RRR-Project

From Research to Implementation

Component 4 – Technology Assessment

Report:

Bangalore, India

Hanoi, Vietnam

Kampala, Uganda

Lima, Peru

Final Report

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Authors

Lars Schoebitz[1], Dr. Charles Niwagaba[2], Dr. Viet-Anh Nguyen[3], Dr. Hien Hoa Tran[3], Dr. Thanh Huyen Dang[3], Dr. Christian Zurbruegg, Dr. Linda Strande[1]

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[1]*Swiss Federal Institute of Aquatic Science and Technology (Eawag) - Department of Water and Sanitation in Developing Countries (Sandec)*

[2]*College of Engineering, Design, Art and Technology (CEDAT) – Makerere University Kampala*

[3] *Institute of Environmental Science and Engineering (IESE), Hanoi University of Civil Engineering (HUCE), Hanoi, Vietnam*

Executive Summary

This technology assessment was conducted as part of a multi-criteria feasibility study to evaluate the potential for implementing RRR business models in four selected cities (Bangalore, India; Hanoi, Vietnam; Kampala, Uganda; Lima, Peru;). The multi-criteria assessment comprised seven components:

1. Waste Supply and Availability
2. Market Demand
3. Financial Analysis
4. Environmental and Health Impact Assessment
5. Technical Assessment
6. Institutional Analysis
7. Socio-Economic Analysis

This report summarizes the findings of the component “technology assessment”. The goal of the technology assessment was to identify risks of technology failures, and prerequisites for technologies to work successfully. The business models do not prescribe a specific technology option or scale, but rather define a process (e.g. anaerobic digestion) and targeted endproduct (e.g. biogas). Based on this limited level of technical detail, the technology assessment gives an overview of treatment options for each of these RRR business models. It furthermore identifies potential environmental hazards of outputs (e.g. emissions from gasification) and proposes mitigation measures to avoid these hazards (e.g. scrubbing). It presents technology score cards that rank technology options based on requirements such as land, electricity and operations and maintenance. For each business model, it presents a context specific evaluation for each of the four cities based on local characteristics, and summarizes the potential of the business model for each city from a technical perspective. A more precise technical feasibility evaluation will be possible later as detailed information becomes available on business model implementation factors such as specific location of the treatment facility, scale, market requirements of the endproduct and its technical implications, and distribution channels, which will allow to narrowed down the possible technology choices.

The executive summary provides a summary of all business models, including input waste streams, endproducts, considered technologies and applied processes, as well was potential environmental hazards and proposed mitigation measures. For each city an individual table was created to provide a summarized overview of the findings. An additional table was created, in which the feasibility is ranked based on the findings of the “Waste Supply and Availability” analysis and the requirements and technical background knowledge that is provided and analysed in this report. Based on the ranking, recommendations for adaptions of the business models to increase feasibility for implementation from a technical perspective are provided.

Bangalore

All business models under consideration for Bangalore are summarized in Table 1, including the input waste streams, endproducts, considered technologies and the applied processes, as well as identified potential environmental hazards and proposed mitigation measures. Each of these categories is described in detail in the full report. In Table 2 the waste streams and endproducts are listed, including a ranking of feasibility for implementation (high/medium/low) and recommendations for adaptions to increase feasibility.

Table 1: Summary of business models under consideration for Bangalore.

Business Model	Waste stream	Endproduct	Technologies	Process	Pot. Env. Hazard	Mitigation measures
1 (a, b)	• AIW • MSW	• 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	• 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-treament
9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conventional 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
10	• WW	• Water (for reclamation) • Water for groundwater recharge	• Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Land treatment	• Groundwater contamination (heavy metals/pathoge ns) • Contamination of irrigated crops with	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Crop selection • 2006 WHO guidelines

					heavy metals and/or pathogens	
11	• Treated WW	• Water (for reclamation)	• Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Land application through irrigation	• Groundwater contamination (heavy metals/pathogens) • Contamination of irrigated crops	• Crop selection • Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • 2006 WHO guidelines
12	• WW • WW sludge	• Biogas -> Electricity	• Conventional WW treatment including anaerobic digestion technologies	• Conventional WW treatment	• Heavy metals in effluent and/or WW sludge • Air emissions • Solid residue (digestate) • Liquid effluent	• Influent free of heavy metals • Monitoring of influent • Air emission control technologies • Solid/liquid residue post-treatment
15	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

					(from FS treatment)	
16	• MSW	• Soil Conditioner	• Windrow (static/turned) • In-Vessel • Inclined step grades • Vermi-composting	• Composting	• 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-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
20	NA	NA	NA	NA	NA	NA

Table 2: Rating of feasibility and recommendations for adaptation of business models in Bangalore.

Business Model	Waste stream	Endproduct	Feasibility	Recommendations
1 (a)	• MSW • AIW	• Briquettes	High Technically feasible (mechanized) - No technology transfer is required given the diffusion of the technology in India	Only relatively dry-waste (<15% wet) should be considered given the high energy or land requirement may be necessary to bring moisture to acceptable levels for briquetting
4	• Feces • Urine • FS	• Biogas -> Cooking fuel	High Technically feasible - No technology transfer is required given the diffusion of the technology	
6	• AM	• Biogas -> Electricity	Medium-High Technically feasible - No technology transfer is required	AD technologies should be selected for wet agro-waste (>80%wet). While gasification technologies for drier waste
8	• WW	• Fish • Treated WW	Medium-High Feasible in Bangalore lakes, but not in any of the treatment plants given the absence of pond treatments.	Maybe aquaculture happening in lakes should be integrated or internalised into WWT businesses
9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	Medium Feasible in Bangalore.	Specific recommendations to be formulated when the exact geography is known (e.g. length of canals/distribution systems)

10	• WW	• Water (for reclamation) • Water for groundwater recharge	Feasible and already taking place via lakes.	
11	• Treated WW	• Water (for reclamation)	Medium Feasible.	Specific recommendations to be formulated when the exact geography is known (e.g. length of canals/distribution systems)
12	• WW • WW sludge	• Biogas -> Electricity	High Feasible given the presence of WWTP based on anaerobic technologies	A generator should be added to burn the biogas generated by anaerobic systems and produce electricity
15	• MSW	• Soil Conditioner	High Technically feasible - Not technology transfer required given the diffusion of the technology and large scales plants in Bangalore	Open turned windrow composting is preferred given the local knowledge and lower electricity requirement
16	• MSW	• Soil Conditioner	High Technically feasible - Not technology transfer required given the diffusion of the technology and large scales plants in Bangalore	Open turned windrow composting is preferred given the local knowledge and lower electricity requirement

17	• MSW • FS	• Fertilizer (NPK added)	High Technically feasible - Not technology transfer required given the diffusion of the technology and large scales plants in Bangalore.	Open turned windrow composting is preferred given the local knowledge and lower electricity requirement. Higher space is required for drying beds. P-enrichment may be considered given the P-deficient quality of soil in the surrounding area.
20	NA	NA		

Hanoi

All business models under consideration for Hanoi are summarized in Table 3, including the input waste streams, endproducts, considered technologies and the applied processes, as well as identified potential environmental hazards and proposed mitigation measures. Each of these categories is described in detail in the full report. In Table 4 the waste streams and endproducts are listed, including a ranking of feasibility for implementation (high/middle/low) and recommendations for adaptions to increase feasibility.

Table 3: Summary of business models under consideration for Hanoi

Business Model	Waste stream	Endproduct	Technologies	Process	Pot. Env. Hazard	Mitigation measures
1 (a, b)	• 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

2 (a, b)	• AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasification • 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-treament

9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conventional 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-treatment • Maintenance of anaerobic digester
15	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
16	• MSW	• Soil Conditioner	• Windrow (static/turned) • In-Vessel • Inclined step grades • Vermi-composting	• Composting	• 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-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
18	• Urine	• Diluted urine	• UDDTs	• Urine collection and storage	• Ammonia intoxication • Ammonia oxidisation	• Urine dilution with water
19	• Urine • Feces	• Stored urine • Soil conditioner	• UDDTs • Co-composting	• Urine application • Co-composting	• Ammonia intoxication • Ammonia oxidisation • Insufficient pathogen inactivation • Leachate from co- composting	• Urine dilution with water • Moisture control • Leachate treatment • Temperature control (compost heap)

Table 4: Rating of feasibility and recommendations for adaption of business models in Hanoi.

Business Model	Waste stream	Endproduct	Feasibility rating	Recommendations
1 (a, b)	• AIW	• Briquettes	Medium Availability of AIW in urban Hanoi is limited. Vegetables are mainly produced in the peri-urban and rural areas south of urban Hanoi and rice, as the main harvested crop, is produced north of urban Hanoi. The use of coal as a cooking fuel is very limited in Hanoi as electricity supply for cooking and heating purposes is sufficient. Therefore, it can be expected that the demand for briquettes as a substitute is limited, but there could be potential market demand for use in industries. From the perspective of technical feasibility, briquetting technologies can be expected to function well, if the operators are trained in operation and maintenance of the equipment. Briquettes are already being produced in Vietnam, mainly from rice husks. They are used to heat industrial boilers for co-firing where it can be combined with coal. Therefore, knowledge on briquetting methods exists and technologies could potentially be implemented if the market demand analysis identifies a demand for the use of briquettes.)	Considering the use of other waste streams for the production of briquettes can increase the feasibility. The calorific value of dried faecal sludge is comparable to other biomass fuels. Other possible adaptions include the production of pellets instead of briquettes, which are often preferred by industries. Targeting industries rather than households as a possible market for the endproduct would decrease the social stigma that is created with using briquettes/pellets made of faecal sludge as a fuel.

2 (b)	• AIW	• Gasification -> Electricity	Low Availability of AIW in urban Hanoi is limited (as described under business model 1(a)).	Application of gasification in the peri-urban and rural areas where AIW is produced.
4	• Feces • Urine • FS	• Biogas -> Cooking fuel	Low The demand for public toilet facilities for sanitation provision is expected to be relatively low in urban Hanoi, as sanitation coverage for households is almost 100%. The high number of public toilets, especially in the districts of Historic Hanoi, shows that toilet facility provision as a public service (e.g. for tourists) is well covered. Upgrading existing facilities ranks low in technical feasibility due to limited availability of space and the combined onsite sanitation and sewer network already in place.	Producing biogas from faecal sludge, especially in co-digestion with other waste streams, is a promising option for the treatment of faecal sludge. A technical adaptation of the business model could include making use of the already collected faecal sludge from public toilets and potentially co-digest it with other waste streams, such as wastewater sludge or the organic fraction of solid waste.
6	• AM	• Biogas -> Electricity	Medium Animal manure is not produced within urban Hanoi, while the application of anaerobic digestion in peri-urban and rural areas has been successfully implemented.	Change of location to peri-urban and rural areas where animal manure is produced

8	• WW	• Fish • Treated WW	Medium Use of wastewater for aquaculture is a well-established system in Hanoi. It is mainly based on farmer’s experience and also utilizes animal manure. However, it can be assumed that these practices are not under safe conditions and that the used wastewater is of mixed domestic and industrial source. To implement a business model, similar to Agriquatics, requires institutional involvement as the city has developed master plans for the expansion of the wastewater treatment infrastructure until 2050. Other limitations include the availability of land for cultivation in urban Hanoi.	
9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	Medium Effluent of existing wastewater treatment plants is in line with local water quality standards for discharge, which decreases the feasibility of reclaiming water for the recovery of nutrients. Anaerobic treatment of WW is not implemented at any of the existing treatment plants and no information exists on the current management of WW sludge.	The feasibility of the business model can be increased by starting the communication of resource recovery within the planning of sanitation and wastewater infrastructure until 2050.

15	• MSW • FS	• Soil Conditioner	Medium-High This business model ranks highest feasibility, as Hanoi already has an existing and functioning composting facility. The composting facility receives market and restaurant waste from four urban areas. This highly decreases the sorting efforts necessary at the facility. Nevertheless, the facility does not make any profits due to the fact that the treatment costs are higher than the revenues that can be created from the endproduct. A functioning business model could increase the profitability of the composting facility. The composting plant also receives faecal sludge from public toilets, of which the liquid part is used to maintain the moisture in the composting piles. Technically, this cannot be considered as co-composting since the solid fraction of the faecal sludge is still disposed of at one of the landfills.	The feasibility can be increased by implementing more source-separation initiatives at the household level to increase the availability of organic solid waste for composting. As faecal sludge is already delivered to the same facility, the solid fraction of the faecal sludge could be utilized for co-composting activities. This would require implementation of faecal sludge drying technologies, such as unplanted drying beds.
16	• MSW	• Soil Conditioner	Low Very limited space in urban Hanoi for decentralised community level composting activities. MSW is not source-separated.	No recommendations for adaptions to increase the feasibility.

17	• MSW • FS	• Fertilizer (NPK added)	Medium-High Same reasons as for business model 15	Same recommendations as for business model 15.
18	• Urine	• Diluted urine	Low No existing urine diverting dry toilets. Agricultural land is far from urban Hanoi. Sanitation coverage is almost 100%.	No recommendations for adaptions to increase the feasibility.
19	• Urine • Feces	• Stored urine • Soil conditioner	Low Same reasons as for business model 18	No recommendations for adaptions to increase the feasibility.

Kampala

All business models under consideration for Kampala are summarized in Table 5, including the input waste streams, endproducts, considered technologies and the applied processes, as well as identified potential environmental hazards and proposed mitigation measures. Each of these categories is described in detail in the full report. In Table 6 the waste streams and endproducts are listed, including a ranking of feasibility for implementation (high/middle/low) and recommendations for adaptions to increase feasibility.

Table 5: Summary of business models under consideration for Kampala.

