 4).

Figure 11 – Countries at risk for Japanese Encephalitis [25]

3.2 Environmental parameters

3.2.1 Liquid waste system

As regard to wastewater, HSDC, a public utility under Hanoi City People's Committee (Hanoi PC), is responsible for treatment and disposal of both domestic and industrial wastewater. HSDC is responsible for the provision, operation and maintenance of the sewerage and drainage network in the core urban area of Hanoi. Hanoi HSDC manages the primary and secondary network (ditches, channels, city's sewers and rivers, as well as other sewerage and drainage facilities)

The water quality monitoring data in the four main rivers and lakes in Hanoi have clearly shown that the water quality of rivers, lakes and ponds is worsening due to the discharge of untreated industrial wastewater, which contains toxic substances, inorganic substances and high organic content. Averagely, concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), heavy metals and coliform in To Lich, Lu, Set and Nhue rivers are 3–4 times higher than standards [26].

Large quantities of untreated industrial and domestic wastewater are discharged from the city of Hanoi into urban rivers. With the industrial wastewater there are also a range of heavy metals discarded. Marcussen and colleagues found high elemental concentrations in the sediment of the To Lich and Kim Nguu rivers [27]. According to the Dutch Target and Intervention Values, it can be concluded that apart from one, all three of the investigated sites in each river were strongly polluted with As, Ba, Cd, Cu, Ni and Zn with maximum sediment concentrations of 73 As, 963 Ba, 427 Cd, 240 Cu, 218 Ni and 1240 Zn mg kg^{-1}. High Cd concentrations of up to 700 mg kg−1 were also found in sediment of To Lich River. Hence, the sediment which is usually reused for agricultural purposes is highly unsuitable for any types of land use [28].

A study conducted in 2010, looked into heavy metal concentration of four rivers that are playing an important role in water drainage in Hanoi [29]. They found that municipal wastewater contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements such as 1090-2140 mg Cd L^{-1}, 0.16-0.33 mg Cu L^{-1}, 2750-4020 mg Pb L^{-1}, 0.20-0.34 mg Zn L^{-1} and 0.22-0.44 mg Mn L^{-1} (see Table 8).

Table 8 – Characteristics of wastewater in drainage river systems of Hanoi [29]

Nº	Parameters	Unit	Lu river	Set river	Kim Nguu river		To Lich river	
			Dinh Cong commune	Set bridge	Mai Dong bridge	Van Dien commune	Moi bridge	Dau bridge
1	pH		7.43±0.22	7.49±0.25	7.56±0.29	7.53±0.25	7.57±0.31	7.44±0.31
2	SS	mg L^{-1}	117±24	75±27	57±14	72±18	112±20	151±30
3	COD	mg O_2 L^{-1}	123±41	125±34	118±17	67±7	101±40	119±51
4	N_{total}	mg N L^{-1}	12.2±4.7	12.7±4.8	12.8±5.0	8.0±3.4	13.1±4.4	13.1±3.4
5	P_{total}	mg P L^{-1}	3.8±1.2	3.7±1.1	3.4±1.2	3.3±0.9	3.6±1.4	3.7±1.4
6	K_{total}	mg K L^{-1}	11.4±3.4	10.3±1.9	11.8±2.2	9.6±2.7	11.7±1.8	13.2±2.1
7	Cd	µg Cd L^{-1}	1.19±0.89	1.11±0.89	1.32±0.94	2.14±1.88	1.59±1.03	1.09±0.98
8	Pb	µg Pb L^{-1}	3.92±1.44	3.53±1.46	3.54±1.39	4.02±1.55	4.45±1.94	2.75±1.05
9	Cu	mg Cu L^{-1}	0.25±0.09	0.22±0.10	0.27±0.09	0.33±0.08	0.32±0.15	0.16±0.07
10	Zn	mg Zn L^{-1}	0.25±0.12	0.24±0.12	0.30±0.17	0.32±0.17	0.34±0.17	0.20±0.11
11	Mn	mg Mn L^{-1}	0.32±0.09	0.29±0.10	0.35±0.12	0.42±0.15	0.44±0.17	0.22±0.06

The concentration of heavy metals in soil and vegetables were studied in agricultural areas along the To Lich and Kim Nguu Rivers of Hanoi [30]. The average concentrations of the heavy metals in the soil were in the order zinc (Zn; 204 mg kg^{-1}) > copper (Cu; 196 mg kg^{-1}) > chromium (Cr; 175 mg kg^{-1}) > lead (Pb; 131 mg kg^{-1}) > nickel (Ni; 60 mg kg^{-1}) > cadmium (Cd; 4 mg kg^{-1}). The concentrations of all heavy metals in the study site were much greater than the background level in that area and exceeded the permissible levels of the Vietnamese standards for Cd, Cu, and Pb [31]. Also the concentrations of Cd, Cr, Cu, Ni, Pb, and Zn in the vegetables exceeded the Vietnamese standards [32]. An additional finding was that the concentrations of Zn, Ni, and Pb in the surface soil decreased with distance from the canal. The transfer coefficients for the metals were in the order of Zn > Ni > Cu > Cd = Cr > Pb. These findings indicate that wastewater fed agriculture cannot be promoted from a health perspective.

Finally, flooding events are also of major concern in South-East Asia and Northern-Vietnam has greatest potential for flooding events. For example in 2007, it was estimated that 400 people died from floods and the economic loss was estimated around 11.5 billion VND (about US$650 million). Moreover, in 2008 the flood caused even more people died while drowning, through injury, acute asthma, outbreaks of gastroenteritis, dengue fever, and respiratory infections. Hence, flood prevention and mitigation strategies are now high up on the cities agenda and efforts are undertaken to regulate the water flow with large infrastructures such as drainage channels and artificial lakes [33].

3.2.2 Solid waste collection system

In Hanoi, the urban solid waste (SW) is managed by Hanoi Urban Environment Company (URENCO); a public non-profit utility belonging to Hanoi city people's committee (Hanoi PC). The mandate of URENCO is to collect, transport and disposal of SW generated in urban districts of Hanoi. The collection and management of solid waste generated in peri-urban districts is responsibility of local authority, the people's committee at district and ward level.

Approximately, 80 % of total generated urban SW is collected and disposed of into landfill by URENCO. The remaining 20% is either improperly disposed of into open landfills or illegally thrown to the city's rivers and lakes. The SW is not on-site classified, and only a small portion of the organic SW is classified and used for compost production in a composting plant placed under management of Hanoi URENCO.

3.2.3 Environmental sampling

24 critical control points where selected along the wastewater chain of To Lich, Nhue and Red River, as well as at the level of each commune (local drainage system and field) where wastewater is used for irrigation of crops and vegetables (Figure 12).

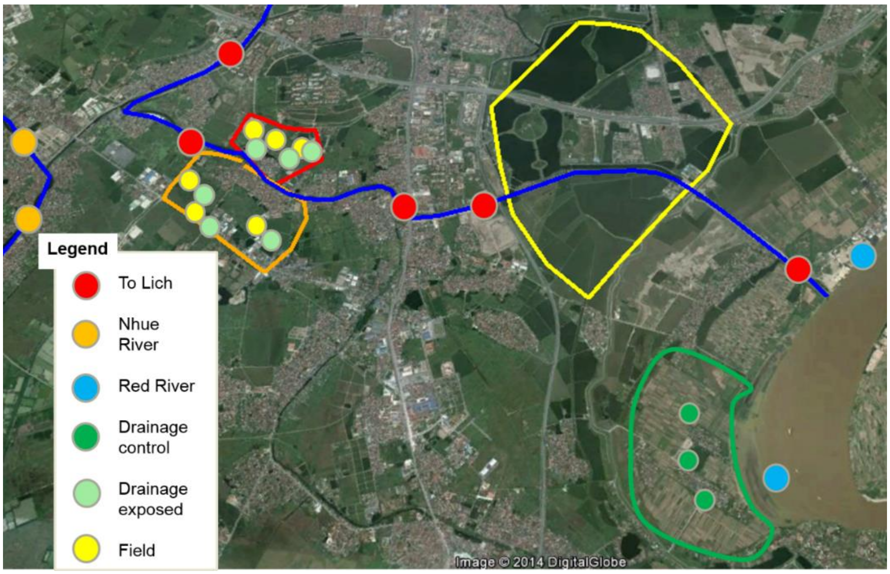

Figure 12 – Environmental sampling points in Thanh Tri district, 2014

In the environmental sampling component of our in-depth study, a total of 230 water samples were collected over a period of 8 weeks (April to June 2014). Samples were tested for the following indicators: coliform forming units (CFU) of (i) faecal coliform bacteria and (ii) *E. coli; Salmonella* spp.; (iv) and helminth eggs.

Bacteria concentration was found highest in Nhue and Red River with up to 6.5 log CFU total faecal coliform. Red River water and water from the control site where people use ground water or Red River water appeared to be cleanest. Figure 13 shows concentrations of faecal coliform bacteria in different water systems along the wastewater reuse chain in Hanoi.

Helminth egg concentration where all below 1 egg/L and hence below WHO thresholds for wastewater reuse in agriculture [3]. Only 5 and 7 samples were found positive for *A. lumbricoides* and *T. Trichiura*, respectively.

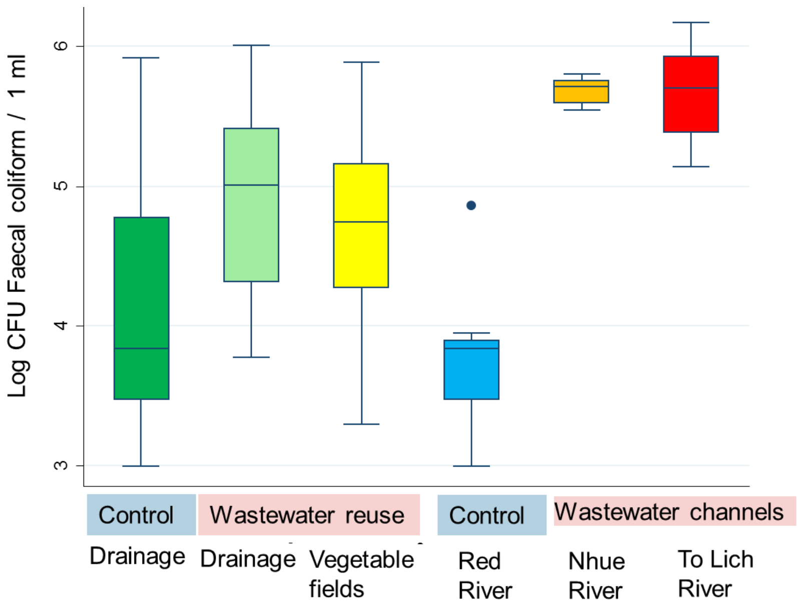

Figure 13 – Concentration of faecal coliform bacteria in different water systems

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 Hanoi, 128 wastewater treatment plant workers, 278 farmers and 259 community members were asked what kind of health complaints they have experiences within the past two weeks. Results are presented in Figure 14 and can be summarized as follows:

Headache and back pain were the most frequently reported health complaints reported by wastewater treatment plant workers (n=128; 39.1% and 35.2%, respectively), farmers (n=278; 54.0% and 55.8%, respectively) and community members (n=259; 40.9% and 39.8%, respectively). These were followed by abdominal pain, acute coughing and muscle pain. Interestingly, no big difference in health complaints was observed between wastewater workers and community members. Hence, the occupational component of the complaints is not obvious. With regard to headache and back pain, farmers were clearly more affected than the other two population groups investigated.

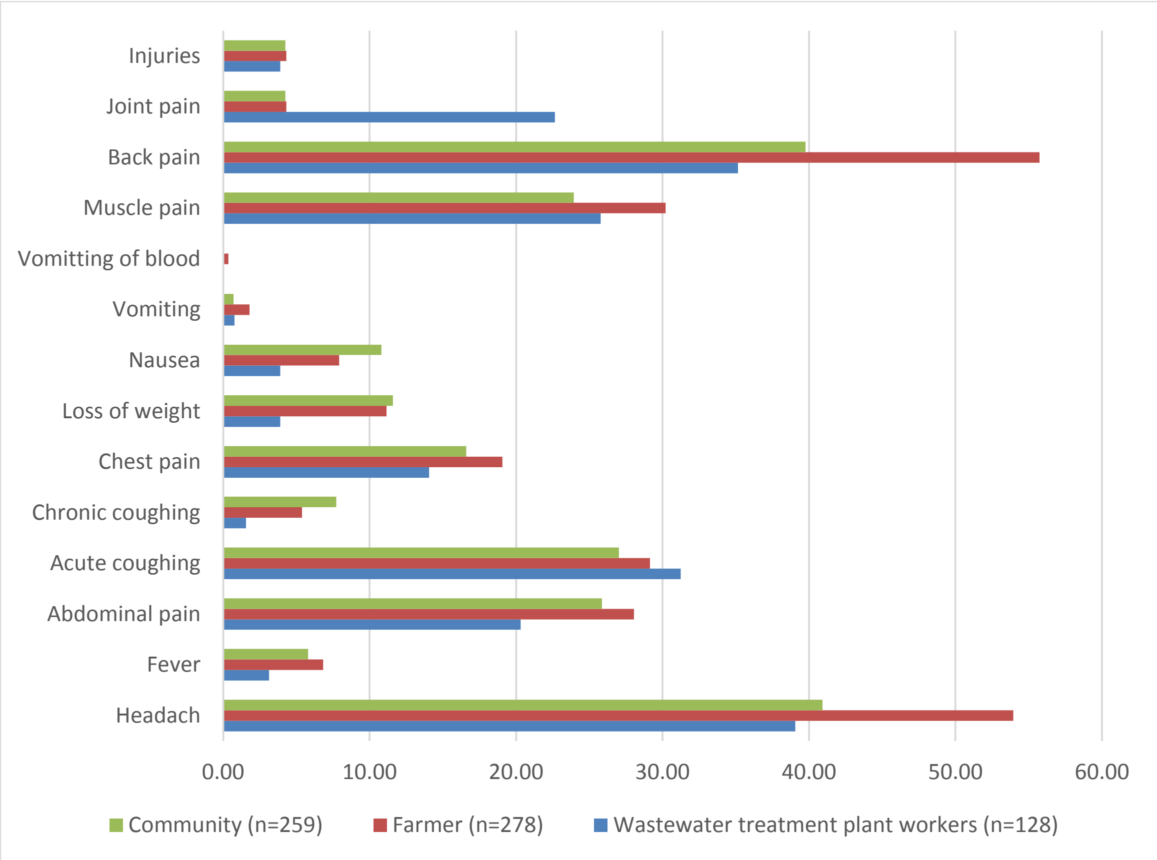

Figure 14 – Health issues reported by workers and community members in Thanh Tri district

3.4 Acceptability and use of personal protective equipment

The acceptability and use of a total of 13 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 Hanoi area. A total of 128 wastewater treatment plant workers, 279 farmers participated in the study.

Over 90.3 % of the farmer own a Vietnams and consider it important to protect against the sun shine. 50% of them also wore it all the time during their work. Also rubber boots, long sleeves, gloves and face masks were owned by more than 2/3 of all farmers and the majority of the famers wear it more than 50% or more of their working time.

Workers at the wastewater treatment plant all own a uniform and 77.5% of the wear them always during their work. Also face mask, rain coat with boots, gloves, helmets, rubber boots and tools belong to their standard protection measures and are owned by more than 75% of all workers. Hence, over 80% of all workers wear rubber boots and rain coats all the time during their working steps. More details can be found in Table 9.

Table 9 – PPE use among farmers and wastewater treatment plant workers

Personal protective equipment	Farmer (n=279)							Worker (n=128)						
	Owning PPE		Wearing PPE (%)					Owning PPE		Wearing PPE (%)				
	Total (n)	Total (%)	*Always (100% of the time)*	*Regularly (75% of the time)*	*Sometimes (50% of the time)*	*Rarely (25% of the time)*	*Don't know*	**Total owning (n)**	Total owning (%)	*Always (100% of the time)*	*Regularly (75% of the time)*	*Sometimes (50% of the time)*	*Rarely (25% of the time)*	*Don't know*
Soft hat	61	21.9	32.8	19.7	14.8	3.3	29.5	7	5.5	100	0	0	0	0.0
Vietnamese hat	251	90.3	50.6	10.0	4.8	0.4	34.3	4	3.1	100	0	0	0	0.0
Helmet	4	1.4	75.0	0	25.0	0	0	117	91.4	77.8	6.8	0.9	0.9	14
working without shoes	41	14.7	31.7	17.1	2.4	2.4	46.3	28	21.9	39.3	0	0	0	60.7
special working shoes	43	15.5	44.2	20.9	18.6	2.3	14.0	57	44.5	94.7	1.8	0.0	1.8	1.8
Rubber boots	237	85.3	40.1	13.1	10.5	3.4	32.9	110	85.9	80.9	2.7	0.9	1.8	13.6
Long sleeves	233	83.8	55.8	6.0	2.1	0.9	35.2	48	37.5	70.8	2.1	2.1	2.1	22.9
Uniform/ Cotton overall	39	14.0	69.2	5.1	5.1	0.0	20.5	128	100	77.5	0.8	0.8	0.8	20.2
Gloves	218	78.4	33.9	11.5	18.8	6.9	28.9	117	91.4	76.1	4.3	1.7	1.7	16.2
Tools	164	59.0	28.0	29.3	9.8	2.4	30.5	96	75.0	79.2	3.1	0	1.0	16.7
Face mask	214	77.0	41.6	14.5	9.3	7.0	27.6	121	94.5	68.6	13.2	2.5	0.8	14.9
Rain coat with boots	77	27.7	20.8	1.3	0	41.6	36.4	120	93.8	81.7	2.5	0.8	0.8	14.2
Rain coat without boots	94	33.8	19.1	2.1	3.2	42.6	33.0	84	65.6	71.4	3.6	0.0	0.0	25.0

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. Of note, if not referenced otherwise, quality standards, pathogen reduction rates and threshold values are as described in the WHO 2006 Guidelines on the safe use of wastewater, excreta and graywater [3].

For the HRA, the data collected at the level of existing RRR cases in Hanoi served as important information source in combination with the epidemiological and environmental indicators summarized in the previous chapter. 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 chapters. 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 Hanoi, a total of 11 BMs were selected to be assessed in the frame of the feasibility studies:

- Model 1a: Dry fuel manufacturing: agro-industrial waste to briquettes
- Model 2a: Energy service companies at scale: agro-waste to energy (electricity)
- Model 4: Onsite energy generation by sanitation service providers
- Model 6: Manure to power
- Model 8: Beyond cost recovery: the aquaculture example
- Model 9: On cost savings and recovery
- Model 15: Large-scale composting for revenue generation
- Model 16: Subsidy-free community based composting
- Model 17: High value fertilizer production for profit
- Model 18: Urine and struvite use at scale
- Model 19: Compost production for sanitation service Delivery

4.1 Model 1a – Dry fuel manufacturing: agro-industrial waste to briquettes

Model 1a aims at processing crop residues like wheat stalk, rice husk, maize stalk, groundnut shells, coffee husks, saw dust etc. for converting them into briquettes as fuel. The process of briquetting involves reducing moisture content in the crop residues and compress the biomass at high temperature or/and using a binding agent. To produce charcoal from crop residues by burning them in low-oxygen atmosphere is also an option. The resulting charred material is compressed into briquettes

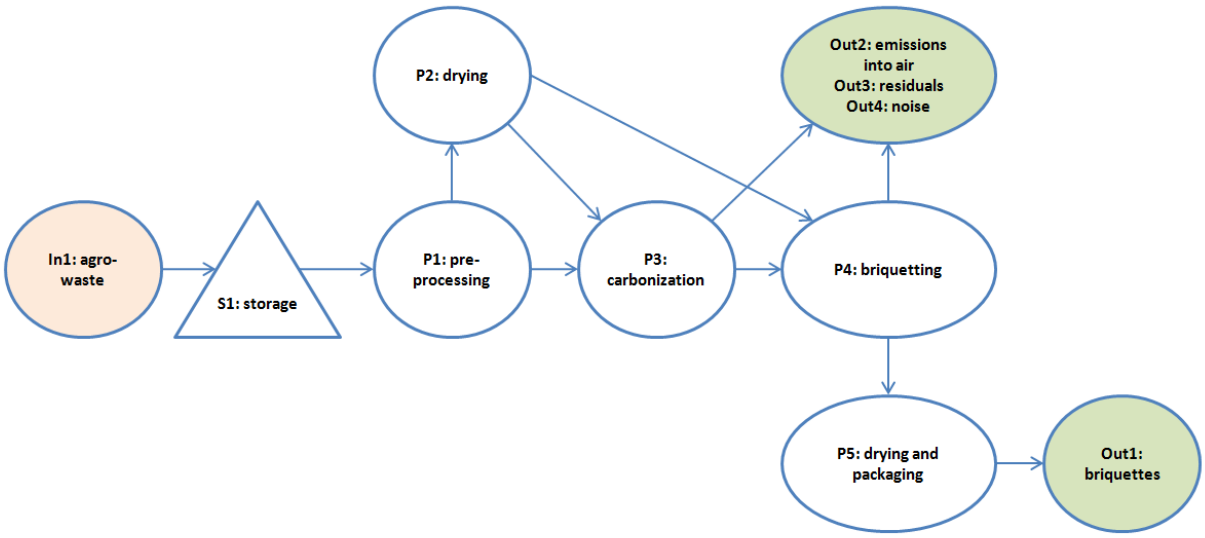

Figure 15 – Model 1: system flow diagram

4.1.1 Health risk assessment

From an occupational health perspective, heat and toxic gas emissions related to the carbonization process are of primary concern. In addition, there is a set of quality requirements linked to the briquettes for warranting safe use at household level. First, it is crucial that the briquettes are free of inorganic components in order to avoid toxic fumes when burning the briquettes. Second, the agro-waste used for briquetting needs to be free of sharp objects for preventing cuts when handling the waste and briquettes. Third, as people are likely to handle the briquettes with their bare hands, hand-to-mouth transmission of pathogens needs to be avoided by reducing pathogen load of the briquettes to a minimum. Finally, it is recommended that moisture content of the briquettes is at low levels to reduce smoke nuisances at household level.

Table 10 – Model 1a: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: agro-waste	Faecal contamination (pathogens)
	Contamination with MSW (inorganic; sharp objects)

Table 11 – Model 1a: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: briquettes	Free of inorganic components; free of sharp objects; free of pathogens; moisture content: <10%

Out2: emissions into air	Ambient air quality standards[a]:
	• $PM_{2.5}$: 10 µ/m³ 24-hour mean; 25 µ/m³ annual mean
	• PM_{10}: 20 µ/m³ 24-hour mean; 50 µ/m³ annual mean
	• Ozone: 100 µ/m³ 8-hour mean
	• NO_2: 200 µ/m³ 1-hour mean; 40 µ/m³ annual mean
	• SO_2: 500 µ/m³ 10-minutes mean; 20 µ/m³ 24-hour 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: residuals	None since considered as waste
Out4: noise	Occupational noise exposure limits[c]: • Equivalent level (8h):85 decibel (dB)(A) • Maximum level (short duration): 140 dB(A) Community noise exposure limits[d]: • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization
[b] WHO (2010). Guidelines for indoor air quality: selected pollutants. Geneva: World Health Organization
[c] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization
[d] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

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 (e.g. agro-waste) need to wear appropriate PPE and use tools (e.g. shovels)
  - Workers that are directly exposed to fumes from the carbonization 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. briquetting process; 85 decibel (dB) permanent or 140 dB short duration) need to wear hearing protection
- Processes
  - Any faecally contaminated agro-waste, as well as any inorganic contaminants such as sharp object, needs to be removed from the organic fraction that enters the briquetting process
- Infrastructure

  - Respect a buffer zone between operation and community infrastructure so that ambient air quality and noise exposure standards are not exceeded (see Table 11). The actual distance is depending on the level of emissions
  - In case the carbonization is done in a closed environment, carbon monoxide (CO) monitors need to be installed
- Behavioural aspects and prevention
  - 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
  - Protect workers from long term exposure to sunlight
  - Restrict access to the operations

4.1.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 1a can be reduced to **low and moderate levels**. The residual moderate risks are linked to the following processes:

- P3: carbonization: inhalation of toxic gases emitted by the carbonization process at workplace and community level was identified as a moderate risk. To enforce the use of gas mask respirators when being exposed to smoke of the process will be important. When selecting the location of the operation, a buffer zone to communities needs to be considered, taking into account pre-dominant wind directions.

Finally, it is recommended to 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.).

4.1.2 Health impact assessment

Under the assumption that the above mitigation measures are implemented, the briquettes should be free of inorganic contaminants, sharp objects and pathogens. Hence, it is a safe product. However, an important health concern that remains is the fugitive emissions from burning the briquettes at household level. Prolonged exposure to CO, sulphur oxides (SO_x), Nitrogen oxides (NO_x), hydrocarbons and particulate matter may cause human health complications [34, 35].

- **Scale of the BM:** the impact assessment of Model 1a is based on the assumption that 1% of the population in Hanoi will use briquettes from the BM as cooking fuel

4.1.2.1 Impact 1: increase in chronic respiratory disease and cancer

For assessing the potential health impact of increased use of briquettes, one has to take into consideration which cooking fuel types are currently used at household level in Hanoi. According to the 2011 Multiple Indicator Cluster Survey (MICS), approximately 80% of rural households in Vietnam use liquefied petroleum gas (LPG) as cooking fuel in Vietnam (see Table 12). Solid fuels such as wood, straw/shrubs/grass and coal were used by 16.9% of the urban households [36]. An analysis of the Vietnam 2011 MICS by the Global Alliance for Clean Cookstoves found that the type of cooking fuel use in Vietnamese households is strongly associated with the level of income as illustrated by Figure 16 [37]. It appears that Vietnames households switch to LPG once their income exceeds USD50 per months.