Business Model	Waste stream	Endproduct	Technologies	Process	Pot. Env. Hazard	Mitigation measures
1 (a,b)	• 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
2 (a,b)	• MSW • AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasification • 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

9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	• Conventional wastewater treatment technologies • Biogas conversion technologies	• Conventional 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-treatment • Maintenance of anaerobic digester
10	• WW	• Water (for reclamation) • Water for groundwater recharge	• Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Land treatment	• Groundwater contamination (heavy metals/pathogens) • Contamination of irrigated crops with heavy metals and/or pathogens	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Crop selection • 2006 WHO guidelines
15	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

17	• MSW • FS	• Fertilizer (NPK added)	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent
19	• Urine • Feces	• Stored urine • Soil conditioner	• UDDTs • Co-composting	• Urine application • Co-composting	• Ammonia intoxication • Ammonia oxidisation • Insufficient pathogen inactivation • Leachate from co-composting	• Urine dilution with water • Moisture control • Leachate treatment • Temperature control (compost heap)

Table 6: Rating of feasibility and recommendations for adaption of business models in Kampala

Business Model	Waste stream	Endproduct	Feasibility rating	Recommendations

1 (a, b)	• MSW • AIW	• Briquettes	Low (see recommendations) MSW in Kampala is not source-separated and therefore unsuitable for the production of briquettes, as inorganic impurities can create hazardous emissions. AIW is not sufficiently available and the competition for the waste is high as it is highly valuable for direct combustion to generate heat, and electricity through gasification. Kampala already has many businesses producing briquettes from AIW, which increases the market competition.	Considering the use of other waste streams for the production of briquettes can increase the feasibility. The calorific value of dried faecal sludge is comparable to other biomass fuels. Other possible adaptions include the production of pellets instead of briquettes, which are often preferred by industries. Targeting industries rather than households as a possible market for the endproduct would decrease the social stigma that is created with using briquettes/pellets made of faecal sludge as a fuel. Targeting the recently commissioned Lubigi Wastewater and Faecal Sludge Treatment plant could be a possibility as there are currently no strategies in place for the accumulated dried faecal and wastewater sludge.

2 (a, b)	• MSW • AIW	• Biogas -> Electricity	Low (see recommendations) Same reasons as for business model 1 (a, b)	The feasibility can be increased by considering the use of faecal sludge for anaerobic digestion. Co-digestion of faecal sludge with other waste streams such as the organic fraction of solid waste and market waste as well as animal manure has high potential. However, this requires arrangements with the municipality and private as well as public faecal sludge emptying and transportation service providers, as regulations prescribe to discharge faecal sludge at the official discharge locations in Lubigi and Bugolobi.
4	• Feces • Urine • FS	• Biogas -> Cooking fuel	Low (see recommendations) Upgrading of existing systems appears unlikely due to the needed acquisition of land in densely populated areas where sanitation services are lacking. The biogas yield from faecal sludge alone is comparatively low.	The Kampala Capital City Authority (KCCA) is currently increasing the implementation of public toilets in Kampala. Adapting the business model and starting communications with the authority to implement anaerobic digestion technologies into planned public toilet facilities can increase the feasibility of this business model. However, sanitation service based business models often only create revenues through the applied user fee and not through utilization of endproducts.

9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	Low (see recommendations) Considering the high investment costs for WW infrastructure this model ranks low in feasibility for Kampala.	The existing Kampala Sanitation Master Plan (2004) and Kampala Sanitation Plan (2008) outline the strategy for upgrading the WW infrastructure in Kampala towards 2030. The feasibility of the business model can be increased through cooperation of the implementing business with the National Water and Sewerage Corporation (NWSC) as part of a PPP agreement. This partnership can lead to the implementation of resource, recovery solutions at WW treatment plants in Kampala.
10	• WW	• Water (for reclamation) • Water for groundwater recharge	Low Even though urban agriculture is practiced widely, business orientated reclamation of wastewater in urban areas is not manageable due to the scattered organization of urban farmers. Large-scale farming activities are located far away from urban areas, where wastewater infrastructure is not planned to be implemented, which would require the treated wastewater to be piped long distances.	No recommendations for adaptions to increase the feasibility.

15	• MSW • FS	• Soil Conditioner	Medium Collected MSW in Kampala is not source separated, and even though characterized by a high organic fraction, the remaining inorganic fraction is considered to be problematic. Mechanical sorting would highly increase the complexity of a composting facility without necessarily significantly improving the input quality and respectively the final compost product. Considering these facts, the final endproduct from composting activities of mixed or mechanically sorted MSW would tend to be of low quality, potentially not fulfilling local regulations for compost quality. Using FS for co-composting not only complicates the business model in terms of health concerns but also complicates the logistics of the business model in the case of Kampala. FS is delivered to the recently commissioned Lubigi Faecal Sludge and Wastewater Treatment Plant, where currently no plans for enduse of the dewatered and dried faecal sludge exist. The dewatered and dried sludge will be transported to Kiteezi landfill for discharge.	The use of market waste instead of mixed MSW can increase the feasibility of the business model. A co-composting facility could be implemented at the Kiteezi landfill, as the location also receives the dewatered and dried faecal sludge. If trucks that solely deliver market waste to the Kiteezi landfill can be identified and diverted from discharging into the landfill, then, co-composting with faecal sludge might be feasible. Another feasible option is to arrange a special PPP agreement with KCCA, which focuses on the collection and management of MW from selected markets and also transports dried faecal sludge form Lubigi to the site of co-composting. Implementing a source-separation campaign at the household level is desirable for the future of solid waste management in Kampala, but unlikely to take effect fast enough for a co-composting business to make use of it in the coming years.

17	• MSW • FS	• Fertilizer (NPK added)	Medium For the same reasons as for business model 15. Fortifying the compost with nutrients does not affect the feasibility other than a slight increase in production complexity, the need for good supply chains, and the need for regular analysis to ensure a high quality fertilizer.	The same recommendations as for business model 15 to increase the feasibility of this business model.
19	• Urine • Feces	• Stored urine, Soil conditioner	Medium Sanitation services based on urine diverting dry toilets have not shown to be successful in Kampala. 73 public toilets have been identified as ecosan toilets in Kampala with no data availability on reuse of urine or feces.	In recent years, many businesses providing sanitation services in Kampala have started. One example is Water for People who not only provide sanitation infrastructure but also gain a significant market share in regular and safe manual emptying of pit latrines and septic tanks. Supporting the existing entities to further expand their business would increase the feasibility of this business model. The user acceptability of urine diverting dry toilets remains low and other sanitation should be considered for implementation.

Lima

All business models under consideration for Hanoi are summarized in Table 7 including the input waste streams, endproducts, considered technologies and the applied processes, as well as identified potential environmental hazards and proposed mitigation measures. Each of these categories is described in detail in the full report. In Table 8 the waste streams and endproducts are listed, including a ranking of feasibility for implementation (high/middle/low) and recommendations for adaptions to increase feasibility.

Table 7: Summary of business models under consideration for Lima.

Business Model	Waste stream	Endproduct	Technologies	Process	Pot. Env. Hazard	Mitigation measures
2 (a, b)	• AIW • AM	• Gasification -> Electricity • Biogas -> Electricity	• Gasification technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Gasification • Anaerobic digestion • Biogas to electricity conversion	• Hazardous air emissions • Residuals (tar, char, oil) • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Collection/Storage/Disposal at appropriate location • Solid/liquid residue post-treatment
3	• AIW • AM	• Ethanol • Electricity	• Fermentation, Distillation Technologies • Single stage • Multi-stage • Batch • Biogas conversion technologies	• Fermentation, • Distillation • Biogas to electricity conversion	• Hazardous air emissions • Solid residue (digestate) • Liquid effluent	• Air emission control technologies • Solid/liquid residue post-treatment
4	• Feces • Urine • FS	• Biogas -> Cooking fuel	• Single stage • Multi-stage • Batch	• Anaerobic digestion	• Air emissions • Solid residue (digestate)	• Maintenance of anaerobic digester • Solid/liquid residue post-

					• Liquid effluent	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 WW treatment technologies • Biogas conversion technologies	• Conventional 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-treatment • Maintenance of anaerobic digester
12	• WW • WW sludge	• Biogas -> Electricity	• Conventional WW treatment including anaerobic digestion technologies • Biogas conversion technologies	• Conventional WW treatment • Biogas to electricity conversion	• Heavy metals in effluent and/or WW sludge • Air emissions • Solid residue (sludge from WW treatment) • Liquid effluent	• Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • Solid residue (sludge from WW treatment) post-treatment • Maintenance of anaerobic

						digester
13	• WW	• Water (for reclamation)	• Conventional WW treatment with limited nutrient removal • Slow rate infiltration • Rapid infiltration • Overland flow • Wetland application	• Conventional WW treatment • Land application	• Groundwater contamination (heavy metals/pathogens) • Contamination of irrigated crops • Solid residue (sludge from WW treatment) •	• Crop selection • Upstream monitoring of heavy metal concentration • Monitoring of effluent and solids • 2006 WHO guidelines • Solid residue (sludge from WW treatment) post-treament
15	• MSW • FS	• Soil Conditioner	• Solid/liquid separation • Drying beds • Co-composting	• Co-composting (MSW + FS)	• Accumulated inorganic waste • Leachate from composting • Insufficient pathogen inactivation • Liquid effluent (from FS treatment)	• Storage/transport/disposal (sanitary landfill) • Moisture control • Leachate treatment • Temperature control (compost heap) • Post-treatment of liquid effluent

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

Table 8: Rating of feasibility and recommendations for adaptation of business models in Lima.

Business Model	Waste stream	Endproduct	Feasibility	Recommendations

2 (a,b)	• MSW • AIW	• Biogas -> Electricity	Medium Feasible but technology transfer may be required for MSW. Pre-treatment technologies may be adapted from the existing mining industry. Water requirement may represent an important constraint in the city if wet technologies are adopted.	
3	• AIW • AM	• Ethanol • Electricity	-	
4	• Feces • Urine • FS	• Biogas -> Cooking fuel	Medium-High Technically Feasible - No technology transfer is required.	
8	• WW	• Fish • Treated WW	Medium-High Already happening in Lima. There is space to cultivate duckweed/aquaculture in existing WWTPs as many of them are have ponds.	Consider southern area of Lima.
9	• WW • WW sludge	• Electricity • Soil conditioner • Water (for reclamation)	High There is plenty of WW sludge that could be processed for energy generation.	There is plenty of WW sludge that could be processed for energy generation.

12	• WW • WW sludge	• Biogas -> Electricity	Medium Feasible but technology transfer may be required for MSW. Pre-treatment technologies may be adapted from the existing mining industry	
13	• WW	• Water (for reclamation)	High Wastewater treated to secondary level is available.	Park irrigation is promising.
15	• MSW	• Soil conditioner	High Feasible. Open turned windrow may be preferred given the low capital, low electricity and high labour requirement.	
17	• MSW • FS	• Fertilizer (NPK added)	Medium-High Feasible. Extra valorisation machinery may be adapted from existing technologies used by the mining sectors (e.g. grinding). Pelletizing machines are already available in the market.	
21	• MSW	• Soil conditioner	High Feasible. Open turned windrow may be preferred given the low capital, low electricity and high labour requirement.	

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Abbreviations

Abbreviation	Explanation
3R	Reduce, Reuse, Recycle
AIW	Agro-Industrial Waste
AM	Animal Manure
BM	Business Model
BOD	Biological Oxygen Demand
CHP	Combined Heat and Power
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
FS	Faecal Sludge
GVEP	Global Village Energy Partnership
HAPs	Hazardous Air Pollutants
HRSG	Heat Recovery Steam Generator
HSLT	High Speed Low Torque
JICA	Japan International Cooperation Agency
KCCA	Kampala Capital City Authority
KCDC	Karnataka Compost Development Corporation
KSMP	Kampala Sanitation Master Plan
KSP	Kampala Sanitation Program
LSHT	Low Speed High Torque
Max	Maximum
MSW	Municipal Solid Waste
MW	Market Waste
NA	Not available
Nox	Oxides of Nitrogen
NPK	Nitrogen Phosphorous Potassium
NWSC	National Water and Sewerage Corporation

O&M	Operation and Maintenance
Pot. Env. Hazards	Potential Environmental Hazards
PPP	Public Private Partnership
PVC	Polyvinyl Chloride
RDF	Refuse Derived Fuel
RRR	Resource, Recovery, Reuse
TS	Total Solids
UASB	Upflow Anaerobic Sludge Blanket Reactor
UIA	Ugandan Investment Authority
Urine Diverting Dry Toilets	UDDTs
USD	US Dollar
VIP	Ventilated Improved Pit
VOCs	Volatile Organic Compounds
WHO	World Health Organization
WSP	Waste Stabilization Ponds
WW	Wastewater
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

1. **Introduction**

This technology assessment was conducted as part of a multi-criteria feasibility study to evaluate the potential for implementing RRR business models in four selected cities (Bangalore, India; Hanoi, Vietnam; Kampala, Uganda; Lima, Peru;). The multi-criteria assessment comprised seven components:

1. Waste Supply and Availability
2. Market Demand
3. Financial Analysis
4. Environmental and Health Impact Assessment
5. Technical Assessment
6. Institutional Analysis
7. Socio-Economic Analysis

This report summarizes the findings of the component "technology assessment". The goal of the technology assessment was to identify risks of technology failures, and prerequisites for technologies to work successfully. The business models do not prescribe a specific technology option or scale, but rather define a process (e.g. anaerobic digestion) and targeted endproduct (e.g. biogas). Based on this limited level of technical detail, the technology assessment gives an overview of treatment options for each of these RRR business models. It furthermore identifies potential environmental hazards of outputs (e.g. emissions from gasification) and proposes mitigation measures to avoid these hazards (e.g. scrubbing). It presents technology score cards that rank technology options based on requirements such as land, electricity and operations and maintenance. For each business model, it presents a context specific evaluation for each of the four cities based on local characteristics, and summarizes the potential of the business model for each city from a technical perspective. A more precise technical feasibility evaluation will be possible later as detailed information becomes available on business model implementation factors such as specific location of the treatment facility, scale, market requirements of the endproduct and its technical implications, and distribution channels, which will allow to narrowed down the possible technology choices.