Table 12 – Cooking fuels used at household level in Vietnam, 2011 [38]

	Percentage of household population in households using:														
						Solid fuels									
	Electricity	Liquefied Petroleum Gas (LPG)	Natural Gas	Biogas	Kerosene	Coal, lignite	Char-coal	Wood	Straw, shrubs, grass	Agricultural crop residue	Other fuel	No food cooked in the household	Total	Solid fuels for cooking[1]	Number of household members
Region															
Red River Delta	0.7	59.9	0.3	1.3	0	9.3	1.4	9.6	16.7	0.6	0.1	0.1	100	37.6	9261
Northern Midland and Mountain areas	0.7	27.5	0.1	1.6	0	1	0.4	66.8	1.5	0	0.1	0.1	100	69.8	7242
North Central area and Central Coastal area	0.3	45.2	0.1	1.1	0.4	0.7	4.1	44.4	3.2	0.1	0	0	100	52.5	9443
Central Highlands	1	49.1	0.2	0.4	0	0.1	1.4	47.6	0	0	0.1	0.1	100	49.1	2551
South East	0.4	81.2	0.2	0.4	1.6	0.1	0.7	13.9	0	0	1.2	1.2	100	14.6	7066
Mekong River Delta	0.5	42	0.1	0.5	0.7	0.1	2.5	51.7	0.2	0.7	0.4	0.4	100	55.2	8434
Area															
Urban	0.6	80.7	0	0.2	0.9	3.7	1.1	11.5	0.6	0	0.6	0.6	100	16.9	13003
Rural	0.5	38.2	0.2	1.3	0.3	1.7	2.2	48.4	6.1	0.4	0.2	0.2	100	58.9	30995
Education of household head															
None	0.5	21.9	0.1	0	0.8	1.3	4.4	67.6	2.9	0	0.5	0.5	100	76.3	2651
Primary	0.5	35.2	0.1	0.5	0.7	0.8	2.9	53.4	4.7	0.4	0.3	0.3	100	62.3	11331
Lower Secondary	0.5	49	0.3	1.4	0.3	3	1.6	37.1	6	0.3	0.3	0.3	100	47.8	17452
Upper Secondary	0.6	65.5	0	1.6	0.5	3.6	1.4	22.1	3.8	0.3	0.3	0.3	100	31.1	7222
Tertiary	0.7	85	0.1	0.3	0.2	2.1	0.1	10	0.7	0.3	0.5	0.5	100	13.2	5190
Wealth index quintiles															
Poorest	0.1	1.5	0	0.3	0.2	0.1	2.2	89.5	5.4	0.2	0.2	0.2	100	97.4	8803
Second	0.9	16.4	0.1	1.1	0.4	1.5	3.7	64.2	10.5	0.5	0.3	0.3	100	80.3	8796
Middle	0.8	52.7	0.5	2.1	1.1	3.8	2.2	29.2	5.8	0.8	0.5	0.5	100	41.7	8798
Fourth	0.8	85.9	0.1	1.4	0.4	4.5	1.1	4.4	0.8	0	0.6	0.6	100	10.8	8797
Richest	0.2	97.4	0	0	0.3	1.7	0.3	0	0	0	0.1	0.1	100	2	8803
Ethnicity of household head															
Kinh/Hoa	0.6	56.5	0.2	1	0.5	2.6	2.1	30.5	5.1	0.3	0.4	0.3	100	40.5	38675
Ethnic Minorities	0.4	9.2	0	0.6	0.1	0.3	0.7	88.3	0.3	0	0	0.1	100	89.5	5323
Total	0.6	50.8	0.2	1	0.5	2.3	1.9	37.5	4.5	0.3	0.3	0.3	100	46.4	43998

[1] MICS indicator 3.11

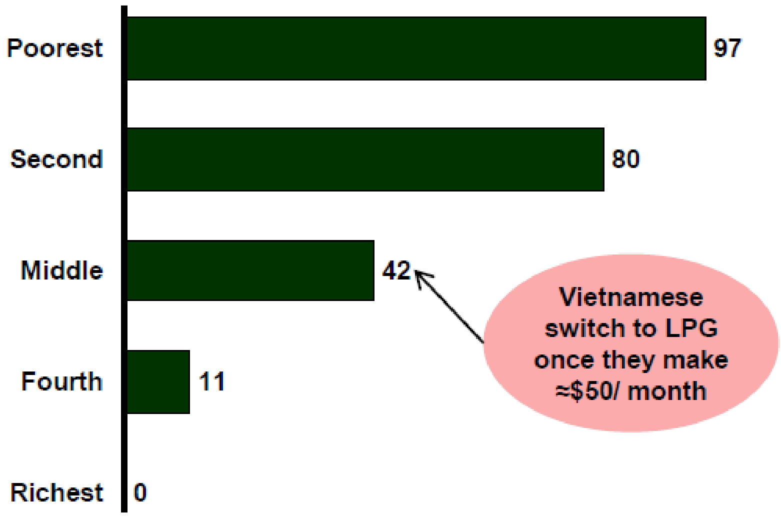

Figure 16 – Solid fuel use (% of households) by income in Vietnam

Literature on emission factors of different cooking fuel types is divers [35, 39-41]. Charcoal, wood, crop residuals and dung are similar in terms of emissions; they all emit a lot of toxic gases and particulate matter, and thus are important causes of chronic respiratory disease and lung cancer in low- and middle-income countries where non improved biomass stoves are used [34]. In terms of potential adverse effects on health, natural gas, kerosene or electricity are clearly better than biomass fuels.

In conclusion, biomass fuels pose many health hazards unless they are used with an improved biomass stove. The replacement of charcoal or wood with briquettes is, however, unlikely to result in a considerable increased or reduction in exposure to toxic gases and particulate matter. If the briquettes are replacing other cooking fuels such as natural gas, kerosene or electricity, an increase in hazardous emissions would result. Hence, in urban areas, where more than 70% of the population is using other cooking fuel types than biomass, the marketing of briquettes could result in a negative health impact.

Of note, to promote or even market improved biomass stoves together with the briquettes might be an interesting addition to the BM that should be further explored.

Since the replacement of wood or charcoal does not make a considerable difference in terms of emissions, the health impact assessment for Model 1a only considers the potential negative impact of people replacing more safe cooking fuels (i.e. kerosene, gas or electricity) with briquettes.

Model 1a, impact 1, assumptions:

- **Impact level:** long term exposure to indoor air pollution may increase the incidence of ARI and result chronic diseases such as COPD and cancer
- **People affected:** the briquetting business would be of interest to 1% of the ~7 million population of Hanoi Municipality; 80% of the urban population is using kerosene, gas or electricity; and only 10% of those would actually switch to briquettes (7.0 million x 0.01 x 0.8 x 0.1 = 5,600 people)
- **Likelihood:** 1 in 10 people being exposed to biomass fuel fumes would develop some form of chronic respiratory diseases or cancer

Table 13 – Model 1a, impact 1: increase in chronic respiratory disease and cancer

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Major negative impact	Medium population group	Unlikely	**Moderate negative impact**
Score	-1	5,600	0.1	**-560**

Proposed mitigation measures for reducing the potential negative impact are:

- to market briquettes only in peri-urban and urban areas where many households are still using wood as cooking fuel;
- to educate consumers of biomass briquettes about the health risks associated with indoor smoke (e.g. hazard labels on briquette packaging); and
- to actively promote improved biomass stoves among buyers of biomass briquettes.

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 carbonization process and/or during use of briquettes, (2) accumulated waste resulting from separation of inorganic fractions from MSW prior to briquetting are disposed of or used improperly, and (3) process water, which accumulates during the carbonization process and during the compaction of uncarbonised input material, and when leaching into the environment can have a negative impact. Mitigation measures to avoid negative impacts include: (1.a) air emission control technologies, such as activated carbon and scrubbers, (1.b) proximate and ultimate analyses, prior to business model implementation for the characterization of the feedstock and the final briquettes, (2) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), and (3) post treatment of process water, which should be monitored for its physical and chemical properties to comply with local regulations prior to discharge into the environment. Further details on technology options are outlined in the “Technology Assessment Report” [2].

Table 14 – Model 1a: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW • AIW	• Briquettes	• Carbonized - low pressure • Raw - mechanized high pressure • Carbonized - mechanized	• Briquetting	• Hazardous air emissions • Accumulated inorganic waste • Process water	• Air emission control technologies (e.g. activated carbon, scrubbers) • Proximate and ultimate analyses • Post-treatment of process water

4.2 Model 2a – Energy service companies at scale: agro-waste to energy (electricity)

This business model aims at transforming animal manure and agro-waste into 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.

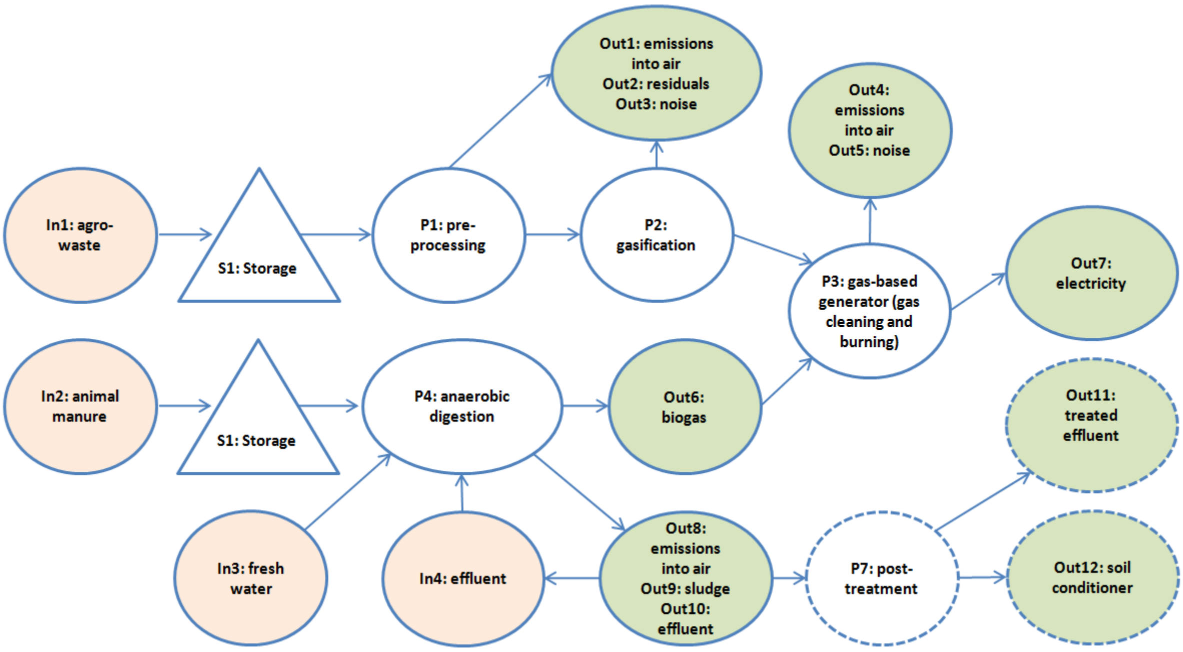

Figure 17 – Model 2a: system flow diagram

Table 15 – Model 2a: 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 16 – Model 2a: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1, Out4 and Out8: emissions into air	<u>Ambient air quality standards</u>[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out2: residuals	None since considered as waste
Out3 and Out5: noise	<u>Occupational noise exposure limits</u>[b]: • Equivalent level (8h):85 dB(A) • Maximum level (short duration): 140 dB(A) <u>Community noise exposure limits</u>[c]: • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)
Out6: biogas	N.a. (within system)
Out7: electricity	Intrinsically safe electrical installations and proper grounding
Out9: sludge	N.a. (within the system)

Out10: effluent	N.a. (within the system)
Out11: 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 ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see Annex IV)
Out12: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization
[b] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization
[c] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

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. Gasification and the operation of 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 gasification plant has to be controlled. There is considerable risk for injury to the body when operating the gasification plant 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 fumes of the gasification 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 (e.g. briquetting process; 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 gasification plant and/or gas-based 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 16). The actual distance is depending on the level of emissions
    - For removing the residuals in the gasification 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)
    - 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.)

For more details on the mitigation of environmental and health risks associated with gasification of biomass, guidelines for safe and eco-friendly biomass gasification that have been developed for the European Commission are available: www.gasification-guide.eu/

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: gasification and 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 gasification plant and the generator. 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 gasification 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 animal and/or crop waste may 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 2a is based on the assumption that 50 villages in peri-urban areas of Hanoi will implement the BM

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

In rural communities, where the BM would most likely be operating due to the availability of agro-waste, animal manure is currently used for agricultural purposes or disposed of into the environment. According to the waste supply and availability report, 19% of animal husbandry waste is discharged untreated into the environment [42]. Consequently, there is a risk that pathogens from animal manure end-up in surface waters, particularly at the start of the rainy season, which 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.

Impact 1, assumptions:

- **Impact level:** pathogens in animal manure generally cause disease of short duration and/or minor disability
- **People affected:** the operations would be based in 50 villages (average size ~300 people) where 1 in 10 individuals is exposed to pathogens from unused animal manure
- **Likelihood:** of those exposed, 1 in 2 would develop some form of clinical infection

Table 17 – Model 2a, 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	Medium population group	Possible	**Moderate positive impact**
Score	0.1	1’500	0.5	**75**

4.2.2.2 Impact 2: 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. The 2009 Vietnam population and housing census reported that 99.6% of urban households are connected to the electricity grid (see Table 5) [6]. Against this background, no health impacts linked to access to electricity are anticipated.

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 50 villages with an average of 300 individuals profits from the BM. Only 5% of the benefiting individuals are not connected to the electricity grid (50 x 300 x 0.05 = 750).
- **Likelihood:** It is possible that access to electricity impacts on the health of people

Table 18 – Model 2a, 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	Specific population	Definite	**Insignificant**
Score	0.0	750	1	**0**

4.2.3 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" [2].