2. Methodology

2.1 Identification of RRR treatment options

The technology assessment includes several steps to formulate recommendations for technologies within each city context. As illustrated in Figure 1, based on processes described in the business model, literature was consulted for relevant technologies to determine the range of possible RRR treatment options.

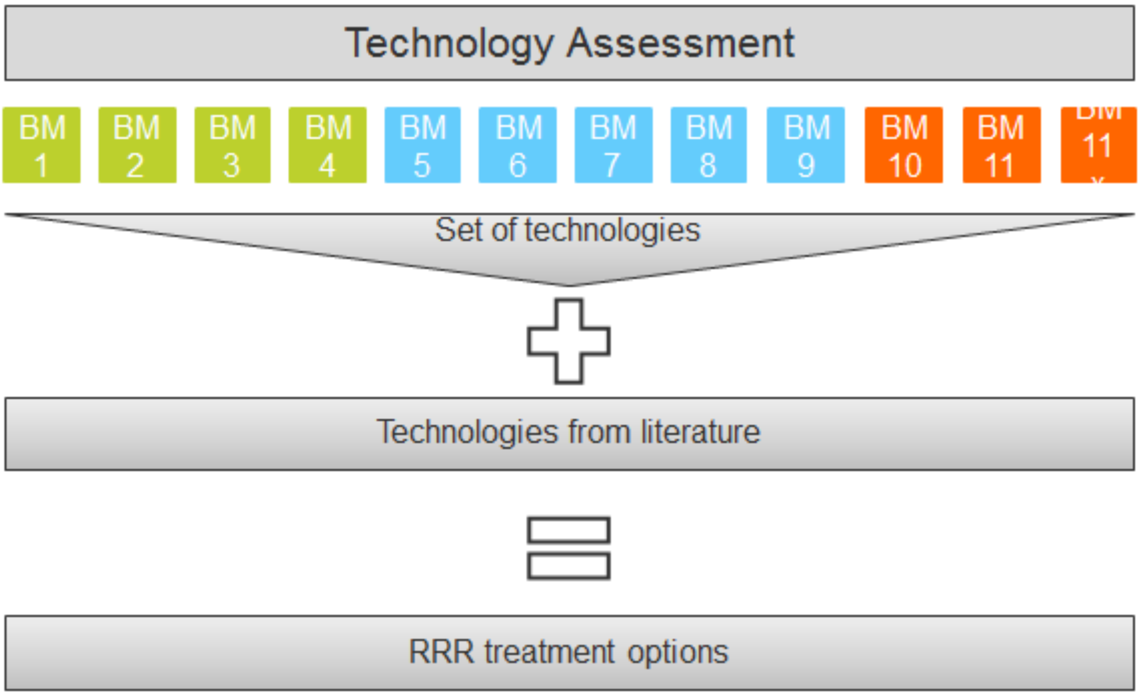


Figure 1: Summary of the selection process for RRR treatment options

Figure 2 presents an overview of all identified RRR treatment technology options. They are divided into three sections based on the specific type of resource recovery (i.e. energy, nutrients and/or water). Water reclamation options are divided into primary, secondary, and advanced wastewater treatment and land treatment/irrigation, and whether or not they are intensive or extensive treatment options. Extensive treatment options require more land but less energy and skilled labor, while intensive technologies require less land but more energy and skilled labor. Energy recovery options are categorized into energy from wastewater, solid waste and/or sludge. Nutrient recovery options are divided into nutrients from solid waste and sludge treatment.

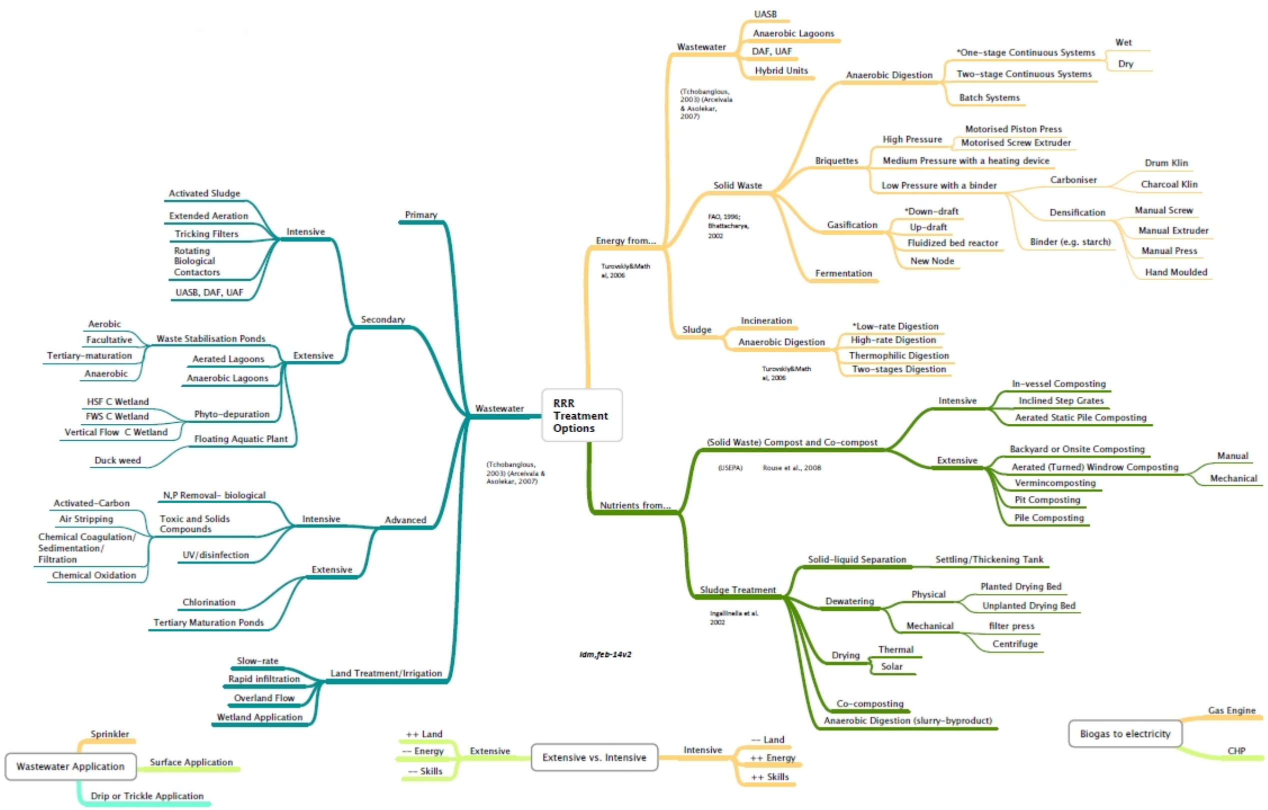


Figure 2: Overview of RRR treatment options. Created by Luca Di Mario.

2.2 Definition of treatment objectives

When assessing, designing and implementing treatment technologies for RRR business models, it is imperative to define specific treatment objectives and goals for enduse. For example, wastewater can be treated to comply with local regulations, but treatment could also be tailored for irrigation purposes with the recovery of nutrients. Different enduses require that different configurations have to be analyzed for that specific enduse. Only when treatment goals are clearly defined in this way can the treatment technologies for business models be more precisely assessed. As shown in Table 1, this level of detail exists for some business models but not all, and where the information is lacking assumptions had to be made. Treatment endproducts were identified for each business model and linked to treatment technology options (also see Figure 2).

Table 9: Overview of business models, the identified endproducts and technology options.

Business Models	Endproducts	RRR technology options
BM1	• Briquettes	• Carbonized - low pressure • Raw – mechanized high pressure • Carbonized - mechanized
BM15 BM16 BM21	• Compost/soil conditioner • Fertilizer	• Aerated (static) windrow • Aerated (turned) windrow • In-Vessel • Inclined step grades • Vermi-composting
BM17 BM9a	• Dewatered faecal sludge for co-composting • Dewatered wastewater sludge as “fertilizer”*	• Physical – unplanted drying beds • Physical – planted drying beds • Mechanical dewatering
BM13a BM9	• Intensive and extensive wastewater treated to secondary level • Wastewater treated to secondary level	• Activated sludge • Extended Aeration • Trickling filters • Rotating Biological Contactors

BM12 BM11		• UASB • Waste stabilization ponds • Aerated lagoons • Anaerobic lagoons • Phyto-depuration • Floating aquatic plants
BM3	• Ethanol	• Fermentation/distillation technologies
BM2 BM3 BM5 BM6 BM4	• Biogas, heat, electricity through anaerobic digestion of MSW and FS	• Single stage • Multi-stage • Batch • Hybrid units

* The business models refer to composted sludge as "fertilizer", but should not be labeled as a fertilizer as typical nitrogen contents remain around 1-2 %. Additional supplement of nutrients, such as nitrogen, phosphorous and potassium to the product, can help qualify the endproduct as a fertilizer and is typically called fortified compost. Therefore, in this report they will be referred to as "soil conditioners".

2.3 Technology description

The analysis of each business model starts out with a flow diagram that was created to illustrate the inputs, processes and outputs. In the text, these are then described, highlighting the following:

Inputs: Inputs are assessed based on their requirements for the technology option. For example, if a business model utilizes mixed municipal solid waste as the input product, sorting mechanisms such manual or mechanical sorting need to be implemented to separate the organic from the inorganic fraction, while market waste can be expected to have less impurities and therefore requires less sorting. This has an influence on the business model in terms of financial and labor requirements but also influences the quality of the output (i.e. compost) product. Furthermore, the inorganic fraction is another output, which requires further treatment and/or safe disposal at a sanitary landfill. The technology description also identifies potential environmental hazards, such as emissions into air from gasification processes and describes technologies that have to be implemented for mitigation. If two business models have the same inputs, processes or outputs, cross-references are made to where they were first explained in the technology assessment report.

2.4 Development of technology score cards

After identifying treatment technologies that are suitable for the identified endproducts of the business models, technology score cards were developed. This step does not include city specific information, but the goal was to create a tool to support decisions on the most suitable treatment technologies for a given context. A qualitative ranking was made based on the following indicators:

1. Land: Compares the required land area, for example waste stabilization ponds require more land to treat the same volume of wastewater than activated sludge treatment plants
2. Skilled labor: Compares the complexity of the technology option and defines the level of skilled labor that is required for appropriate operation and maintenance. For example, an anaerobic digester with continuous feed and moving parts requires a higher level of skilled labor than a batch fed digester with no moving parts
3. Water: Compares the water requirement used in treatment processes to generate resource recovery endproducts. These are largely the same for technology options within the same business model. For example, all anaerobic digestion technologies based on wet fermentation of organic waste, require similar addition of water to control the total solids (moisture) content, whereas other treatment processes such as composting require less water to control moisture
4. Electricity: Compares electricity requirements. For example, activated sludge processes for wastewater treatment require a constant supply of electricity for mixing and/or addition of oxygen to maintain aerobic conditions, whereas waste stabilization ponds are passive and do not require mixing to maintain either aerobic or anaerobic designed phases.
5. Climate: Compares the climate requirements of technology options. For example, unplanted drying beds for the dewatering of faecal sludge are more affected by climate (e.g. plants require certain levels of sun and rain), than mechanical dewatering technologies, which are not climate dependent.
6. Supply + support chain: Compares the need of an existing supply and support chain to ensure continuous operation of the treatment technology. For example, mechanized high pressure technologies for briquetting of organic solid waste have higher requirements for spare and replacement parts than low pressure technologies, because of greater complexity of the reactors.
7. Environmental: Compares the potential environmental impact of the technology options. These are largely the same within one business model. For example, wastewater treatment technologies treating wastewater to secondary level have similar effluent characteristics regardless of the process, based on the definition of secondary treatment.
8. Capital: Compares the relative capital and investment costs. For example, investment costs for aerated composting technologies with windrows are higher than manually turned windrows due to the required infrastructure.
9. O&M: Compares relative operation and maintenance requirements. For example, this is based on requirements for skilled labor and replacement parts. For example, a briquetting business implementing a mechanical compaction technology with high pressure requires higher skilled labor and replacement parts than a manual compaction technology with low pressure.
10. Risk of failure (level of robustness): Compares the risk that the technology fails. For example, windrow composting is a more established and less easily upset process than vermi-composting

Results in the technology score cards are based on the following ranking:

Score 0: The technology has no requirements for the indicator or the indicator is not applicable

Score 1: The technology has low requirements for the indicator, compared to the other options in the same score card

Score 2: The technology has medium requirements for the indicator, compared to the other options in the same score card

Score 3: The technology has high requirements for the indicator, compared to the other options in the score card

Only technology options within the same score card are comparable with one another. If technologies have the same ranking and therefore have the same requirements for one indicator, the scores rate the relative requirement to this indicator. For example, all composting technologies require water, but the amount of water that is required is low. All options therefore get the ranking of “1”. But this does not mean that a technology ranking “3” for water in a different technology score hard has much higher requirements than composting technologies as they are not on the same score card.

2.5 City context

In addition, for each business model, the relative feasibility of implementation for each of the four cities is presented based on information that was collected and reported in the “Waste Supply and Availability” reports [1-4]. The city context furthermore highlights the level of experience that already exists for the proposed technology option. If the feasibility of a business model ranks low for factors such as the required waste is not available in the desired form, suggestions are made for alternative input products.

3. Business Model technologies

A total of 21 business models were considered for the feasibility studies, seven for energy recovery, seven for water recovery and seven for nutrient recovery. An overview of the 21 business models, and which ones were considered in each city, is presented in Table 10. The decision of business models for cities was carried out with a methodology that is presented in the city inception workshop reports. In September 2014, the names of business models and the numbering were revised. Refer to Annex 1, section 8.1 for the revised names and numbers.

Table 10: Business models selected for feasibility testing.

RRR Business Models	**Kampala**	**Hanoi**	**Bangalore**	**Lima**
ENERGY				
Model 1: Dry-fuel manufacturing a. Agro-waste --> Briquettes b. Municipal solid Waste --> Briquettes	X -	X -	X -	-
Model 2: Independent Power Producer/ Private power developer a. MSW --> Electricity b. Agro-waste --> Electricity	- X	- X	- -	X -
Model 3: Onsite Energy Generation (Agro-waste to Biogas, Electricity, Carbon credit)	-	-	-	X
Model 4: Onsite Energy Generation in Enterprises Providing Sanitation Service	X	X	X	X
Model 5: Power capture model (Agro-industrial effluent to energy)	-	-	?	-
Model 6: Power capture model - Livestock waste to energy	-	X	X	-
Model 7: Generator model*	-	-	?	-
WASTEWATER				
Model 8: Phyto-remediative wastewater treatment and fish production	-	X	X	X
Model 9: Treated wastewater for irrigation/fertilizer/energy - *Cost recovery*	X	X	X	X
Model 10: Untreated wastewater for irrigation and groundwater recharge	X	-	X	-
Model 11: Wastewater & drinking water exchange *(water exchange – irrigation and drinking water)*	-	-	X	-
Model 12: Wastewater treatment for carbon emissions reduction	-	-	X	X
Model 13: Wastewater treatment for irrigation *(profit and social responsibility)* a. Sale of treated wastewater for irrigation b. Sale of advanced treated wastewater for other uses	-	-	?	X

Model 14: Wastewater treatment via hedging & matchmaking of futures contracts for commoditized treated wastewater	-	-	-	-
NUTRIENTS				
Model 15: Centralized large-scale compost production for carbon emissions reductions (MSW --> Compost)	X	X	X	X
Model 16: Decentralized multi-partnership community based model (MSW --> Compost)	-	X	X	-
Model 17: High Quality Branded/Certified Organic Fertilizer from Faecal Sludge and MSW	X	X	X	X
Model 18: Urine for Agricultural Production (Urine --> Organic Fertilizer)	-	X	-	-
Model 19: Sustainable Sanitation Service Delivery via Compost Production from Faecal Sludge	X	X	-	-
Model 20: Informal reuse of faecal sludge for agricultural production (FS collection service and on-farm use)	-	-	X	-
Model 21: MSW collection service and low-cost organic fertilizer	-	-	-	X

4. Technology Assessment of 21 Business Models

This section presents the information that was collected for the technology options presented in Figure 2 of section 2.1. Each business model is described briefly along with the flow diagram for visualization. Following, all inputs, processes and outputs are presented. The processes include the description of technology options, which also provides background information that helps to develop an understanding of RRR technology options. The output section furthermore describes mitigation measures to prevent potential environmental risks and to ensure compliance with local regulations. This is followed by the technology score cards and the city specific considerations for each of the four cities.

4.1 Business models for energy recovery

4.1.1 Model 1a: Dry-fuel manufacturing from Agro-waste (Briquettes)

Business model 1a is based on the following case study, which is available in “Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse.” [5]

1. Case Study Kampala Jellistone Suppliers Ltd./Uganda

The business case provides a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.1.1 Brief description

Business model 1a aims at recovering energy from agro-industrial waste (AIW), such as rice husks or corn cobs. In general, briquettes can be produced from any type of biomass/organic material that derives from plants or animals (manure). Briquettes can be used as a fuel in industries as well as at the household level as cooking fuel. Innovative briquetting technologies have been developed and the use of briquettes made of AIW and other organic solid waste streams are increasingly being used in low and middle income countries. Alternatively, charcoal briquettes made from wood are the main source of cooking fuel, which has a negative impact on the environment due to increasing deforestation.

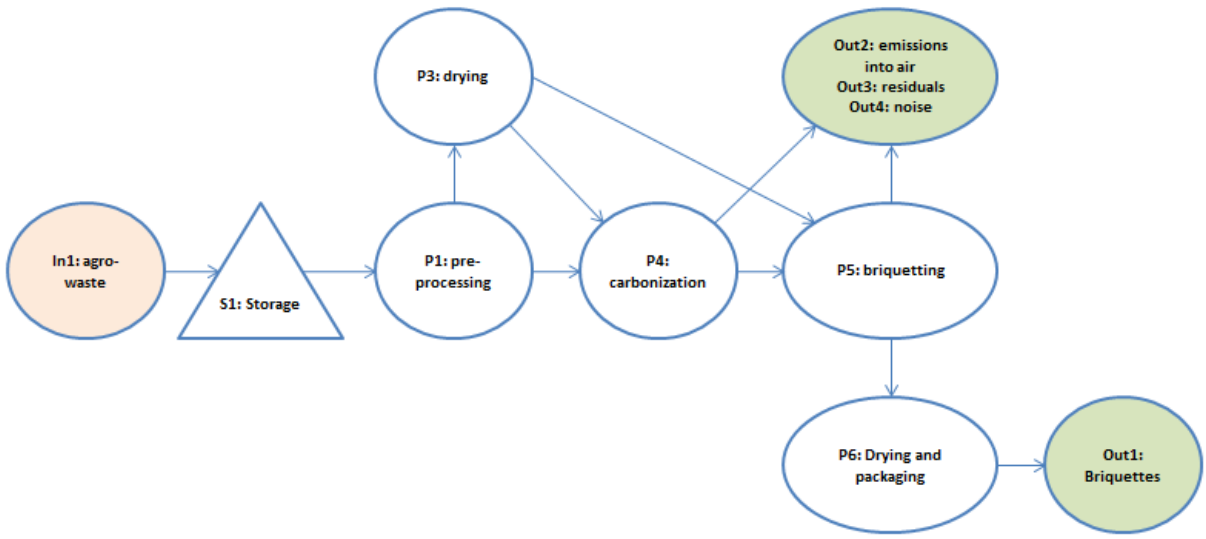


Figure 3: Flow diagram for business model 1a

4.1.1.2 Inputs

In1: Agro-Industrial waste

The business model uses AIW as the input material. In general, all biomass products could be used to produce briquettes. AIW has a high carbon content and calorific value and is therefore more suitable for the production of briquettes. AIW is a high quality input product for the production of briquettes, with expected low contamination if not mixed with other waste streams. Potential sources of contamination include pesticides and weed seeds. For a high quality endproduct, the briquettes have to be homogeneous, compact, dry and of high carbon content to be comparable with other used products, such as charcoal briquettes made from wood

4.1.1.3 Processes

P1: Pre-processing

Briquettes from AIW have to be homogeneous, compact, dry and of high carbon content to be comparable to other used products such as charcoal briquettes made from wood. To ensure high quality, pre-processing of the input waste is an important step. The input material has to be shredded to ensure a consistent small particle size that can be fed into a compaction device.

Depending on the characteristics of the input waste stream, different shredding technologies can be applied (e.g. coconut shells need a mechanical device, such as an electric grinding machine or industrial hammer mill grinder, compared to fresh leaves or rice husks which can also be crushed manually). The technologies are low tech and can be manufactured locally, which has a positive impact on the required supply and support chain [6].

Briquettes can be produced in a carbonized or an uncarbonized form. Carbonization is the term for the conversion of organic material into carbon or a residue with an increased carbon proportion. The process drives off volatile compounds and moisture, leaving a fuel with higher proportion of carbon remaining. For the carbonization process, the biomass is heated in the absence of oxygen, or partially combusted with limited oxygen supply [6]. Processes that can be applied are pyrolysis, combustion and gasification.

Carbonization methods range from simple traditional earth pit kilns over brick & steel kilns to large-scale plants that can be operated continuously. The product of carbonization is also referred to as "char". Whether or not the waste is converted into a carbonized form before it is compacted into a briquette depends on the application. The advantage of carbonized briquettes is reduced smoke and the reduction of emissions compared to when untreated biomass is burned. Due to the cleaner emissions and the increased heating value compared to uncarbonized briquettes, carbonized briquettes are more suitable to be used as a cooking fuel at the household level. To be used as a fuel in industries, the requirements of the fuel that will be substituted first need to be evaluated which depends on a case-to-case basis. Carbonizing the briquettes before compaction increases the requirements of the business model for skilled labor, water and operation and maintenance. It adds complexity, but also creates a higher value product. Due to the increase in carbon density and the mass reduction, transportation costs can also be reduced [6].

P2: Drying

Uncarbonized briquettes require the input material to have moisture content of around 13%. Input material for carbonized briquettes also need to be dried prior to carbonization for the process to be effective. After carbonization the remaining char is compacted into briquettes, at which time water is required. The final briquettes are then dried to a moisture content of less than 10% for packaging and storage [6].

Freshly harvested feedstock can have moisture content of up to 70% and solar drying is the most commonly used drying method. This increases the land requirements for the business model and is a critical step to produce high quality briquettes. Climate has an influence on the drying process, as the material needs to be covered during rain events. A roof could be implemented, but would increase the investment costs. Drying of the material is one of the critical steps to produce high quality briquettes, as it influences the compaction of the briquette and therefore the burning characteristics. It requires space and the increasing scale therefore increases the land requirements, which often are a critical factor for the investment costs due to low land availability and high costs in urban areas. Depending on the distribution channel, the briquetting facility could also be implemented at the source of the waste [6].

P3: Briquetting

Briquettes are mainly used as a cooking fuel or heat source at the household level, but could potentially also be used as a fuel in industries. Although industries usually prefer a product of smaller size, such as pellets, because higher temperatures can be obtained more quickly, while the burning time is reduced.

Briquetting methods can be divided into 1) high pressure compaction; 2) medium pressure compaction assisted by a heating device; 3) low pressure compaction with a binding agent. For these methods a wide range of technologies have been developed that can produce briquettes on different scales from small-scale production to highly mechanized large scale production. The scale depends on the relative size of the machinery and whether it is motorized or manually operated. The most common technology options are described below [6].

1. Piston extruders

Mainly used for non-carbonized briquettes. A heavy piston forces biomass material through a tapered die, which compacts the biomass due to a reduction of the diameter, using high pressure. Depending on the operating method, piston extruders can produce between 200 and 750 kg of briquettes per hour. Briquettes are extruded as a continuous cylinder and the machines are capable to produce non-carbonized briquettes.

2. Screw extruders

Screws are used to extrude a briquette through a die and produce high quality briquettes with a homogenous structure. They can be operated continuously, which is the main advantage compared to piston extruders. The main disadvantage is the wear of the screw, which needs relatively high investment costs compared to the costs of the extruder itself. It needs be ensured that spare parts are available and accessible. Three types of screw extruders are commonly used:

- The **conical die screw extruder** can achieve high pressures using a conical screw that tapers from larger (at the input) to small (at the output). Sufficient compaction can be achieved for both carbonized and uncarbonized feedstocks
- The **heated die screw extruder** uses a non-tapered screw and a heated die, which enables lignin breakdown to occur. Lignin and proteins in biomass act as a natural binder and can be activated to create solid bonds through pressure, temperature and moisture. More information about the binding process is provided below. The technology is suitable for carbonized and uncarbonized feedstocks
- The **plain screw extruder** is only suitable for making carbonized briquettes. It is the most commonly used technology in East Africa, due to the simplicity of the mechanism and the possibility to be produced locally by skilled workers. They are often adapted from similar devices, such as a meat mincer.

3. Roller press

This technology is mainly used to produce carbonized briquettes and is also widely applied for the production of charcoal briquettes. Water needs to be added and binders such as cassava or wheat flour are used to hold the powdered input material together as this technology does not provide enough pressure to hold them together. Lignin is a natural binder and can act as glue, if high temperatures and pressure are applied. If high temperatures cannot be achieved, additional binding agents need to be added to support the binding process. Other binders commonly in use are molasses, fine clay or red soil.

4. Manual technologies

A number of manual technologies exist that have been developed as low-cost options especially in the rural context. These include manual extruders that can be fabricated with local materials or simply making the briquettes by hand. Manual extruders cost around 150 USD and can produce around 6 kg briquettes/hour, while piston and roller press extruders range between 14,000 and 30,000 USD with a capacity between 250 and 1500 kg/hour.

P4: Drying and packaging

Uncarbonized briquettes do not require drying after compaction, while carbonized briquettes need to be dried to moisture content below 10%. Drying is described under “P2: Drying”. This increases the land requirements for technologies producing carbonized briquettes. The most common method is solar drying if the climate conditions are favorable. The drying process can take up to four days until the briquettes reach the desired dryness. In case the area is prone to heavy rainfalls, the drying areas should be covered with a roof. Kampala Jellitone Suppliers, the largest producer of non-carbonized briquettes in Uganda, uses a Flash Drier for the drying of feedstock for non-carbonized briquettes [6].

4.1.1.4 Outputs and Potential Environmental Hazards

Out1: Briquettes

The characteristics of fuel briquettes are strongly affected by the raw material properties. Proximate and ultimate analyses have to be performed for the characterization of the feedstock and the final briquettes. This is important to gather knowledge about the fuel properties as well as to ensure compliance with local emissions regulations. Proximate analyses characterize moisture content, volatile content, fixed carbon and ash, the inorganic residue remaining after combustion, and the high heating value based on complete combustion to carbon dioxide and liquid water. Ultimate analysis gives the composition of the biomass in weight% of carbon, hydrogen and oxygen as well as sulfur and nitrogen. Existing standard methods for these analyses can be consulted. In one study, characterization results of fuel briquettes made from rice husk and corncob demonstrated that corncob briquettes have more positive attributes of biomass fuel than rice husk briquettes. Corncob briquettes had a moisture content of 13%, higher density of 650 kg/m^3, higher volatile matter of 87%, higher heating value of 20,890 kJ/kg and compressive strength of 2.34 kN/m^2 [7]. The results of all analyses are shown in Table 11 and Table 12.

Table 11: Physical and fuel characteristics of rice husk and corncob briquettes. Analysed by [7].