Table 19 – Model 2a: 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

4.3 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.

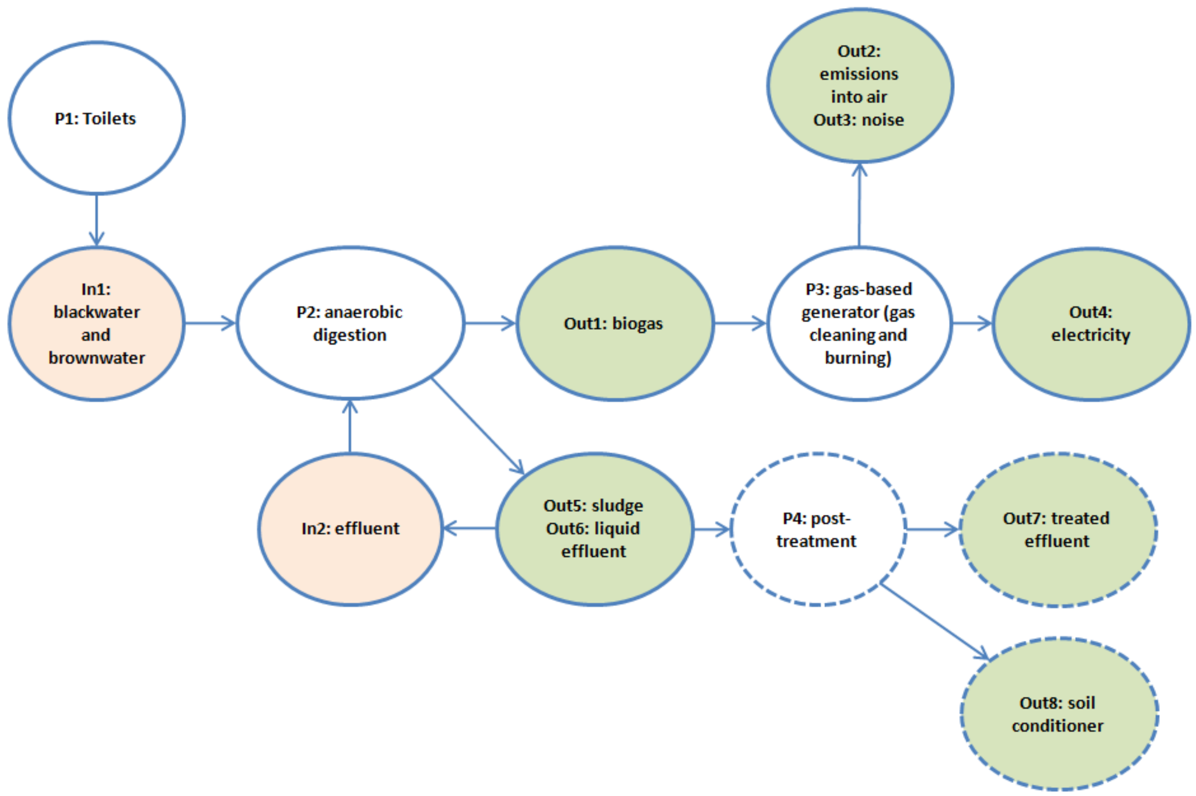

Figure 18 – Model 4: system flow diagram

Table 20 – 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 21 – Model 4: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: biogas	N.a. (within the system)
Out2: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m³ 24-hour mean; 25 µ/m³ annual mean • PM_{10}: 20 µ/m³ 24-hour mean; 50 µ/m³ annual mean • Ozone: 100 µ/m³ 8-hour mean • NO_2: 200 µ/m³ 1-hour mean; 40 µ/m³ annual mean • SO_2: 500 µ/m³ 10-minutes mean; 20 µ/m³ 24-hour mean
Out3: noise	Occupational noise exposure limits[b]: • Equivalent level (8h):85 dB(A) • Maximum level (short duration): 140 dB(A) Community noise exposure limits[c]: • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)
Out4: electricity	Intrinsically safe electrical installations and proper grounding
Out5: sludge	Considered as waste or within the system (in the case of post-treatment)
Out6: effluent	Considered as waste or within the system (in the case of post-treatment)
Out7: treated effluent (optional)	**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 ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see 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

	➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization
[b] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization
[c] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

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 disposal or post-treatment of the sludge and effluent 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 (e.g. agro-waste or animal manure) 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. 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 4.2.1.1)
- 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 30 villages in rural and peri-urban areas of Hanoi will implement the BM

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

According to the 2011 MICS, 93.8% of urban and 71.4% of rural households have improved sanitation facilities in Vietnam. In both urban and rural settings, the predominant improved sanitation systems (as defined by the Joint Monitoring Program) are septic tanks (81.1% and 38.6%, respectively). Other types of improved sanitation systems in use in rural areas are composting toilets and pit latrines with slab (see Table 22) [36].

Table 22 – Type of sanitation facilities used at household level in Vietnam, 2011 [38]

Percentage distribution of household population according to type of toilet facility used by the household, and the percentage of household population using improved sanitation facilities, Viet Nam, 2011

	Type of toilet facility used by household												Open defecation (no facility, bush, field)	Total	Percentage of population using improved sanitation facilities	Number of household members
	Improved sanitation facility							Unimproved sanitation facility								
	Flush/pour flush to:															
	Piped sewer system	Septic tank	Pit latrine	Unknown place/not sure/ DK where	Ventilated improved pit latrine	Pit latrine with slab	Compos-ting toilet	Flush/ pour flush to somewhere else	Pit latrine without slab/ open pit	Bucket	Hanging toilet/ hanging latrine	Other				
Region																
Red River Delta	3.1	65.4	3.4	0	0	8.5	17	0.3	1.3	0	0.1	0.6	0.3	100	97.4	9261
Northern Midland and Mountain areas	1.6	23.5	1.7	0.1	1.3	19.9	28.2	0.7	7.8	0.2	0.2	0.1	14.8	100	76.3	7242
North Central area and Central Coastal area	0.4	48.3	4.9	0	0.1	15.6	12.9	0.2	7.5	0	1	0	9	100	82.2	9443
Central Highlands	0.8	39.6	10.3	0	0.3	12.5	5	0.5	12	0	0.1	0.5	18.2	100	68.5	2551
South East	2.8	79.3	6.4	1.1	1.4	1.4	0.1	0.5	4.1	0	0.7	0.2	2	100	92.5	7066
Mekong River Delta	1.1	42.2	0.8	0	0	0	0	1.1	0	0.3	50.7	0.7	2.9	100	44.3	8434
Area																
Urban	3.9	81.1	3.1	0.4	0.7	2.4	2.1	0.6	1.1	0.1	3.2	0.1	1.1	100	93.8	13003
Rural	0.8	38.6	4.1	0.1	0.4	12.3	15.2	0.5	6	0.1	13	0.5	8.6	100	71.4	30995
Education of household head[§]																
None	1.1	26.7	2.5	0.3	0.4	7.1	9	0.6	8.1	0.4	16.4	0.7	26.9	100	47	2651
Primary	1	36.2	3.3	0.2	0.5	9.1	11.4	0.6	6.6	0	20.9	0.5	9.7	100	61.7	11331
Lower Secondary	1.3	49.6	4.1	0.1	0.5	12.1	15.3	0.5	4.1	0.1	7.3	0.3	4.7	100	82.9	17452
Upper Secondary	2.7	67.1	4.6	0.2	0.2	7.7	8	0.5	3.2	0.1	3.5	0.3	1.8	100	90.5	7222
Tertiary	3.7	79.5	3.8	0.5	0.7	3.9	3.8	0.5	1.4	0.1	1.5	0	0.6	100	95.9	5190
Wealth index quintile																
Poorest	0.6	2.6	1.4	0	0.7	16.2	20.5	0.2	14.5	0.2	19.8	0.5	22.9	100	42	8803
Second	0.6	18.4	6.3	0.1	0.4	18.7	21.5	0.7	5.3	0.2	20.8	0.8	6.2	100	66	8796
Middle	1.6	52.3	6.1	0.4	0.7	10.7	12.7	0.9	2.7	0.1	8.8	0.5	2.5	100	84.5	8798
Fourth	3	87.6	3.5	0.2	0.5	1.2	1.8	0.7	0.2	0	1.1	0	0.2	100	97.7	8797
Richest	2.7	94.9	1.8	0.3	0.1	0	0	0.1	0	0	0	0.1	0	100	99.9	8803
Ethnicity of household head																
Kinh/Hoa	1.8	56.7	4	0.2	0.3	8.7	10.5	0.5	2.9	0.1	10.5	0.4	3.4	100	82.2	38675
Ethnic Minorities	1.1	10.9	2.5	0.1	1.7	14.3	17.4	0.8	16.1	0.2	6.9	0.3	27.7	100	48	5323
Total	1.7	51.2	3.8	0.2	0.5	9.4	11.3	0.5	4.5	0.1	10.1	0.4	6.4	100	78	43998

Unsafe sanitation practices are closely associated with diarrhoeal diseases and helminth infections, as well as acute respiratory infections. In a recent meta-analysis by Ziegelbauer and colleagues (2012), it was found that the availability of sanitation facilities was associated with a 50% protection against infection with soil-transmitted helminths [43]. Also the link between safe sanitation systems and reduction in diarrhoeal diseases is well established

[44]. However, the fact that the large majority of urban households already have access to improved on onsite sanitation technologies or is connected to the piped sewer system, reduces the potential of this BM to reduce the burden of diarrhoeal diseases and infection with soil-transmitted helminths in Hanoi.

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 30 villages rural and peri-urban villages (average size ~300 people) where 1 in 5 households do not have access to an onsite sanitation system (30x300x0.20=1,800 people)
- **Likelihood:** it is possible that the business positively impacts on diarrhoeal diseases and helminth infections, particularly in communities with a lot of farming activities

Table 23 – 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	Medium population group	Unlikely	**Moderate positive impact**
Score	0.1	1,800	0.5	**90**

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

- to target communities with particularly low access to sanitation for the implementation of the business;
- to keep the fee for the usage of the toilets at a minimum;
- to provide free access to the toilet facilities to children; 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 2a, impact 1 (section 4.2.2.2).

Impact 2, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 30 villages with an average of 300 individuals profit from the BM. Only 5% of the benefiting individuals are not connected to the electricity grid (30 x 300 x 0.05 = 450).
- **Likelihood:** It is possible that access to electricity impacts on the health of people

Table 24 – 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	Large population	Definite	**Insignificant**
Score	0.0	450	1	**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" [2].

Table 25 – 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 6 – Manure to power

The business model aims at transforming manure to power for carbon credit and sustainable value chain or rural electrification. The model can be initiated either by (i) livestock processing factories such as meat or diary processing factories; (ii) small, medium and commercial-sized livestock farms to utilize livestock waste to produce off-grid power for rural electrification; or (iii) individual livestock farms to achieve a self-sustaining system. The quality of the soil conditioner, and resulting reuse options, depend 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 (digestate) and liquid effluent of the anaerobic digestion are disposed of, 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.

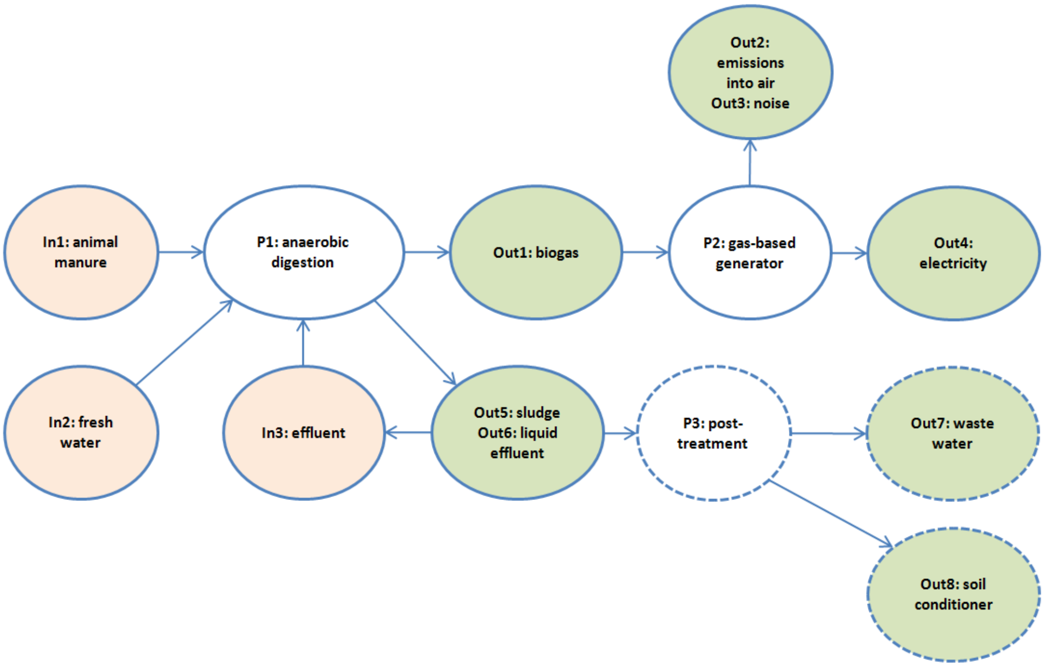

Figure 19 – Model 6: system flow diagram

Table 26 – Model 6: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: animal manure	Pathogens
	Contamination with MSW (inorganic; sharp objects)
In2: fresh water	None
In3: effluent	Pathogens

Table 27 – Model 6: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: biogas	N.a. (within the system)
Out2: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out3: noise	Occupational noise exposure limits[b]: • Equivalent level (8h):85 dB(A) • Maximum level (short duration): 140 dB(A) Community noise exposure limits[c]: • Day time equivalent level: 55 dB(A) • Night time equivalent level: 45 dB(A)
Out4: electricity	Intrinsically safe electrical installations and proper grounding

Out5: liquid effluent	N.a. (within the system)
Out6: sludge	N.a. (within the system)
Out7: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and $<10^3$ E. coli per gram total solids ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV
Out8: 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 ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see Annex IV)

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

[b] WHO (1995). Occupational exposure to noise: evaluation, prevention and control. Geneva: World Health Organization

[c] WHO (1999). Guideline values for community noise in specific environments. Geneva: World Health Organization

Pathogens contained in the animal manure are the primary health hazard associated with BM 6. 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 post-treatment of the sludge (digestate) and liquid effluent is required. If for some reason this is not feasible, only then should disposal of solids (treated digestate) at sanitary landfills be considered.