Parameter	Unit	Briquettes	
		Rice Husk	Corncob
Length	m	0.075	0.075
Breadth	m	0.075	0.075
Thickness	m	0.008	0.006
Weight	kg	0.025	0.024
Compactive pressure	MPa	2.10	2.10
Carbon content	%	42.10	19.72
Hydrogen content	%	5.80	15.56
Oxygen content	%	51.67	62.12
Sulphur content	%	0.05	0.82
Ash content	%	18.60	1.40
Nitrogen content	%	0.38	0.38
Volatile matter	%	67.98	86.53
Fixed carbon	%	13.40	12.07

Table 12: Combustion characteristics of rice husk and corncob briquettes. Analysed by [7].

Parameter	Unit	Briquettes	
		Rice husk	Corncob
Moisture content	%	12.67	13.47
Compressive strength	kN/m^2	1.07	2.34
Heating value	kJ/kg	12,389.00	20,890.00
Initial density	kg/m^3	138	155
Maximum density	kg/m^3	524	650
Relaxed density	kg/m^3	24.0	385
Density ratio	-	0.45	0.59
Compaction ratio	-	3.80	4.19

Relaxation ratio	-	2.22	1.70

Out2: Emissions into air

As illustrated in Figure 3, there are two possible routes for air emissions. Firstly, if the raw material is carbonized prior to converting it into the form of a briquette, emissions will be released during the carbonizing process. Secondly, emissions will be released at the household or industry when using the briquettes. Health related concerns, such as respiratory diseases, are investigated in the health impact and risk assessment [24]. Industries, using briquettes as a fuel, have to implement mitigation measures. Emissions of concern are carbon monoxide, polycyclic aromatic hydrocarbons, methane and nitrous oxide.

The emissions from the carbonization process will vary as a result of a number of factors of which the most important are:

- Method of carbonization (retort or kiln)
- Pyrolysis temperature
- Moisture content of input material
- Type of input biomass

At temperatures above 100°C volatile organic compounds are released during the carbonization process. The slightly smoky exhaust plume, also called “blue haze”, can be hazardous and needs to be mitigated. A central flue, afterburner or equipment such as cyclones and adsorption beds have to be implemented if the emissions do not comply with local regulations [8].

The briquettes itself produce emissions at two different user levels. Emissions during the combustion at the household level are generally lower than those of firewood stoves. Nevertheless, stoves produce a large amount of smoke during the cold start. Emissions that are produced from briquettes used as fuel in industries (e.g. cement factories) need to be monitored to ensure compliance with local regulations. The following treatment processes are used by commercial firms to mitigate emissions:

- Activated carbon
- Thermal oxidation
- Scrubbers
- Particulate filters
- Catalytic oxidation

The applications of these technologies need to be effectively characterized. At least the following information needs to be available:

- Flow rate – continuous or intermittent
- Contaminants present – individual contaminants, concentration and variability
- Temperature - average and maximum
- Flammability – upper and lower explosive limits

The suitability of emission control technologies is presented in Table 13. Depending on the ultimate analyses and proximate analyses, industries can decide whether or not it is necessary to implement mitigation measures. Emissions are furthermore influenced by the design and quality of the kiln.

Table 13: Application of emission control technologies for different parameters. Taken from [9].

Evaluation of alternative treatment processes	Low VOC levels	High VOC levels	Continuous loads	Intermittent loads	Halogenated organics	Temp > 65°C	Temp < 65°C	High flows	Low flows	High humidity	Inorganic particles
Activated Carbon	x		x	x	x		x	x	x		
Thermal oxidation		x	x			x			x	x	
Scrubbers	x	x	x			x	x	x	x		
Particulate filters			x	x			x			x	x
Catalytic oxidation		x	x			x			x	x	

Out3: Residuals

Residuals of the sorting process compromise of recyclables and non-recyclable material. Recyclables can be stored onsite for sale and generate another income source. Non-recyclable material may be used as refuse-derived-fuel (see Section 4.1.3) or have to be disposed of safely at municipal landfills. From the carbonization process, ash and process water remain as residuals. Ash can be returned to soil to restore depleted land or to improve long term fertility. Process water has to be analyzed for its physical and chemical characteristics and treated further if not complying with local regulations for discharge into the environment.

Out4: Noise

Noise plays a role for the health impact assessment but the potential measurable impact on the environment is of minor influence.

4.1.1.5 **Technology Score Card**

Three briquetting technologies are compared based on the requirements described in the methodology section (compare Section 2.4).

The technologies all have similar requirements for **land** because the capacity for treatment is the same. The main influence on land requirements is the process of drying the briquettes. Drying either need to take place under cover, or have full-time monitoring, so that the briquettes can be covered in the event of rain.

Carbonized mechanized technologies require a higher level of **trained labor**, as operation skills for the carbonization process in addition to the handling of mechanized equipment are needed. Emission control is important when carbonization is included and requires that labor is trained and educated to perform analyses and maintain the system.

Raw mechanized requires less **water**, as the process does not need additional water for the compaction of the feedstock. In most cases the naturally occurring binder lignin is sufficient when high pressure is used with un-carbonized feedstock. Carbonized feedstock requires water for the compaction of the briquettes.

Electricity requirements are similar for all three processes. It is important that electricity supplies are reliable during processing hours.

Climatic conditions do not directly influence the briquetting process, but rather indirectly if rain events occur during solar-drying of feedstock and endproducts.

Mechanized technologies have higher requirements on the **supply and support chain**, as the availability of spare parts needs to be ensured.

The potential impact on the **environment** for raw-mechanized technologies is lower than for carbonized methods, as emissions are only released during the carbonization process.

Capital costs are higher for technologies applying mechanization in their processes, as the investment costs are higher than for low pressure technologies without mechanization. The benefit is that more briquettes can be produced in less time, which increases the profit of the business. Another cost factor are mitigation measures that have to be implemented for the carbonization process.

Operation and maintenance are highest for carbonized mechanized technologies. The carbonization process adds complexity to the briquetting business and mechanized parts require regular maintenance.

The risk of failure is highest for carbonized mechanized and carbonized low pressure technologies. The carbonization process requires skilled labor to ensure consistent quality of the endproduct.

Table 14: Technology score card: briquetting

Requirements	Carbonized -Low Pressure	Raw-mechanized - High Pressure	Carbonized mechanized
Land	2	2	2
Skilled Labor	2	2	3
Water	2	1	2
Electricity	2	2	2
Climate	0	0	0
Supply + Support Chain	2	3	3
Environmental	2	1	2
Capital	2	3	3
O&M	2	2	3
Risk of failure (lack of robustness)	3	2	3

4.1.1.6 City context

Bangalore

Briquetting technologies from agro-waste are well established and diffused in India (in fact It is a technology exporter). Therefore, this BM is technologically feasible and technology transfer is not required in Bangalore. Mechanized technologies such as screw extruders and press may be preferred to manual methods, given the higher quality output they produce. Despite higher energy input (60 kWh t^{-1}) screw extruders may be preferred to piston press given: the low maintenance requirement; the final product homogeneity and higher density; and the suitability with both carbonized or not carbonized raw material [10].

For an Indian context, a typical briquette plant of 1.5 t/hr production rate may require a 76.2 kWh per tonne of product and requires a capital investment of 150,000 USD [10].

Usually, the raw material input should have a low moisture content (close to the 8-10% which is the optimal operating capacity of briquetting). In this case, the transfer coefficient raw material to briquette is close to 1:1. However, if the raw material has higher moisture content, a drying step has to be added to the plant layout.

Hanoi

It was apparent based on the Waste Supply and Availability analysis that AIW production in urban Hanoi (for the boundaries of urban Hanoi refer to “Waste Supply and Availability” report) is minimal [2]. Vegetables are mainly produced in the peri-urban and rural areas south of urban Hanoi and rice, as the main harvested crop, is produced north of urban Hanoi. The use of coal as a cooking fuel is very limited in Hanoi as electricity supply for cooking and heating purposes is sufficient. Therefore, it can be expected that the demand for briquettes as a substitute is limited, but there could be potential market demand for use in industries. From the perspective of technical feasibility, briquetting technologies can be expected to function well, if the operators are trained in operation and maintenance of the equipment. Briquettes are already being produced in Vietnam, mainly from rice husks. They are used to heat industrial boilers for co-firing where it can be combined with coal [11]. Therefore, knowledge on briquetting methods exists and technologies could potentially be implemented if the market demand analysis identifies a demand for the use of briquettes.

Kampala

The Waste Supply and Availability analysis identified that most AIW is not produced within the boundaries of Kampala, as large scale agricultural activities mainly take place in the rural areas of Uganda [1]. Other than cassava, maize has the highest yield of all cash crops in Kampala, with 1,054 t/y and 245 t/y, respectively. The analysis did not conclude how much of this production remains as unused waste, as this information is not available.

From the perspective of the technological feasibility, briquetting is a promising option for Kampala. Demand for alternative fuels is high, as charcoal from wood is the main cooking fuel and there is rapid and extensive deforestation in Uganda. Furthermore, hundreds of briquetting businesses already exist in Uganda. The Global Village Energy Partnership (GVEP) has supported many micro-enterprises throughout Uganda, producing less than 20 t/y by using mainly manual technologies [6]. Businesses like Eco-Fuel Africa and Green Bio Energy are producing <200 t/y but utilize motorized machines that are locally fabricated (e.g. electric screw extruders). The feedstock is mainly charcoal dust, as it is not economically viable for the business owner to transport raw materials from far distances. Instead, the business owner leases small carbonization kilns to the farmer, so that the raw material is carbonized at source. Other charcoal dust is collected from local charcoal vendors. One company producing briquettes at larger scale is Kampala Jellitone Supplies (between 200 and 2,000 t/y). Equipment is imported and is fully mechanized (e.g. roller press / large (flywheel) piston). Information exists about a tender by the Ugandan Investment Authority (UIA) for a large scale briquetting factory utilizing dried organic municipal solid waste. A large centralized factory is planned in Kampala and the required investment is 2.2 million USD. However, detailed information on the current status of the project is not available. This analysis identified that adequate local knowledge is available and for small scale implementations of 200 t/y the required machinery could be produced locally.

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.1.2 **Model 1b: Dry Fuel manufacturing (briquettes) from municipal solid waste**

Business model 1b is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Coopérative Pour La Conservation De L'Environement (COOCEN)/Rwanda
2. Case Study Eco-Fuel Africa/Uganda

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.2.1 Brief description

Business model 1b aims at recovering energy from municipal solid waste (MSW) in the form of briquettes. Briquettes can be used as a source of heat and fuel at the household or as a fuel in industries. This model has the same technology setup as model 1a with the difference of MSW being utilized instead of AIW. For the briquetting process only the organic fraction is of interest and has to be collected separately at source or sorted manually or mechanically.

Additionally, characteristics of MSW differ from AIW in terms of moisture, ash and carbon content, volatile matter and calorific value which influences the characteristics of the final product and therefore the burning characteristics as well as emissions. Higher moisture contents also result in higher land requirements for drying prior to compaction. Emissions and mitigation measures are covered in Section 4.1.1.4 of business model 1a. Separation of MSW can be problematic as it is never achieved 100% successfully and adds on additional costs and logistics to the process. They come in different shapes and sizes depending on the technologies that are used and can be carbonized or uncarbonized. The process description is covered in Section 4.1.1.3, "Processes". The feasibility of business model 1b will not be tested in any of the four project cities as it was eliminated during the pre-assessment as depicted in Table 10.

4.1.3 **Model 2a: Independent Power Producer Using Municipal Solid Waste**

Business model 2a is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Husk Power Systems/India
2. Case Study Greenko–Ravikiran Power Project/India

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.3.1 Brief description

Business model 2a is based on the anaerobic digestion of MSW to produce biogas and recover energy. Other possibilities for recovery include burning of refuse derived fuel (RDF) to produce steam, which is fed into generators for electricity production, and digestate (sludge remaining following anaerobic digestion). However, the option of resource recovery from digestate is not analysed in detail as it is not part of the main business model and post-treatment technologies are not defined. Producing electricity is the main component of the business model, which will be fed into the grid for revenue generation.

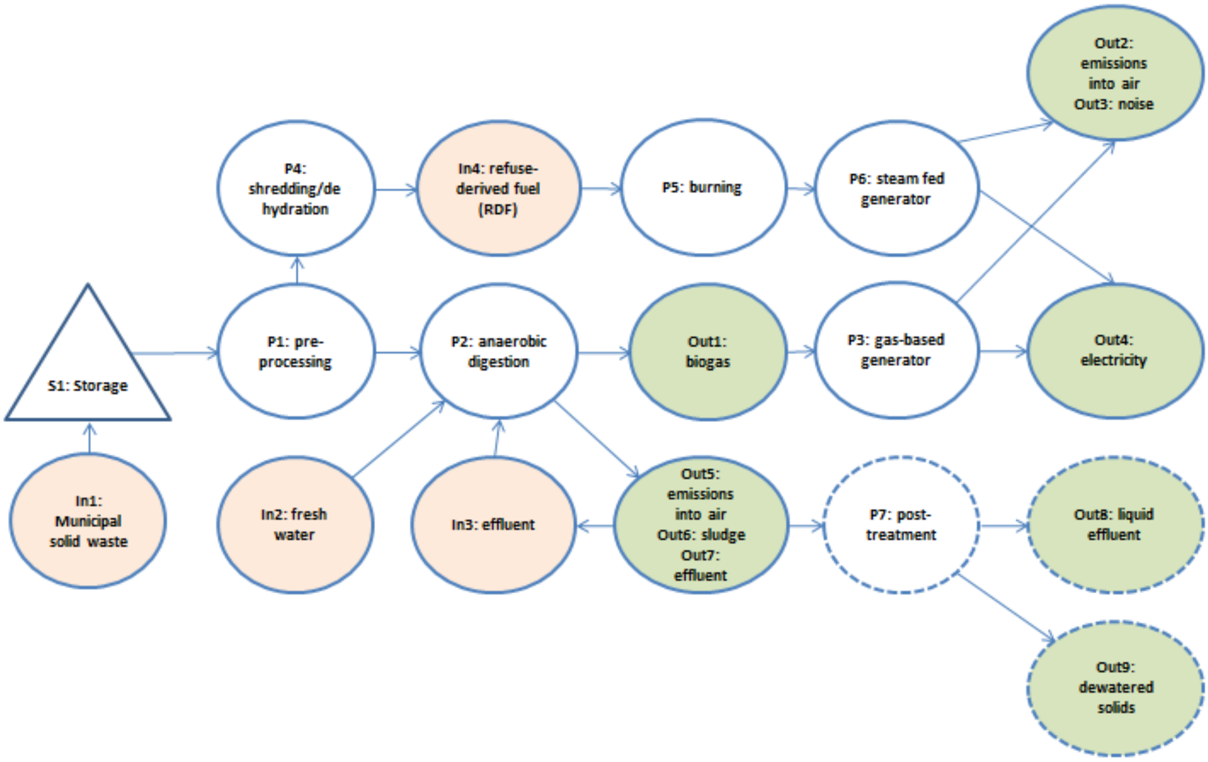


Figure 4: Flow diagram for business model 2a

4.1.3.2 Inputs

In1: municipal Solid Waste

MSW has to be collected separately at the source or sorted manually or mechanically by the business. This adds costs and increases the labor requirements for the business. The organic fraction of the sorted waste is used for anaerobic digestion and residues, such as cardboard, paper and plastics, is used as RDF for electricity generation.

In2: water

Addition of water is required to keep the moisture content at the required level. The water requirements depend on the moisture content of the input material and the applied technology. Technology options that are based on wet fermentation require a total solids (TS) content below 16%, while semi-dry and dry systems require a TS from 22 to 40% [12]. Other requirements and technological options are described under “P4: Anaerobic Digestion” in section 4.1.4.3.

In3: effluent

The effluent of the anaerobic digestion process can be recycled to the influent to maintain the proper moisture content, or reclaimed for agriculture. If reclamation for agriculture is a resource recovery option for the implementing business, appropriate post-treatment technologies need to be implemented that allow safe use of the effluent. MSW should be analyzed for heavy metals to prevent environmental contamination. Use of effluent for irrigation in rural areas is a promising enduse opportunity, while it is not recommended for urban areas and transportation and storage costs.

In4: refuse-derived fuel (RDF)

RDF is the non-recyclable, high calorific value fraction of the sorted MSW. A number of different processes have to be implemented by the business to produce RDF:

- Separation of MSW source
- Manual or mechanical separation of MSW
- Size reduction (shredding, chipping and milling)
- Separation and screening
- Blending
- Drying and pelletizing
- Packaging; and
- Storage

These processes add complexity to the business model, increase costs and labor requirements and furthermore highly increase the need for electricity, which is minimal when operating anaerobic digestion processes.

The waste material is screened to remove the recyclable fraction (e.g. metals) and to separate the biodegradable fraction with a high moisture content and high ash material. The remaining material, such as paper, cardboard, wood, plastic and textiles can be burned directly as coarse fuel or dried and pelletized into dense RDF. The decision of whether or not to pelletize the material is usually based transport concerns by the distance between the RDF manufacturing company and the combustion facility [13]. The production of RDF from MSW is illustrated in Figure 5. The set-up of this process has been used in European countries for many years, while examples from low- and middle-income countries are rare. The following options are commonly used for the utilization and conversion of RDF from MSW to energy:

- On-site in an integrated thermal conversion process, such as fluidized bed combustion, gasification or pyrolysis
- Off-site at a remote facility using processes like fluidized bed combustion, gasification or pyrolysis
- Co-combustion in coal fired boilers
- Co-incineration in cement kilns
- Co-gasification with coal or biomass

While the business model is based on on-site production of electricity and feeding it into the grid for revenue generation, the decision on which of the above listed options is most attractive for the business has to be made on a case by case basis and requires information from the market assessment.

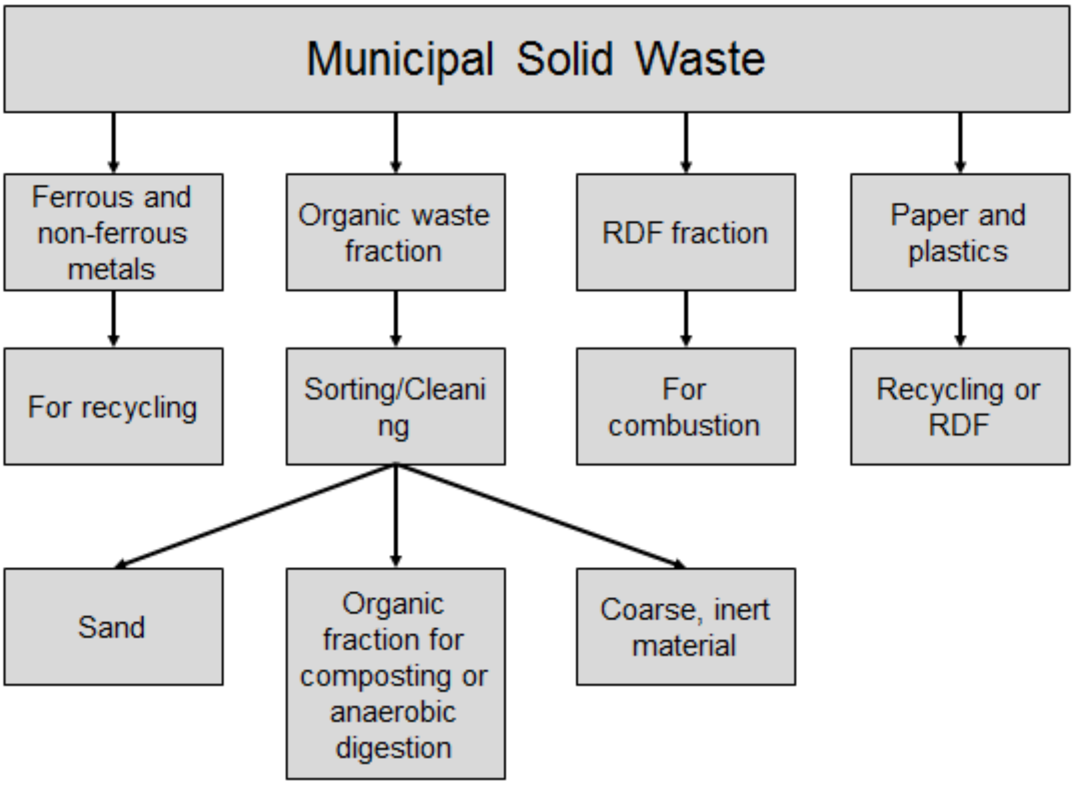


Figure 5: Schematic process of the production of RDF. Adapted from [13].

4.1.3.3 Processes

P1: pre-processing

The pre-processing consists of sorting the MSW into organic and inorganic fractions. Land, electricity and labor requirements are increased if the waste is not separated at source. More information on manual and mechanical sorting is covered in section 4.3.1.3, P1: pre-processing (segregation/sorting).

P2: anaerobic digestion

Anaerobic digestion is a microbial process where organic matter is decomposed in the absence of oxygen. Several groups of micro-organisms are involved in the different stages of anaerobic digestion, and biogas and digestate are generated as endproducts. The biogas can be used for cooking, heating or electricity generation and the digestate can be used to maintain the water content in the anaerobic digester as described in section 4.1.3.2.

The complexity of anaerobic digestion technologies ranges from simple reactors with no moving parts to fully automated industrial facilities. The following operational parameters are important for the design of an anaerobic digester [12]:

- Total solids content of the feedstock (wet/dry systems)
    - Wet systems: TS < 16%
    - Semi-dry and dry systems: TS from 22 to 40%
- Feeding mode (continuous/batch)
- Operation temperature
    - Mesophilic: 30 to 40°C
    - Thermophilic: 45 to 60°C
- Operation types
    - Single stage systems are simple, easy to design, build and operate
    - Multi stage systems are suitable for a plant with capacity above 50,000 t/yr
    - Batch systems, simple and easy to design, build and operate

The decision on the design of the reactor is based on the local context, technical parameters and the experience of the operators. In low- and middle income countries, three main types of digesters have proven to be appropriate for local conditions. The fixed-dome digester, the floating-drum digester and the tubular digester. These three types are all wet digestion systems operated in continuous mode under mesophilic conditions. The main advantage of these systems is that they are inexpensive, built with locally available material, easy to handle, do not have many moving parts and are therefore less prone to failure [14]

Reactors can be operated in three different modes; batch reactor, single stage and multi-stage reactor. Batch reactors are loaded once and only emptied at the end of the anaerobic process. The reactors are simple and have continuous leachate recirculation. The main advantage of batch fermentation is the possibility to recover byproducts, such as anaerobic sludge, after digestion is completed. Batch systems can furthermore be divided into single batch and sequential batch systems. Single batch systems have one chamber where the waste is being digested, while sequential batch systems have two or more reactors, with the advantage of being able to treat a higher volume of waste with more biogas production. Batch reactor require significantly more land acquisition compared to single and multi-stage reactor, while investment costs are around 40% lower [15].

In single stage reactors all four anaerobic digestion stages take place in one reactor, while multi-stage reactors separate these stages in time and space (i.e. hydrolysis and methanogenesis). Single stage systems have the advantage of being simple and easy to operate and they require low investment costs, while the biogas output is lower compared to multi stage reactors. The system is continuously operated and mixed with retention times between 14 and 28 days. Due to the separation of the hydrolysis and methanogenesis step in multi-stage systems, retention times decrease to seven days [15].

P3: gas-based generator (gas cleaning and burning)

For the production of electricity from biogas, gas-based generators are required that convert the chemical energy bound in biogas into mechanical and thermal energy and ultimately electricity. The equivalent of 6 kWh of heating energy is contained in each cubic meter of biogas. About 2 kWh of useable electricity can be obtained when biogas is converted to electricity. The remaining biogas is converted to heat which can then be used for heating applications [14].

The principle behind the conversion is that chemical energy of the combustible gases is converted to mechanical energy, which then activates a generator to produce electrical power. Atmospheric air is compressed, heated and then expanded. The power produced by the expander (turbine) over that consumed by the compressor is used for electricity generation. This thermodynamic process is also known as the Brayton cycle, of which many variations exist today. Figure 6 illustrates the primary components of a simple cycle gas turbine.

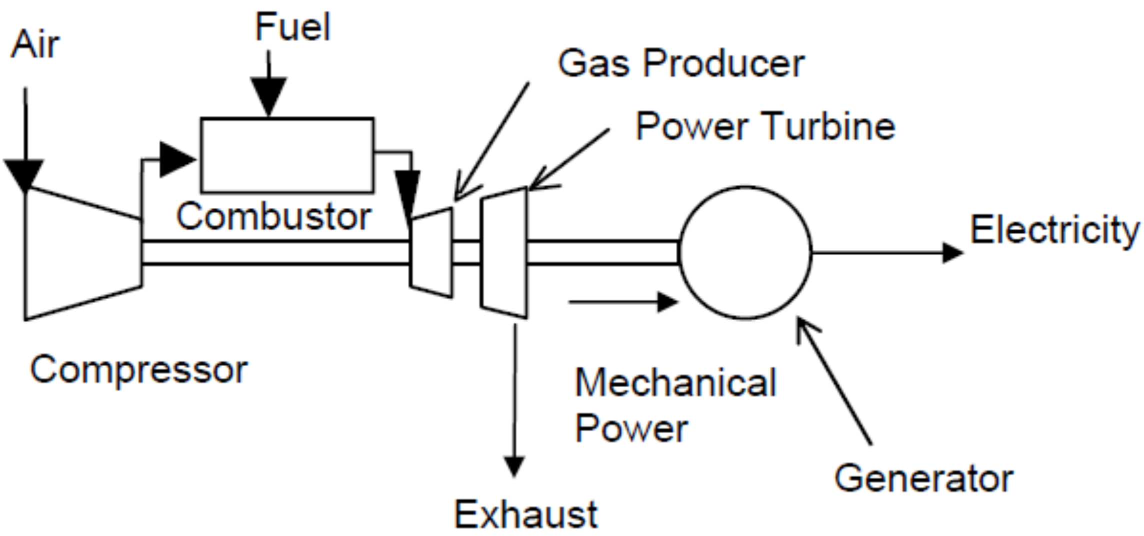


Figure 6: Schematic overview of the components of a simple-cycle gas turbine. Taken from [16].

Two types of heat engines are most commonly used for biogas conversion. These are internal combustion engines, such as gas turbines, and external combustion engines, such as Sterling engines. Gas turbines are more efficient when operating in a cogeneration unit producing heat and electricity. Combined heat and power (CHP) is the commonly used name for these cogeneration units. The units can reach an efficiency of up to 89% as the heat is used, which would be wasted in a conventional power plant [17].

In large scale applications, the most common use of the thermal energy contained in the exhaust gas is for steam generation, also called unfired heat recovery steam generator (HRSG). The generated steam produces electricity, the exhausted steam is condensed and the low temperature heat is utilized for district heating [16, 17]. The process, including a simplified gas turbine, is illustrated in Figure 7.