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

4.4.1.1 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 (i.e. animal manure) 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
    - 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. 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 4.2.1.1)
- 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 of the soil conditioner, indicating 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.)

4.4.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 6 can be reduced to **low, moderate and high levels**. The residual moderate risks are linked to the following processes:

- P2: 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

4.4.2 Health impact assessment

The production of power by using 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 6 is based on the assumption that 10 villages in rural and peri-urban areas of Hanoi will implement the BM

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

➔ For the impact definition, see Model 2a, impact 1 (section 4.2.2.1).

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 ~300 people) where 1 in 10 people is exposed to pathogens deriving from animal manure (10x300x0.1=300 people)
- **Likelihood:** it is likely possible that the business reduces the incidence of diarrhoeal diseases and helminth infections, particularly in communities with a lot of farming actitivies

Table 28 – Model 6, 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	Small population group	Likely	**Moderate positive impact**
Score	0.1	300	0.9	**27**

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

➔ For the impact definition, see Model 2a, impact 2 (section 4.2.2.2).

Impact 2, 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 possible that access to electricity impacts on the health of people

Table 29 – Model 6, 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	Large population	Definite	**Insignificant**
Score	0.0	3,000	1	**0**

Impact 2, 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 profit from the BM. Only 5% of the benefiting individuals are not connected to the electricity grid (10 x 300 x 0.05 = 150).
- **Likelihood:** It is possible that access to electricity impacts on the health of people

4.4.3 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) hazardous air emissions, such as volatile organic compounds, carbon monoxide, polycyclic aromatic hydrocarbons, methane and nitrous oxide, which the conversion of biogas into electricity, (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, which when disposed of or used improperly can have a negative impact due to high nutrient and organic matter concentrations. Proposed mitigation measures include: (1) regular maintenance of the anaerobic digester to prevent leakages, (2) air emission control technologies, such as activated carbon and scrubbers during the process of converting biogas into electricity, 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 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” [2].

Table 30 – Model 6: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• AM	• Biogas -> Electricity	• Single stage • Multi-stage • Batch • Biogas conversion technologies	• Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Solid residue (digestate) • Liquid effluent	• Maintenance of anaerobic digester • Air emission control technologies • Solid/liquid residue post-treatment

4.5 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.

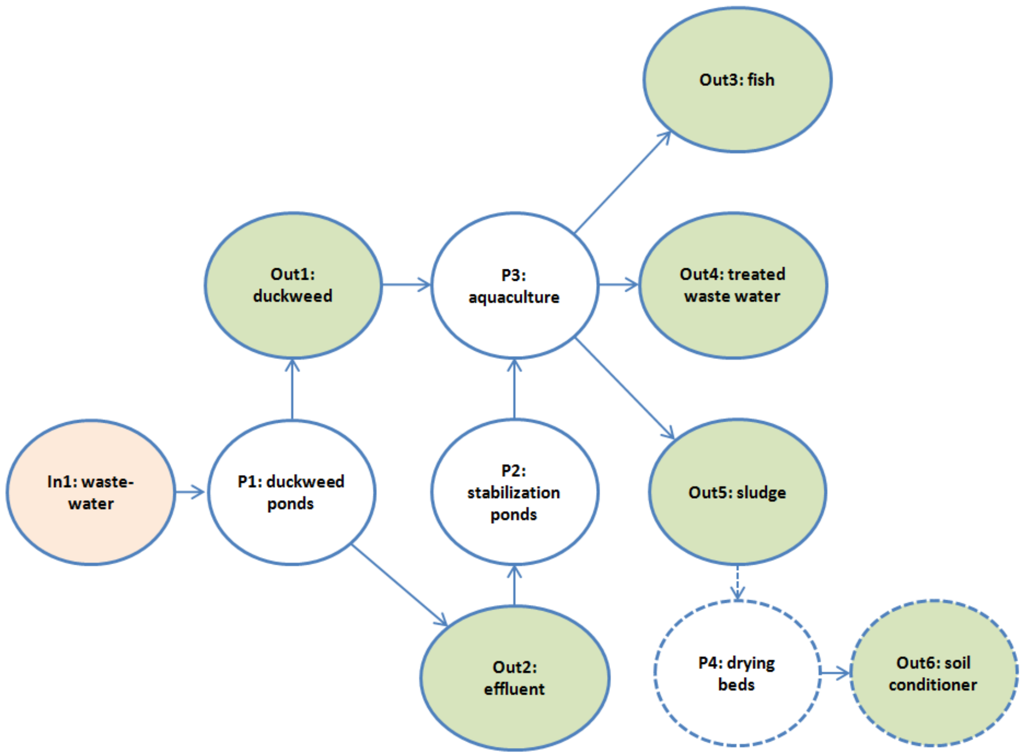

Figure 20 – Model 8: system flow diagram

Table 31 – 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 32 – Model 8: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: duck week	N.a. (within system)
Out2: effluent	N.a. (within system)
Out3: fish	➔ See national technical regulation on the limits of heavy metals contamination in food (QCVN 8-2:2011/BYT), provided in Annex IV
Out4: 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
Out5: wastewater sludge	N.a. (within system)
Out6: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and $<10^3$ E. coli per gram total solid ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

4.5.1 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 data presented in section 3.2.1 show that pollution with toxic chemicals) deriving from industrial and other sources are an important concern of many surface water bodies in Hanoi. This is clearly linked to the currently relatively small wastewater treatment capacity of the city. 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.

The study on the concentration of heavy metals in soil and vegetables in agricultural areas along the To Lich and Kim Nguu Rivers of Hano by Nguyen and colleagues (2010) shows that the concentration of heavy metals in soils and vegetables are close or even exceed WHO 2006 Guidelines and national standards (e.g. lead: WHO threshold: 84 mg kg^{-1}; versus average concentration found: 131 mg kg^{-1}). **These findings suggest that, from a health perspective, wastewater fed agriculture in Hanoi 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.**

This does, however, not exclude that there are sites where the concentration of toxic chemicals in wastewater and receiving agricultural soils are at acceptable levels in Hanoi. For identifying those, environmental analyses at the specific potential sites would be needed. 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. This is also crucial in order to mitigate the risk of contamination of fish with trematode eggs, which are an important concern in Hanoi as described in section 3.1.1.4.

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
    - 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
  - 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.)

4.5.1.2 Residual risks

By implementing all the proposed control measures, all the identified health risks of Model 8 are still at **moderate to very high 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 Hanoi.
- 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

4.5.2 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. 3 x 50,000 consumers). In view of the size of the operation, the general downstream population is not considered for the impact assessment since no effect is anticipated

4.5.2.1 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 Hanoi. 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 33 – Model 8, impact 1: reduction in respiratory, diarrhoeal, intestinal and skin diseases

	Impact level	People affected	Likelihood or	Magnitude

	(IL)	(PA)	**frequency** (LoF)	(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**

4.5.3 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, and (2) solid residue (accumulated sludge from wastewater (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" [2].

Table 34 – 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

4.6 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. 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.

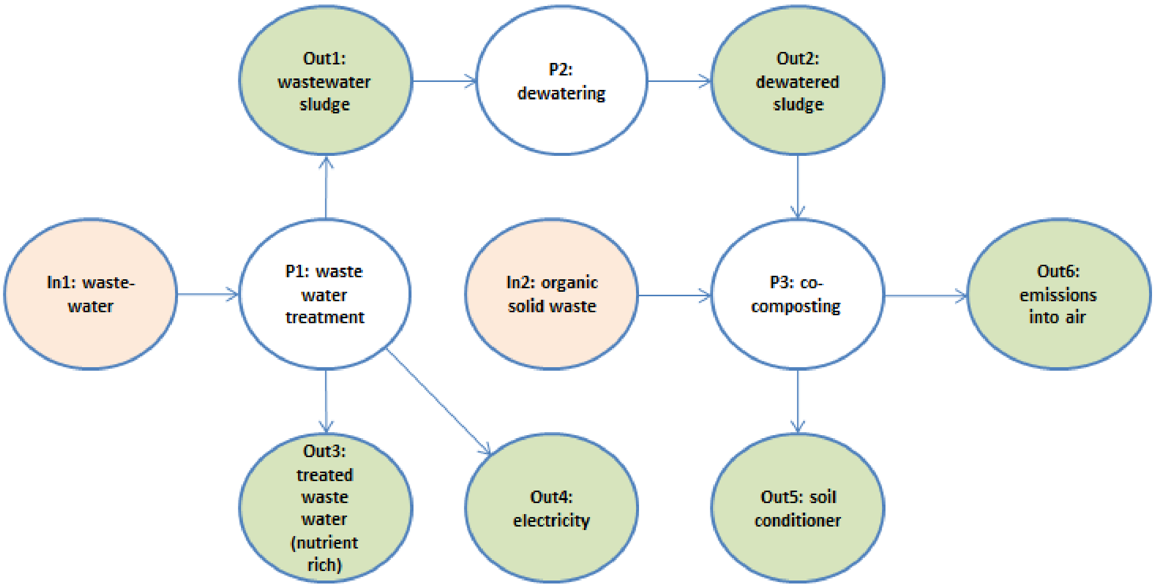

Figure 21 – Model 9: system flow diagram

Table 35 – 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 36 – 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	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 E. coli per gram total solids ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV
Out6: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.6.1 Health risk assessment

Risks associated with the business derive from the various potential hazards contained in wastewater as outlined in section 4.5.1. 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 technically not feasible, which will result in heavy metals being present in the liquid effluent and/or in accumulated wastewater sludge. Therefore, it is important that heavy metal concentrations are compliant with the National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT [45].

Overall, for determining whether, and if so which kind of physico-chemical treatment processes are needed in order to assure sufficient quality of the effluents of the proposed business, further environmental sampling will be required at the site where the business will be implemented.

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%
    - The sludge of the treatment plant should be compliant with the heavy metal thresholds defined by national and international standards (Annex IV). Otherwise the sludge must not be further processed for producing fertilizer
    - 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. 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.)

4.6.1.2 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 wehere 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 Hanoi.
- P1: wastewater treatment plant and P2: dewatering: there is moderate risk for disease vector breeding in ponds of the treatment plant and the drying beds. Therefore, special attention is needed for implementing vector control.
- 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

4.6.2 Health impact assessment

The health benefits of a modern wastewater treatment plant in an environment like Hanoi primarily relate to down-stream issues like reduced exposure to pathogens and potentially also toxic chemicals. Model 9 specifically aims at producing safe irrigation water. Therefore, farmers might be the primary beneficiaries from the business.

- **Scale of the BM:** the impact assessment of Model 9 is assuming a wastewater treatment plant with 500 farmers and 10,000 community members being exposed to the treated wastewater

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

As per our in-depth study in Thanh Tri district, prevalence rates of STH in farmers practicing irrigation with wastewater are at medium levels (e.g. hookworm: 15.5% in farmers and 3.9% in communities near wastewater channels (see section 3.1.1.2)). In addition, there is a high burden of gastrointestinal disease in the population of Hanoi and also skin and respiratory diseases are important public health concerns, particularly in people exposed to untreated wastewater. Hence, unsafe irrigation practices do negatively impact on the health of community members, be it through direct contact, ingestion or the consumption of contaminated products. Consequently, the business has considerable potential to reduce the burden of diarrhoeal diseases, ARI and helminth infections in exposed population groups since it aims at transforming untreated wastewater into treated wastewater, soil conditioner and electricity.

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would affect 500 farmers and 10,000 community members
- **Likelihood:** farmers are likely and for community members it is possible that they will experience a reduction in wastewater-related disease episodes

Table 37 – 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 group	Likely Possible	**Moderate positive impact**
Score: farmers	0.1	500	0.9	45
Score: community	0.1	10'000	0.5	500
			TOTAL	**545**

4.6.2.2 *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. Therefore, the impact assessment applies a simplified approach: under the assumption that the business model will operate in settings with acceptable concentrations of toxic chemicals, will eliminate these to acceptable levels, a minor positive health effect is anticipated at individual level.