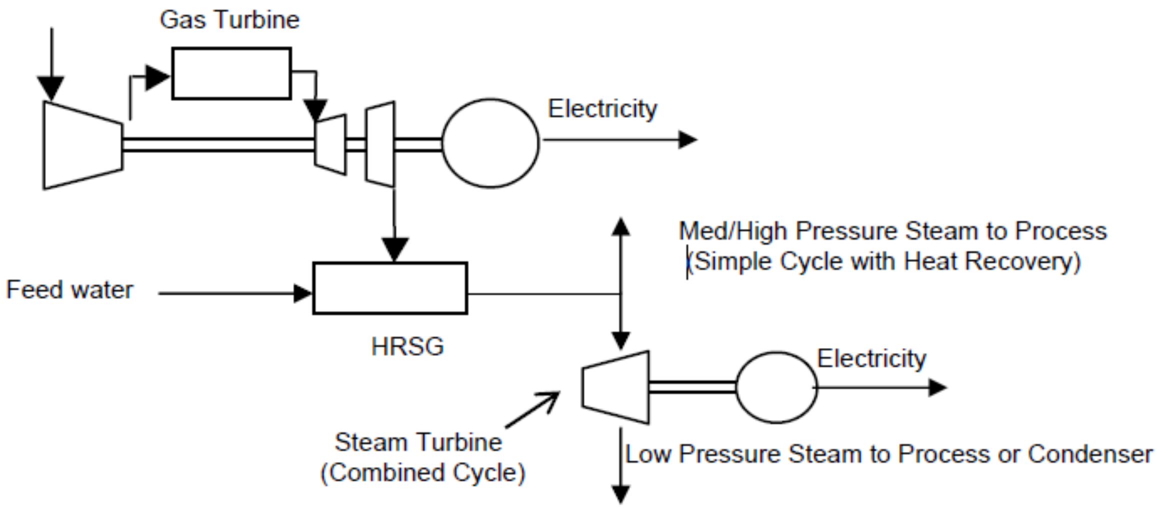


Figure 7: Heat recovery from a gas turbine system. Taken from [16]

Maintenance

Gas turbines require routine maintenance on a daily, monthly and yearly basis, which requires highly skilled personnel. Routine maintenance practices include: online running maintenance, predictive maintenance, plotting trends, performance testing, fuel consumption, heat rate, vibration analysis, and preventive maintenance procedures. On a daily basis, site personnel should monitor filters and general site conditions. Routine inspections are required every 4,000 hours to insure that the turbine is free of excessive vibration due to worn bearings, rotors and blade tips. A reliable spare part supply chain is required for this. The gas turbine itself needs to be overhauled every 25,000 to 50,000 hours which typically includes a complete inspection and rebuild of components to restore the gas turbine to nearly original performance standards [16].

Emissions

Even though gas turbines are among the cleanest fossil-fueled power generation equipment that is commercially available, some emissions still need to be taken into consideration. Primary pollutants are oxides of nitrogen (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs). The gas turbine operating load has a significant effect on the emissions level of these pollutants. At higher loads, higher NO_x emissions occur, while lower loads results in higher emissions of CO and VOC. NO_x emissions can be controlled and limited by the control of peak flame temperature using diluent (water or steam) injection or by maintaining homogenous fuel-to-air ratios. CO and VOCs result from incomplete combustion. CO is usually regulated to levels below 50 ppm (parts per million) for both health and safety reasons. A wide range of compounds can be contained in VOCs, some of which are hazardous air pollutants. Emission control options are [16]:

- Diluent injection
- Lean premixed combustion
- Selective catalytic reduction
- Carbon monoxide oxidation catalysts
- Catalytic combustion
- Catalytic absorption systems

P4: post-treatment

If reclamation of water and use of sludge are resource recovery option for the implementing business, appropriate post-treatment technologies that allow safe use of effluent and sludge have to be implemented. The goal of RRR based businesses should be full resource recovery from all endproducts, and disposal at landfills is not advocated. In any case, the effluent and sludge have to comply with local regulations and post-treatment technologies have to be implemented.

Post-treatment technologies have to be designed depending on the intended enduse and level of treatment. Dewatering, stabilization, nutrient removal and pathogen reduction are achieved by different technology set-ups.

Dewatering can be achieved by sedimentation of effluent and sludge in settling-thickening tanks, Imhoff tanks and drying beds. Refer to section 4.3.1.2: In2: faecal sludge, for a full description of these technologies.

Stabilization and pathogen reduction of sludge can be achieved by composting processes, such as windrow composting, which is described in detail in section 4.3.1.3. Pathogen reduction of sludge from planted and unplanted drying beds, depends on the retention time on the beds and needs to be evaluated on a case by case basis, as the intended enduse also influences the required level of treatment [18]. For example, sludge that is used for a soil conditioner needs to be safe for handling and requires higher pathogen reduction than sludge that is used as a fuel in industries.

Liquid effluent can be treated by a range of technologies, such as constructed wetlands, stabilization ponds or activated sludge processes, which are also common for the treatment of wastewater. Treatment technologies that are commonly implemented in low- and middle-income countries are covered in detail in the 2nd revised version of the Compendium of Sanitation Systems and Technologies [19]. A detailed technology assessment for post-treatment of byproducts from anaerobic digestion can be performed, once the resource recovery intention of the implementing business is decided.

P5: shredding dehydration

Shredding and size reduction of MSW has three main benefits [20]:

- The bulk waste stream is broken up into its components by tearing and breaking open paper, plastic and glass containers, which enhances the efficiency of the following separation mechanisms
- It reduces the average particle size which makes it easier to be handled by any subsequent processing equipment or personnel
- It produces different size distributions for the different material components of MSW, allowing for automated material separation such as air classifiers, screens and optical sorters

Shredding devices for MSW range from automobile shredders, which are able to process almost anything, to granulators and paper shredders that can process only relatively soft materials. Two main types of shredders are used widely; high speed, low torque (HSLT) hammermills and low speed, high torque (LSHT) shear shredders. HSLT and LSHT are quite different, and hence have distinct advantages and disadvantages regarding the acceptable MSW feed, as well as the size distribution of the product and overall process capacity. HSLT devices have a power consumption of 6-22 kWh/ton, while LSHT machines are in the range of 3-11 kWh/ton [20]. The right choice of technology depends on the characteristics of the incoming MSW, whether it is source separated, pre-sorted or mixed and parameters such as moisture content. For a final decision on technology, these parameters need to be evaluated.

P6: burning

During the burning process emissions will be released, which require mitigation measures to ensure compliance with local regulations and protection of the environment.

P7: steam fed generator

A steam fed generator is used to convert the thermal energy, which is created by the burning of the RDF, into mechanical energy to produce electricity. The principle is the same as for the gas-based generator, where the chemical energy of the gas is converted into mechanical energy.

4.1.3.4 Outputs and Potential Environmental Hazards

The production of RDF causes at least two different types of potential environmental hazards:

1. The burdens due to consumption of process energy (mostly electricity from the public grid or onsite production of steam)
2. Process discharges to the air (particulate matter from mechanical treatments, vapours from drying or pressing processes)

Emissions and the impact of RDF highly depend on the use and form of the fuel. A comprehensive environmental impact assessment was done by the European Commission in the Document “Refuse derived fuel, current practice and perspectives (B4-3040/2000/306517/MAR/E3)” [13].

Out1: biogas

Biogas is generated as an endproduct of the anaerobic digestion process. As shown in Table 15, biogas mainly consists of methane and carbon dioxide. In this form it has impurities but could be used as a cooking fuel. For electricity generation, further cleaning and a gas-based generator are required, which is described in section 4.1.3.3, P3: gas-based generator.

Table 15: Typical composition of biogas from the organic fraction of municipal solid waste

Components		Concentration
Methane	CH_4	55-60 (50-75)
Carbon dioxide	CO_2	35-40
Water	H_20	2 (20°C9 – 7 (40°C)
Hydrogen sulphide	H_2S	20-20,000 ppm (2%)
Nitrogen	N_2	<2
Oxygen	O_2	<2
Hydrogen	H_2	<1

Out2: emissions into air

Emissions into air are covered under P3: gas-based generator “Emissions” in section 4.1.3.3 and in section 4.1.1.4, Out2: emissions into air.

Out3: noise

Noise will not be covered as part of the technology assessment, but is covered by the environmental and health assessment

Out4: electricity

Electricity is the core revenue stream of the implementing business and will be fed into the grid for revenue generation.

Out5: emissions into air

Emissions from anaerobic digestion processes are minimal if the reactor is operated appropriately. It needs to be ensured that the digester does not have any leakages as this can cause health and environmental threats. Methane is a greenhouse gas and there is potential for explosion.

Out6: sludge

Sludge that is produced during the anaerobic digestion processes requires post-treatment. The goal of RRR based businesses should be full resource recovery from all endproducts, and disposal at landfills is not advocated. In any case, the effluent and sludge have to comply with local regulations and post-treatment technologies have to be implemented. Post-treatment processes are covered in section 4.1.3.3, P4: post-treatment.

Out7: effluent

Refer to section 4.1.3.2, In3: effluent.

Out8: liquid effluent

Liquid effluent is an endproduct of the post-treatment steps for the treatment of by-products from anaerobic digestion. The effluent can be discharged into the environment, if complying with local regulations, or used for reclamation of water and/or nutrients in agriculture. The decision has to be made by the business and is out of scope of the business model assessment.

Out9: dewatered solids

Dewatered solids are an endproduct of the solid-liquid separation performed by the implemented post-treatment technologies. Various enduse possibilities for dewatered solids exist. Which enduse is most appropriate and could potentially create another revenue source for the implementing business relies on the applied post-treatment technologies. The decision has to be made by the business and is out of scope of the business model assessment.

4.1.3.5 Technology Score Card

In this assessment, possible anaerobic digestion technologies are compared Figure 8, based on their operating system. Single and sequential batch systems are summarized as one system as the differences are minimal. Land requirements for batch systems are highest, as the systems are not operated in a continuous mode. Incoming waste needs to get stored and the anaerobic sludge requires post-treatment and drying after the digestion process is complete. Multi-stage systems require more space than single stage systems, as two or more reactors are utilized.

Batch systems require the least skilled labor, as they are easier to operate than single stage and multi-stage systems. Multi-stage systems can be highly complex, equipped with moving parts and intelligent sensors, which help to operate the plant but need highly educated personal. Batch systems on the other hand require more maintenance work, which requires less educated personal but makes the system more prone to failure.

Water is required in all three systems with medium requirements.

Multi-stage systems require the most electricity due to the operation of several reactors, which include moving parts. Batch reactors only require electricity if external heating of the system is included.

Even though anaerobic digestion processes and conversion rates are highly dependent on temperatures, the climate requirements are comparatively low as the systems can be heated externally. In tropical conditions, external heating is generally not required unless anaerobic digester is operated under thermophilic conditions, which would increase the electricity requirements.

For similar reasons as to skilled labor the requirements on the supply and support chain are highest for multi-stage systems and decreasing for single stage and batch systems due to the decrease of moving parts and complexity in operation. The same accounts for capital costs.

The potential environmental impact of all three technologies is low. A remaining risk is explosion during the emptying process and potential pollution with methane and carbon dioxide, which are both greenhouse gases.

Capital costs are highest for multi-stage systems, as the business needs to invest into a more complex technology set-up with moving parts. Single stage systems require less capital than multi-stage systems and batch systems are the least costly option.

Operation and maintenance requirements are highest for multi-stage system, as the operation requires knowledge of highly skilled labor and more regular maintenance is necessary compared to batch and single-stage systems.

The risk of failure is highest for batch reactors, as the loading of the reactor has to be repeated after anaerobic digestion of one batch is finished. During the start-up of the reactor, all parameters have to be adjusted, so that optimal conditions for anaerobic digestion exist. Multi-stage systems are less prone to failure as the material inside the system is constantly mixed. The separation of hydrolysis and methanogenesis increases the risk of failure compared to single stage systems.

Requirements	Single Stage	Multi-Stage	Batch
Land	1	2	3
Skilled Labor	2	3	1
Water	2	2	2
Electricity	1	2	1
Climate	1	1	1
Supply + Support Chain	2	3	1
Environmental	1	1	1
Capital	2	3	1
O&M	1	3	1
Risk of failure (lack of robustness)	1	2	3

Figure 8: Technology score card: anaerobic digestion.

4.1.3.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

As of the pre-selection of cities for feasibility testing, presented in Table 10, Hanoi was not selected for testing of this business model.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

This business model is based on the production of electricity from organic solid waste via biogas. Technologically speaking the implementation of this business model may be challenging in Lima given that: there are only few examples of anaerobic digestion from MSW at large scale in the region (therefore, technology transfer may be required); and the majority of solid waste at the moment is mixed and needs to be well sorted at plant level. Furthermore, this technology may need large quantity of water, necessary to lower the concentration of TS from 20-30% (typical of organic waste) to <10%. This is a typical operating condition of wet anaerobic digestion [14].This may be an important operating constraint in a water scarce region such as Lima.

Nevertheless, anaerobic digestion from other waste streams (e.g. manure) exists in the region and technological transfer may not be too problematic.

4.1.4 **Model 2b: Independent Power Producer Using Animal or Crop Waste**

Business model 2b is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study BRAC / Bangladesh
2. Case Study Mailhem Pune Corporation/India

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.4.1 Brief description

Business model 2b produces electricity by gasification of AIW and anaerobic digestion of animal manure (AM). The revenue streams of the business model are the same as in business model 2a, where the generated electricity is sold to households, businesses or local electricity authorities.