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:** the business would affect 500 farmers and 10,000 community members
- **Likelihood:** it is possible that farmers will have an improvement of their health status due to reduce exposure to toxic chemicals but unlikely that community members will experience any difference

Table 38 – 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 group	Possible Unlikely	**Moderate positive impact**
Score: farmers	0.1	500	0.5	25
Score: community	0.1	10,000	0.3	300
			TOTAL	**325**

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

➔ For the impact definition, see Model 2a, impact 2 (section 4.2.2.2).

Impact 1, assumptions:

- **Impact level:** minor positive and negative health impacts anticipated. Therefore, the impact level is insignificant
- **People affected:** 5'000 people will get access to electricity
- **Likelihood:** It is possible that access to electricity impacts on the health of people

Table 39 – Model 9, impact 3: changes in health status due to access to electricity access

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Insignificant	Large population	Possible	**Insignificant**
Score	0.0	5'000	1	**0**

4.6.3 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" [2].

Table 40 – 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

4.7 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 faecal sludge from the city for producing organic fertilizer. The business would be implemented in urban Hanoi linked to the increased availability of MSW.

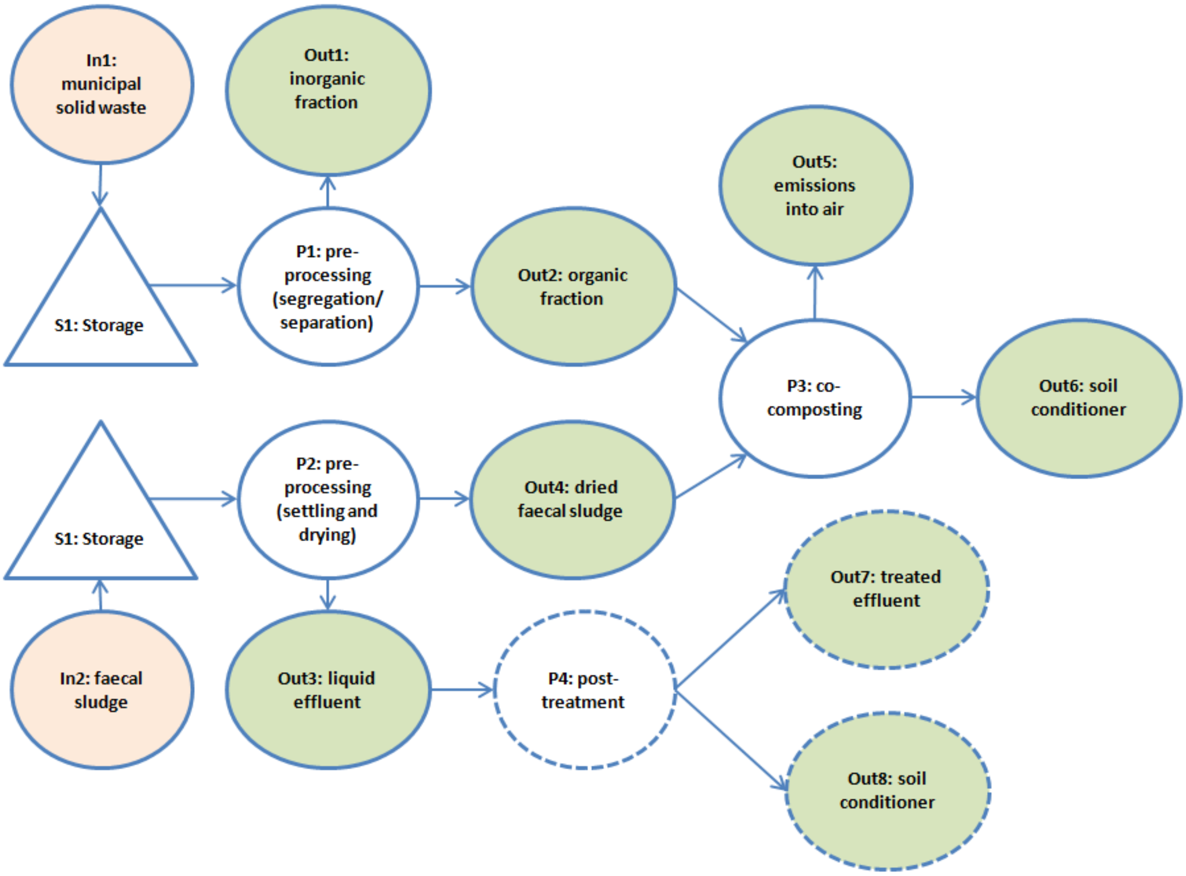

Figure 22 – Model 15: system flow diagram

Table 41 – 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 42 – 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]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean

	• SO_2: 500 µ/m³ 10-minutes mean; 20 µ/m³ 24-hour 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 ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see 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 ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

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 off 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 effluent of the faecal sludge, off-site and on-site post-treatment options are available (see section 4.2.1.1)
  - 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. 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. Hence, exposure to faecal pathogens may be reduced at community level. Moreover, the business could indirectly impact people who are currently exposed to landfills (waste pickers or surrounding communities), since it will reduce the load of MSW ending up on landfills.

- **Scale of the BM:** the impact assessment of Model 15 is assuming that two centralised co-composting plants are installed in Hanoi, 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. Model 15 is more suitable for an urban environment with high density in MSW. The faecal sludge input for the business would be collected from onsite sanitation systems. According to the waste supply analysis [42], emptying of onsite sanitation systems (i.e. septic tanks) is primarily done by private emptying service companies. While URENCO has permission to discharge faecal sludge at the Cau Dien composting facility, there is, however, absolutely no legal discharge location for private companies within all of Hanoi. This results in discharge directly into the urban environment, in open channels, lakes and rivers. Other than that, some small quantities of untreated FS are sold to farmers for direct application as a soil amendment and for use in fish ponds. Hence, the business has the potential to considerably reduce the amount of faecal sludge that is disposed of into the environment in Hanoi. This, in turn, will result in a reduction in the incidence of diarrhoeal diseases, ARI and helminth infections due to reduced exposure to faecally contaminated soil and wastewater. Positive health impacts will primarily occur at the level of farmers who practice wastewater fed agriculture and in a second instance at consumer level. In consideration of the scale of the business and the total amount of wastewater in Hanoi, the likelihood of a positive health impacts linked to the business is small.

Impact 1, assumptions:

- **Impact level:** pathogens in human faeces generally cause disease of short duration and/or minor disability
- **People affected:** the business would serve 2 x 2,000 people, which is the volume that serves approximately 50 farmers annually, who produce food crops for 15,000 consumers.
- **Likelihood:** it is very unlikely that the business will make a difference in disease incidence

Table 43 – Model 15, 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	Specific population group	Very unlikely	**Moderate positive impact**
Score: farmers	0.1	500	0.3	**15**
Score: consumers	0.1	15,000	0.05	**75**
			TOTAL	**90**

4.7.2.2 Impact 2: health benefits due to reduced MSW loads on landfills

In Hanoi, landfills are associated with a range of negative health impacts ranging from the poor working conditions of the waste pickers to downstream issues such as contamination of surface waters. Hence, a reduction of the load of waste that arrives on landfills has the potential to have an indirect positive impact on health.

According to the waste supply and availability analysis, the per capita production of MSW is approximately 1 kg [42]. This results in approximately 35 tonners per day that are generated by 10,000 households, which is less than 1% of the daily volume of MSW collected in Hanoi per day. Consequently, the business is very unlikely to make a considerable difference at the level of existing landfills.

Impact 2, assumptions:

- **Impact level:** various pathologies are associated with landfills
- **People affected:** an estimated 500 waste pickers work on the landfills that would be affected by the business
- **Likelihood:** it is very unlikely that the business will make a difference in disease incidence

Table 44 – Model 15, impact 2: health benefits due to reduced MSW loads on landfills

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Specific population group	Very unlikely	**Minor positive impact**
Score: farmers	0.5	500	0.05	**12.5**

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" [2].

Table 45 – 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 16 – Subsidy-free community based composting

In this business model, the implementing business utilizes household and market waste as well as animal waste to produce soil conditioner for direct sale to small-scale farmers through trust and personal links. The business is a decentralized operation and soil may be fortified.

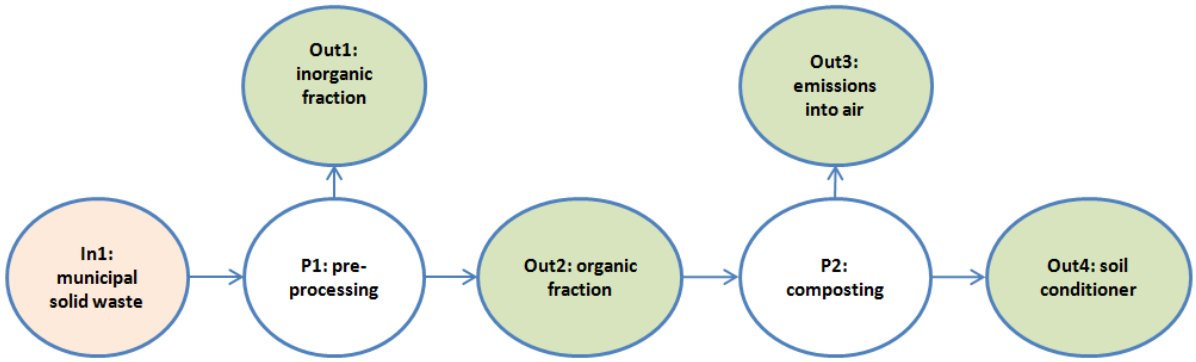

Figure 23 – Model 16: system flow diagram

Table 46 – Model 16: 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

Table 47 – Model 16: 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: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out4 soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids • See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.8.1 Health risk assessment

Health risks of this business are associated with the potential input of MSW, which is commonly 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. Moreover, the operation of a composting plant involves emissions into the air such as malodours, thermophilic fungi and dust.

4.8.1.1 Indicated control measures

- Protective equipment
  - Workers handling any raw material (e.g. MSW, market waste, organic waste) 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 composting
  - Moisture of 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. 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.)

4.8.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 16 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: 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 composting
- P2: 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
- P2: 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**

4.8.2 Health impact assessment

By reducing the load of MSW ending up on landfills, the business will indirectly impact people who are currently exposed to landfills (waste pickers or surrounding communities).

- **Scale of the BM:** the model ranks high on scalability as it can be implemented anywhere in communities having cooperatives visions. Hence, the HIA of Model 16 is assuming that a waste volume of 10,000 households will be collected by the business

4.8.2.1 Impact 1: health benefits due to reduced MSW loads on landfills

➔ For the impact definition, see Model 15, impact 2 (section 4.7.2.2).

Impact 1, assumptions:

- **Impact level:** various pathologies are associated with landfills
- **People affected:** an estimated 500 waste pickers work on the landfills that would be affected by the business
- **Likelihood:** it is very unlikely that the business will make a difference in disease incidence

Table 48 – Model 16, impact 1: health benefits due to reduced MSW loads on landfills

	Impact level (IL)	**People affected** (PA)	**Likelihood or frequency** (LoF)	**Magnitude** (ILxPAxL)
Category	Minor positive impact	Specific population group	Very unlikely	**Minor positive impact**

Score: farmers	0.5	500	0.05	**12.5**

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, and (2) leachate from the composting process, which if moisture is not well controlled can leach into the environment.. Mitigation measures to avoid negative impacts include: (1) storage, transport and disposal at a designated recycling facility or solid waste discharge site (sanitary landfill), and (2) appropriate moisture control of the compost heap and/or collection of leachate and post-treatment. Further details on technology options are outlined in the "Technology Assessment Report" [2].

Table 49 – Model 16: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• MSW	• Soil Conditioner	• Windrow (static/turned) • In-Vessel • Inclined step grades • Vermi-composting	• Compo-sting	• Accumulated inorganic waste • Leachate from composting	• Storage/transport/ disposal (sanitary landfill) • Moisture control • Leachate treatment

4.9 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.

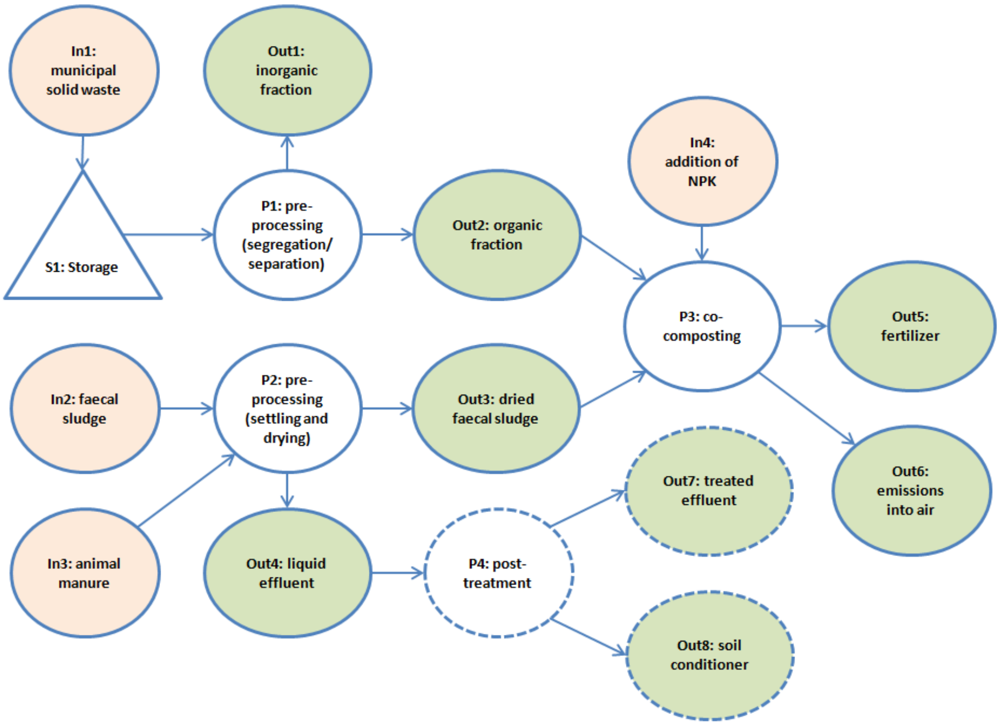

Figure 24 – Model 17: system flow diagram

Table 50 – 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

Table 51 – Model 17: 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: dried faecal sludge	N.a. (within the system)
Out4: liquid effluent	N.a. (within the system)
Out5: dried sludge	N.a. (within the system)
Out5: fertilizer	For agricultural use: • <1 helminth egg per 1 gram total solids; and <10^3 *E. coli* per gram total solids • See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

Out6: emissions into air	<u>Ambient air quality standards[a]:</u> • $PM_{2.5}$: 10 µ/m³ 24-hour mean; 25 µ/m³ annual mean • PM_{10}: 20 µ/m³ 24-hour mean; 50 µ/m³ annual mean • Ozone: 100 µ/m³ 8-hour mean • NO_2: 200 µ/m³ 1-hour mean; 40 µ/m³ annual mean • SO_2: 500 µ/m³ 10-minutes mean; 20 µ/m³ 24-hour mean
Out7: treated effluent	**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 ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see Annex IV)
Out8: soil conditioner	<u>For agricultural use:</u> • <1 helminth egg per 1 gram total solids; and $<10^3$ *E. coli* per gram total solids

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.9.1 Health risk assessment

➔ Same as for Model 15 (section 4.9.1)

4.9.2 Health impact assessment

➔ Same as for Model 15 (section 4.9.2)

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, (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" [2].

Table 52 – 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

4.10 Model 18 – Urine and struvite use at scale

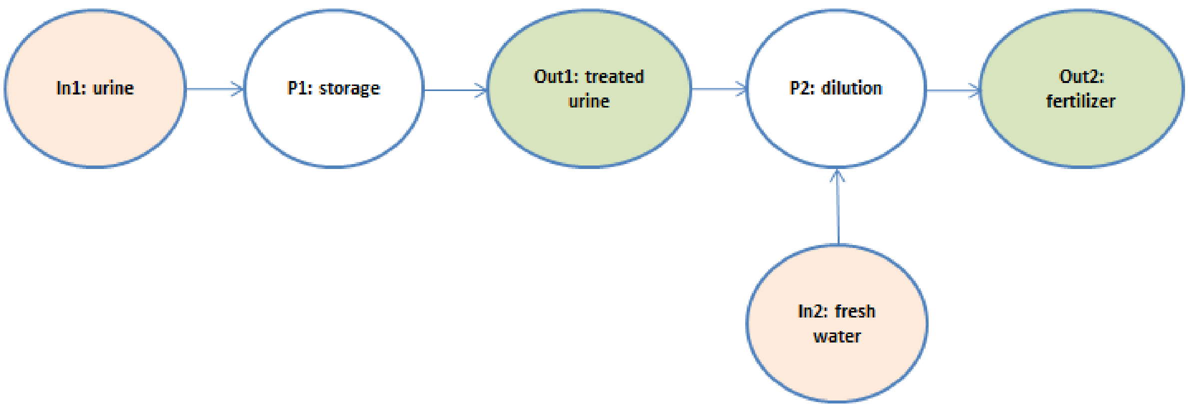

Figure 25 – Model 18: system flow diagram

Table 53 – Model 19: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: urine	Pathogens
In2: fresh water	None

Table 54 – Model 19: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: treated urine	N.a. (within the system)
Out2: fertilizer	Extremely low pathogen loads (viruses and protozoa of major concern) ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

4.10.1 Health risk assessment

Health risks of this business are primarily associated with pathogens that may be contained in urine. However, over all Model 19 is at low risk from an occupational and community perspective.

4.10.1.1 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. urine) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Avoid any contamination of the urine with faecal matter
  - Discharge urine that is contaminated with faecal matter or other solid or liquid waste components
  - The following storage times and temperatures are indicated depending on the use of the urine-based fertilizer:
    - Unrestricted, i.e. all crops: ≥6 month at ≥20°C
    - Food and fodder crops that are to be processed: ≥1 month at ≥4°C
    - Food crops that are to be processed, fodder crops (not grass lands): ≥6 month at ≥4°C
    - Food crops that are to be processed, fodder crops (not grass lands): ≥1 month at ≥20°C
- Behavioural aspects and prevention applying to unrestricted use of the urine-based fertilizer:
  - Farmers applying urine-based fertilizer should be advised to wear boots and gloves. In addition, the urine-based fertilizer should be applied close to the ground or worked into the soil
  - The application of the urine-based fertilizer should be halted one month before harvesting
  - 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.)

4.10.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 19 can be reduced to **low and moderate levels**. The residual risks are linked to the following processes:

- P1: storage of urine: in order to avoid exposure of consumers to pathogens bound in urine, it will be crucial to respect the temperature and duration indicated for the storage of the urine depending on the use of the urine-based fertilizer

4.10.2 Health impact assessment

No health impacts at community or consumer level are anticipated for Model 18.

4.10.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) "burning" of crops due to ammonia concentrations above the maximum limit for respective crops, and (2) application of nitrogen above soil and crop needs, resulting in ammonia being oxidised to nitrate, leaching through soil and ending up in ground and/or surface waters. Mitigation measures to avoid negative impacts include: (1) and (2) urine dilution with water to ensure that the ammonia concentration for the respective crop is appropriate for plants and soil conditions. Further details on technology options are outlined in the "Technology Assessment Report" [2].

Table 55 – Model 18: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• Urine	• Diluted urine	• UDDTs	• Urine collection and storage	• Ammonia intoxication • Ammonia oxidization	• Urine dilution with water

4.11 Model 19 – Compost production for sanitation service delivery

The business model on compost production for sanitation service delivery builds on separating human excreta into liquid and solid portions at source, no water for flushing the toilet, and simple nutrient recovery methods to secure a pathogen free product for sale in the market. The model can be replicated and scaled up and out in communities with no access to toilets and also for public toilets.

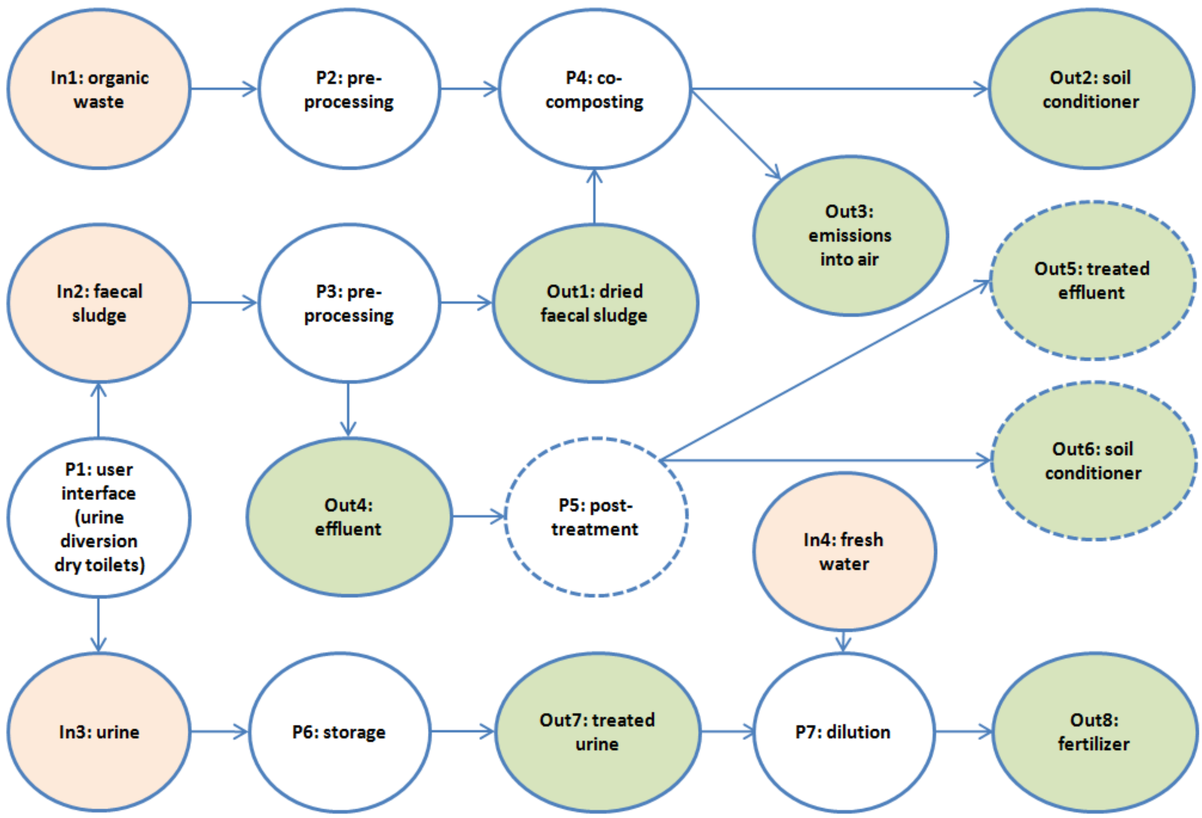

Figure 26 – Model 19: system flow diagram

Table 56 – Model 19: Inputs and associated potential health hazards

Inputs of health relevance	Potential hazards
In1: organic 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: urine	Pathogens
In4: fresh water	None

Table 57 – Model 19: Quality/safety requirements for outputs

Outputs of health relevance	Quality/safety requirements
Out1: dried faecal sludge	N.a. (within the system)
Out2 and Out6: soil conditioner	For agricultural use: • <1 helminth egg per 1 gram total solids; and $<10^3$ E. coli per gram total solids
Out3: emissions into air	Ambient air quality standards[a]: • $PM_{2.5}$: 10 µ/m^3 24-hour mean; 25 µ/m^3 annual mean • PM_{10}: 20 µ/m^3 24-hour mean; 50 µ/m^3 annual mean • Ozone: 100 µ/m^3 8-hour mean • NO_2: 200 µ/m^3 1-hour mean; 40 µ/m^3 annual mean • SO_2: 500 µ/m^3 10-minutes mean; 20 µ/m^3 24-hour mean
Out4: liquid effluent	N.a. (within the system)

Out5: 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 ➔ Chemical indicators in treated wastewater and receiving soils must not exceed thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see Annex IV)
Out7: treated urine	N.a. (within the system)
Out8: fertilizer	Extremely low pathogen loads (viruses and protozoa of major concern) ➔ See National Decree on the Quality of Soil Conditioner and Fertilizer: 41/2014/TT-BNNPTNT, provided in Annex IV

[a] WHO (2005). Air quality guidelines - global update 2005. Geneva: World Health Organization

4.11.1 Health risk assessment

Health risks of this business are primarily associated with the processing of faecal sludge. Pathogens and contamination with organic waste such as sharp objects are of major concern. Pathogens contained in urine are also of concern, to a relatively minor extent though. Also organic waste input may be contaminated with inorganic waste components. 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 effluents are disposed off or reused 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 reuse scenario.

4.11.1.1 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. faecal matter, urine or organic waste) need to wear appropriate PPE and use tools (e.g. shovels)
- Processes
  - Quality check of organic waste for 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 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%
  - 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
  - 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
  - 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
  - Install facilities where the soil conditioner can be sieved carefully for removing any sharp objects
  - 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
  - Depending on the further use of the effluent of the faecal sludge, off-site and on-site post-treatment options are available (see section 4.2.1.1)
- Behavioural aspects and prevention
  - In case the safety of the product cannot be assured, 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 soil conditioner and urine
  - 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.)

4.11.1.2 Residual risks

By implementing all the proposed control measures, the identified health risks of Model 19 can be reduced to **low and moderate levels**. The residual risks are linked to the following processes:

- P1: user interface: 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 sharp objects or other inorganic waste to be disposed of in the toilets (i.e. clearly visible signs, provide trash bins)
- P3: settling and drying, and P4: 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
- P4: 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
- P4: co-composting and P5: 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.
- P6: storage of urine: in order to avoid exposure of consumers to pathogens bound in urine, it will be crucial to respect the temperature and duration indicated for the storage of the urine depending on the use of the urine-based fertilizer

4.11.2 Health impact assessment

The provision of sanitation services to underserved communities is likely to reduce incidence of diarrhoeal diseases, ARI and helminth infections.

- **Scale of the BM:** the impact assessment of Model 19 is based on the assumption that 30 villages in rural and peri-urban areas of Hanoi will implement the BM

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

➔ For the impact definition, see Model 4, impact 1 (section 4.3.2.1).

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 30 villages rural and peri-urban villages (average size ~300 people) where 1 in 5 households does not have access to an onsite sanitation system (30x300x0.20=1,800 people)

- **Likelihood:** it is possible that the business positively impacts on diarrhoeal diseases and helminth infections, particularly in communities with a lot of farming activities

Table 58 – Model 19, 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	Medium population group	Possible	**Moderate positive impact**
Score	0.1	1’800	0.5	**90**

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

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

4.11.3 Environmental Impact Assessment

Potential negative environmental impacts include: (1) “burning” of crops due to ammonia concentrations above the maximum limit for respective crops, (2) application of nitrogen above soil and crop needs, resulting in ammonia being oxidised to nitrate, leaching through soil and ending up in ground and/or surface waters (3) insufficient pathogen inactivation, which may occur when temperatures are not well control over a sufficient period of time, and (4) leachate from the composting process, which if moisture is not well controlled can leach into the environment. Mitigation measures to avoid negative impacts include: (1) and (2) urine dilution with water to ensure that the ammonia concentration for the respective crop is appropriate for plants and soil conditions, (3) appropriate moisture control of the compost heap and/or collection of leachate and post treatment, and (4) temperature control of the compost heap to ensure sufficient pathogen inactivation. Further details on technology options are outlined in the “Technology Assessment Report” [2].

Table 59 – Model 19: potential environmental hazards and proposed mitigation measures

Waste stream	End-product	Technologies	Process	Pot. Env. Hazard	Mitigation measures
• Urine • Feces	• Stored urine • Soil conditioner	• UDDTs • Co-composting	• Urine application • Co-com-posting	• Ammonia intoxication • Ammonia oxidization • Insufficient pathogen inactivation • Leachate from co- composting	• Urine dilution with water • Moisture control • Leachate treatment • Temperature control (compost heap)

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6 Appendices

6.1 Appendix I – Health risk assessment tables

6.1.1 Model 1a – Dry fuel manufacturing: agro-waste to briquettes

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 P1: pre-processing (handling and separation) P2: drying	Biological hazards	Pathogens	Agro-waste is contaminated with faeces or urine	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
					Separation and discharge of any faecally contaminated agro-waste	2	3	Moderate			
				Inhalation	PPE	3	2	High			
		Rodents and insect vectors	Rodents or insect vectors are attracted by agro-waste and are thus a risk for diseases transmission	Hand to mouth, vectors living on rodents	Rodent and vector control at storage sites	3	2	Moderate	2	2	**Low risk (4)**
					Use of tools	2	3	Moderate			
	Chemical hazards	Toxic gases	**At consumer level:** burning of inorganic contaminants bound in briquettes at household level	Inhalation	Separation and discharge of any inorganic contaminants	2	3	Moderate	4	1	**Low risk (4)**
	Physical hazards	Sharp objects	Skin cuts when handling agro-waste	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
P3: Carbonization	Chemical hazards	Toxic gases	Inhalation of toxic gases at workplace and community	Inhalation	PPE (gas mask respirators)	3	2	Moderate	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
			level		Install CO monitors around the plant	2	2	Moderate			
					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			
	Physical hazards	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			
P4: Briquetting P5: Drying and packaging	Physical hazards	Dust	Long time exposure to dust	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	2	Moderate	8	1	**Moderate risk (8)**
					PPE	3	3	High			
		Noise	Noise in exceed of OH limits	Air	PPE	3	2	Moderate	2	2	**Low risk (4)**
			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	Moderate	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
Generalities	Physical hazard	Radiation	Long-time exposure of workers to direct sunlight	Environmental	Protect workers from long-term exposure to sun light	2	2	Moderate	4	2	**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 measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards etc.)	2	2	Moderate	4	3	**Moderate risk (12)**
	Various	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	e.g. rotating parts	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	4	1	**Low risk (4)**
	Physical hazard	Ergonomic hazards	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	Moderate	4	2	**Moderate risk (8)**

6.1.2 Model 2a – Energy service companies at scale: agro-waste 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
P1: pre-processing (handling and separation)	Biological hazards	Pathogens	Agro-waste is contaminated with faeces or urine	Hand to mouth; inhalation	PPE	3	3	High	4	1	**Low risk (4)**
					Use of tools	3	3	High			
	Physical hazards	Sharp objects	Skin cuts when handling agro-waste	Skin contact	PPE	3	3	High	4	1	**Low risk (4)**
S1: storage	Biological hazards	Rodents → disease transmission	Rodents attracted by agro-waste	Hand to mouth, vectors living on rodents	Use of tools	2	3	Moderate	2	2	**Low risk (4)**
		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)**
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	3	2	Medium	2	4	**Moderate risk (8)**
			Exposure of community to malodours		Assure good ventilation	2	3	Medium	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	Medium	4	3	**Moderate risk (12)**
P2: gasification P3: 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 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			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					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			
		Injuries	Accidents while operating technical processes	Injury to the body	Education of workers handling technical processes	2	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
					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)**
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		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)**
P5: 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	Radiation	Long-time exposure of	Environm	Protect workers from long-	2	2	Medium	8	1	**Moderate**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
	hazard		workers to direct sunlight	ental	term exposure to sun light						**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 measures are promoted (e.g. regular hand washing, purpose of PPE and sun protection, ergonomic hazards etc.)	2	2	Medium	4	3	**Moderate risk (12)**
	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				Risk assessment		
						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	Storage sites/treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding at storage sites and/or treatment 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 6 – Manure to power

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: 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	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 requirements for outputs)	3	2	Medium	4	1	**Low risk (4)**
	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			
P2: 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	Fire/explos	A fire or explosion occurs		Develop and implement	3	3	High	16	1	**High risk**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
	hazards	ion	due to gas leakage, etc.		fire/explosion response plan						(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)
		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
P3: 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	Storage sites/treatment ponds serve as vector breeding sites	Insect bites	Prevent mosquito breeding at storage sites and/or treatment ponds	2	2	Moderate	4	2	**Moderate risk (8)**
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		Workers suffer of	Injury to	Worker education for	2	2	Medium	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
	hazard		musculoskeletal damage due to inappropriate working practices	the body	preventing musculoskeletal damage due to inappropriate working practices						**(4)**

6.1.5 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 threshold values (see annex IV), **the treated wastewater is not suitable for irrigation**	**Not a control measure but a pre-condition. The likelohood of chemical parameters being above health-based threshold values is high in Hanoi**			16	3	**48**
	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	2	**Moderate risk (8)**

6.1.6 *Model 9 – On cost savings and recovery*

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	4	3	**Moderate risk (12)**
	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 thresholds as per QCVN 03 : 2008/BTNMT - National technical regulation on the allowable limits of heavy metals in the soils (see Annex IV)						
					Option A.) Apply a physico-chemical removal process (e.g. absorption)	3	1	Low	4	4	**High risk (16)**
					Option B.) Do not promote the treated wastewater for	2	1	Low	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
					irrigation						
		Heavy metals	**Downstream exposure:** Poor sludge quality results in contaminated fertilizer	Ingestion	In case the sludge does not comply with National heavy metal thresholds (see Annex IV) physico-chemical removal process must be applied. **Otherwise the sludge must not be further processed for producing fertilizer**	2	1	Low	4	4	**High risk (16)**
	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	4	2	**Moderate risk (8)**
P3: co-composting	Biological hazards	Pathogens	Sludge and organic-waste is contaminated with pathogens (e.g. chicken	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				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
			waste → campylobacter, salmonella)								
			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			
		Thermophilic fungi and actino-mycetes	Inhalation of airborne spores	Inhalation	PPE	3	2	Moderate	4	3	**Moderate risk (12)**
					Moisture (>40%) control for reducing bio-aerosol emission	3	2	Moderate			
		Malodors	Exposure to malodors	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	2	**Moderate risk (8)**
	Physical		Physical injury of workers		Prevent the risk of drowning in ponds by means of PPE, worker education and only	3	3	High	8	1	**Moderate risk (6)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
					employ workers that know how to swim						

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	4	2	**Moderate risk (8)**
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	4	2	**Moderate risk (8)**
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			
			Downstream exposure:	Hand to	≤45°C for ≤5 days (2 log	3	2	Moderate	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
			Those that apply the compost are exposed to pathogens such as *E. coli* and helminth eggs	mouth and inhalation	reductions in bacteria and <1 viable helminth eggs per g dried matter)						**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	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	4	2	**Moderate risk (8)**
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 16 – Subsidy-free community based composting

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 MSW	Vectors	Screening of storage facility	2	2	Moderate	4	1	**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 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	2	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
					objects (e.g. razor blades). To be discharged into the inorganic fraction and disposed of appropriately.						
		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: 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	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)**
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	Injury to	Restrict access to	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
			community access the plant and get hurt, are exposed to pathogens or other hazards	the body, hand to mouth, inhalation	operations for external individuals						**(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)**

6.1.10 Model 18 – Urine and struvite use at scale

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: storage (and handling)	Biological hazards	Pathogens	Workers are exposed to pathogens present in urine	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Avoid any contamination of the urine with faecal matter.	2	3	Moderate			
					Discharge urine that is contaminated with faecal matter or other solid or liquid waste components.	2	2	Moderate			
			Downstream exposure: The ultimate product of the urine, i.e. fertilizer, is contaminated with pathogens (viruses and protozoa of major concern)	Hand to mouth	The following storage times and temperatures are indicated depending on the use of the urine-based fertilizer: 1) Unrestricted, i.e. all crops: ≥6 month at ≥20°C 2) Food and fodder crops that are to be processed: ≥1 month at ≥4°C 3) Food crops that are to be processed, fodder crops (not grass lands): ≥6 month at ≥4°C 4) Food crops that are to be processed, fodder crops (not grass lands): ≥1 month at ≥20°C	3	2	Moderate	4	2	**Moderate risk (8)**
					Urine should be applied close to the ground or	3	2	Moderate			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures	TE	Acc	Mitigation potential	IL	LoF	Residual risk
					worked into the soil.						
					Recommend workers and farmers to wear PPE when applying the urine-based fertilizer	3	2	Moderate			
					The application of the urine-based fertilizer should be halted one month before harvesting.	3	2	Moderate			
	Physical hazard	Malodours	Exposure of workers and farmers to malodours	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
Generalities	Various	Various	Unusual contamination of organic waste	Various	Do not introduce the contaminated material into the system. In case the contamination has been observed at a later stage, discharge any material that was potentially contaminated	2	2	Moderate	4	1	**Low risk (4)**
	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)**

6.1.11 Model 19 – Compost production for sanitation service delivery

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P1: user interface (urine diversion dry toilets) S1: storage	Biological hazards	Rodents → disease transmission	Rodents attracted by organic waste	Hand to mouth, vectors living on rodents	Use of tools	3	3	High	2	2	**Low risk (4)**
		Disease vectors	Flies feeding on organic waste or breed on faecal matter of the urine diversion dry toilets, which can result in disease transmission	Vectors	Screening of storage facility and fly traps on toilets	2	2	Moderate	4	2	**Moderate risk (8)**
	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: pre-processing (segregation/ separation)	Biological hazards	Pathogens	Organic waste is contaminated with pathogens deriving from human and animal waste	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					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			

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
				Inhalation	PPE	3	2	Moderate			
	Chemical hazards	Chemicals	Organic waste 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	2	Moderate	2	1	**Low risk (2)**
	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.	3	3	High			
		Malodours	Permanent exposure of workers to malodours	Inhalation	PPE	2	2	Moderate	2	2	**Low risk (4)**
					Rapid processing of MSW after arrival	2	2	Moderate			
P3: 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	Vectors	Screening of drying beds	3	2	Medium	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
			disease								
P4: 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			
			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)**

Element of the process	Category	Hazard(s)	Hazardous event	Exposure route	Control measures				Risk assessment		
						TE	Acc	Mitigation potential	IL	LoF	Residual risk
P5: 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)**
P6: storage and handling of urine and P7: dilution	Biological hazards	Pathogens	Workers are exposed to pathogens present in urine	Hand to mouth	PPE	3	3	High	4	1	**Low risk (4)**
					Avoid any contamination of the urine with faecal matter.	2	3	Moderate			
					Discharge urine that is contaminated with faecal	2	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
					matter or other solid or liquid waste components.						
			Downstream exposure: The ultimate product of the urine, i.e. fertilizer, is contaminated with pathogens (viruses and protozoa of major concern)	Hand to mouth	The following storage times and temperatures are indicated depending on the use of the urine-based fertilizer: 1) Unrestricted, i.e. all crops: ≥6 month at ≥20°C 2) Food and fodder crops that are to be processed: ≥1 month at ≥4°C 3) Food crops that are to be processed, fodder crops (not grass lands): ≥6 month at ≥4°C 4) Food crops that are to be processed, fodder crops (not grass lands): ≥1 month at ≥20°C	3	2	Moderate	4	2	**Moderate risk (8)**
					Urine should be applied close to the ground or worked into the soil.	3	2	Moderate			
					Recommend workers and farmers to wear PPE when applying the urine-based fertilizer	3	2	Moderate			
					The application of the urine-based fertilizer	3	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
					should be halted one month before harvesting.						
	Physical hazard	Malodours	Exposure of workers and farmers to malodours	Inhalation	PPE	3	2	Moderate	2	2	**Low risk (4)**
Generalities	Various	Various	Unusual contamination of organic waste	Various	Do not introduce the contaminated material into the system. In case the contamination has been observed at a later stage, discharge any material that was potentially contaminated	2	2	Moderate	4	1	**Low risk (4)**
	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)**