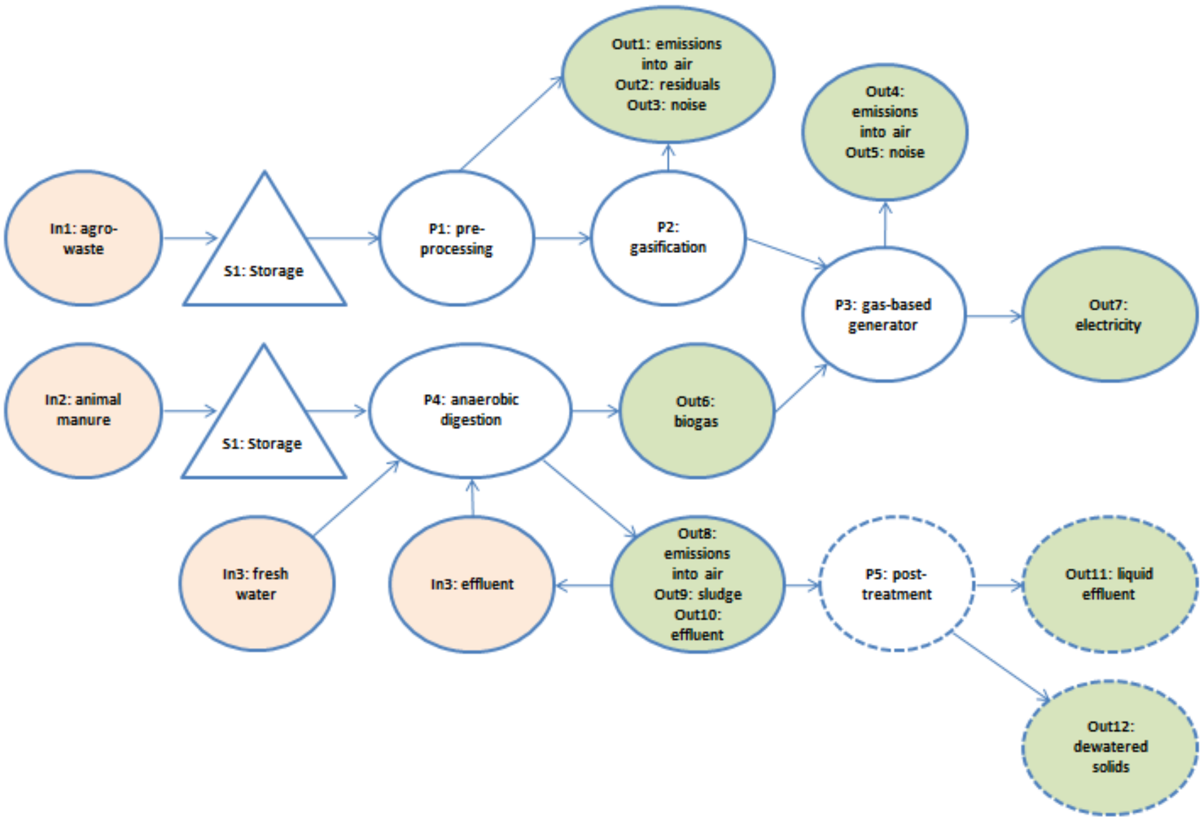


Figure 9: Flow diagram for business model 2b

4.1.4.2 Inputs

In1: AIW

The characteristics of the utilized biomass greatly influence the performance of the gasifier. Therefore, a proper understanding of the physical and chemical properties of the used AIW is essential for the design of a gasifier that will be reliable. As this report focuses on a general description, all possible parameters are not evaluated here. For the implementation of the business model, it will be inevitable to analyze the waste stream on its characteristics prior to the design of the treatment technology. Important parameters include: moisture, organic matter, ash content and higher heating value.

In2: Animal manure

As described by the business model, animal manure is the only substrate for the anaerobic digestion process. The process itself is described in more detail in section 4.1.3.3, P2: anaerobic digestion. Animal manure, has been used as a substrate and co-substrate for anaerobic digestion over many years because of the following reasons: high buffer capacity and high water content with total solids contents of 3-5% for pig manure and 6-9% for manure from cattle and dairy cows. It is also rich in a wide variety of nutrients that are necessary for optimal bacterial growth. These characteristics are beneficial when treating animal manure in co-digestion with other organic solid waste, but when treating animal manure alone, the methane yield is relatively low, ranging from 10-20 m^3 CH_4/ton. This is due to the low solids content and a high content of fibers, consisting of lignocellulose. Other organic solid wastes are characterized by a high content of carbohydrates, proteins and lipids which are bioavailable and ultimately lead to a biogas yield higher than 25 m^3/ton feedstock, which leads to a more economically feasible digestion process [21]. It is recommended to consider an alteration of the business model from digestion of animal manure only, to co-digestion with other solid organic waste streams, such as MSW.

In3: Water

Addition of water at the influent of the anaerobic digester is required to keep the moisture content at the required level. The water requirements depend on the characteristics of the utilized animal manure and the applied technology. Technology options that are based on wet fermentation require a TS content below 16%, while semi-dry and dry systems require a TS from 22 to 40% [12]. Other requirements and technological options are described in section 4.1.3.3., P2: anaerobic digestion.

In4: effluent

The effluent of the anaerobic digestion process can be recycled to the influent to maintain the proper moisture content, or reclaimed for agriculture. If reclamation for agriculture is a resource recovery option for the implementing business, appropriate post-treatment technologies need to be implemented that allow safe use of the effluent, as anaerobic digestion cannot ensure the inactivation of pathogens that are present in AM.

4.1.4.3 Processes

P1: pre-processing

The pre-processing of AIW is similar to briquetting and composting pre-processes. Even though the impurities in AIW can be expected to be low, some manual sorting has to be implemented to ensure highest quality. Further input requirements for gasification are covered under P2: gasification.

P2: gasification

Gasification is a chemical process that converts carbonaceous materials into useful gaseous fuels or chemical feedstock. During gasification, hydrogen is added and carbon is stripped away from the feedstock to produce gases with a higher hydrogen-to-carbon ratio. The gas is water cooled and cleaned through a series of filters and a cloth filter to eliminate particulate matter. The range of technologies that has been developed for the gasification of organic waste is presented in Figure 11.

A typical gasification process includes the following steps:

- Drying
- Thermal decomposition or pyrolysis
- Partial combustion of some gases, vapors and char
- Gasification of decomposition products

Pyrolysis partially removes carbon from the feed but does not add hydrogen, while gasification requires a gasifying medium. The conversion of biomass through gasification can be applied with supercritical water, air/oxygen and steam and the use of a medium is essential for the gasification process.

There are three types of primary fuel that are produced from biomass gasification:

- Liquid (ethanol, biodiesel, methanol, vegetable oil, and pyrolysis oil)
- Gaseous (biogas (CH_4, CO_2), producer gas (CO, H_2, CH_4, CO_2, H_2), syngas (CO, H_2), substitute natural gas (CH_4))
- Solid (charcoal, torrefied biomass)

Yield and composition are influenced by different factors, such as:

- Type of waste
- Reactor system
- Peak temperature
- Heating rate
- Gas residence time
- Vapor/solid contact time
- Pressure range

Depending on these parameters the primary fuel products vary in their composition, as presented in **Table 16**.

Table 16: Parameters and yields in different operation modes.

	Max char yield	**Max liquid yield**	**Max gas yield**
Temperature	Low	Low	High
Heating rate	Low	High	Low
Gas residence time	Long	Short	Long
Particle size	Large	Small	Very small

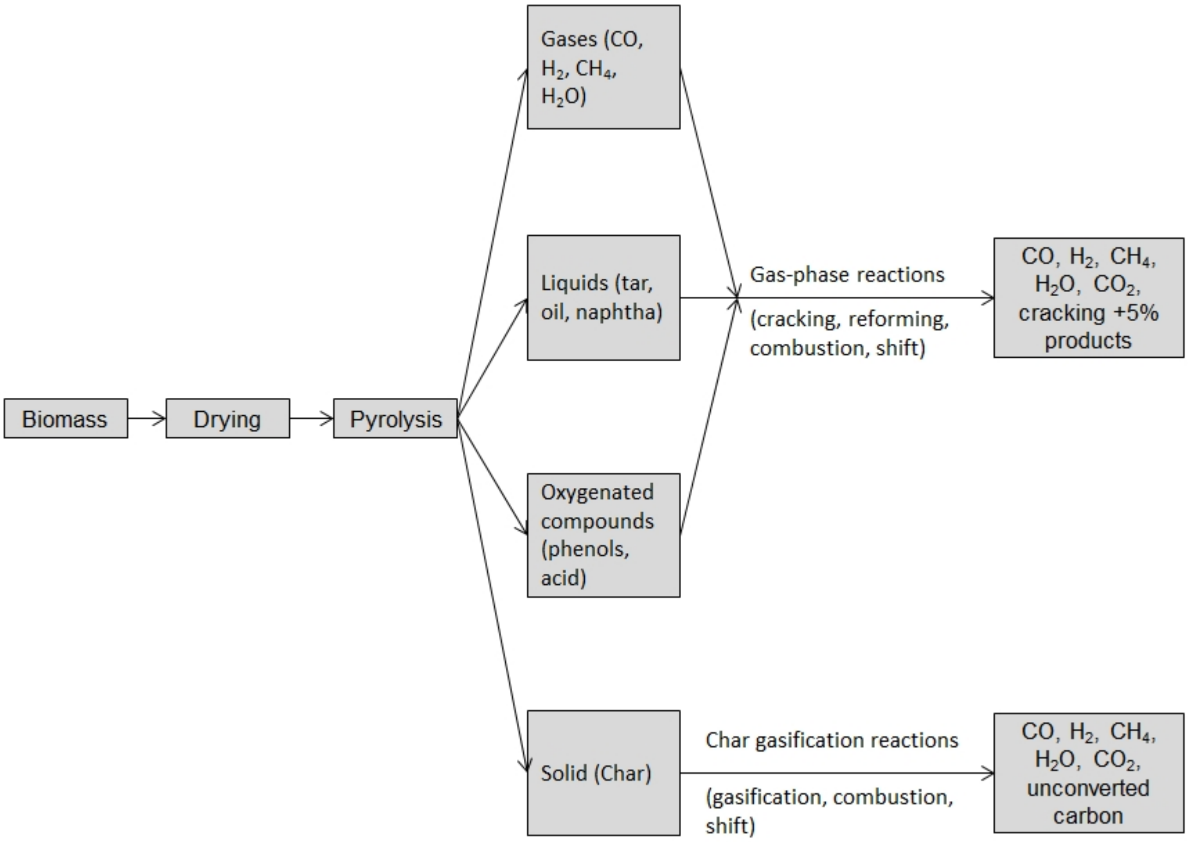


Figure 10: Different potential paths for gasification of biomass. Adapted from [22]

Tar is another by-product and major nuisance of biomass gasification. It is a highly viscous liquid that condenses in the low-temperature zones of the gasifies, which leads to clogging of the gas passage and can create the following problems:

- Condensation and subsequent clogging of downstream equipment
- Formation of tar aerosols
- Polymerization into more complex structures

The amount of tar production depends on the applied gasifier type. Existing types are:

- Moving bed reactor
- Downdraft gasifier
- Fluidized bed reactor
- Entrained flow reactor

The tar concentration in the product gas of these gasifier types is presented Table 17 and Figure 11 shows commercial suppliers of gasification technologies. The technologies are presented to illustrate a range of what exists, and are not being assessed in more detail.

Table 17: Tar concentration for different gasifier types [22].

Gasifier type	**Average tar concentration in product gas (g/Nm^3)**	**Tar as % of biomass feed**
Downdraft	<1.0	<2.0

Fluidized bed	10	1-5
Updraft	50	10-20
Entrained flow	Negligible	

Existing gasification technologies are:

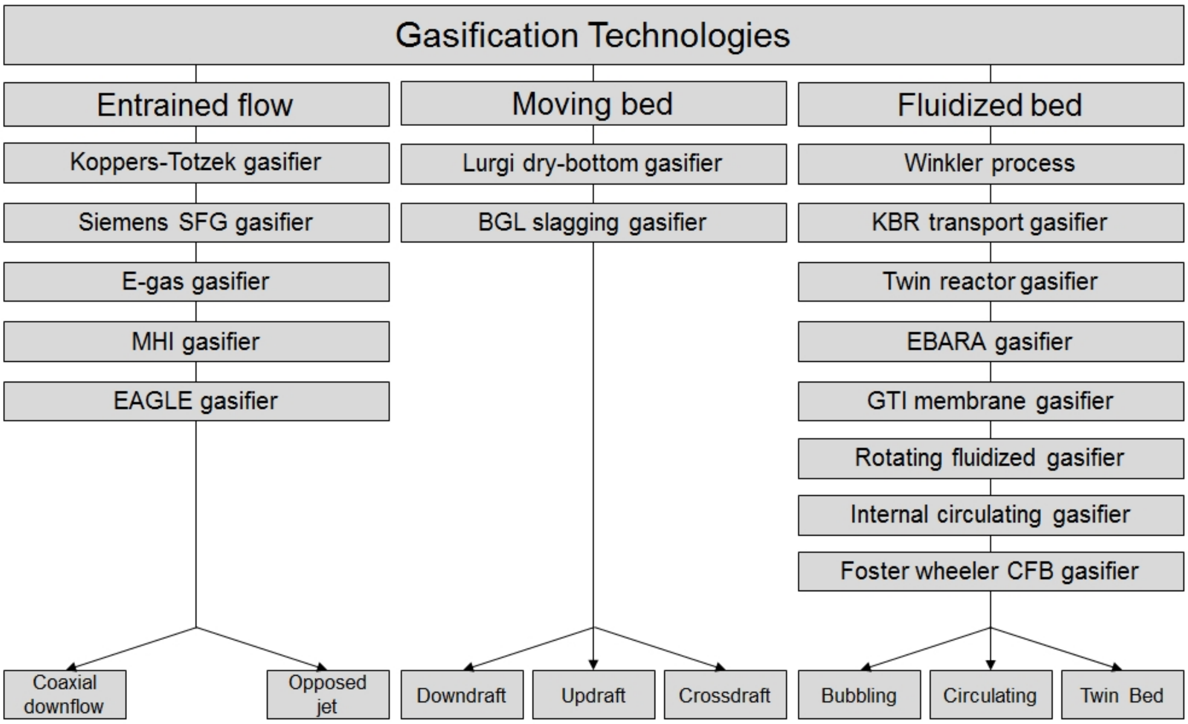


Figure 11: Gasification technologies and their commercial suppliers. Adapted from [22].

Another important factor in the decision making process for gasifier types is the range of applicability amongst energy outputs. Downdraft types are applicable in the range of 10 kW to 1MW and entrained flow types at the upper range between around 80 to 1000 MW. Fluidized bed and updraft reactors can be applied between 1 and 100 MW (compare Figure 12).

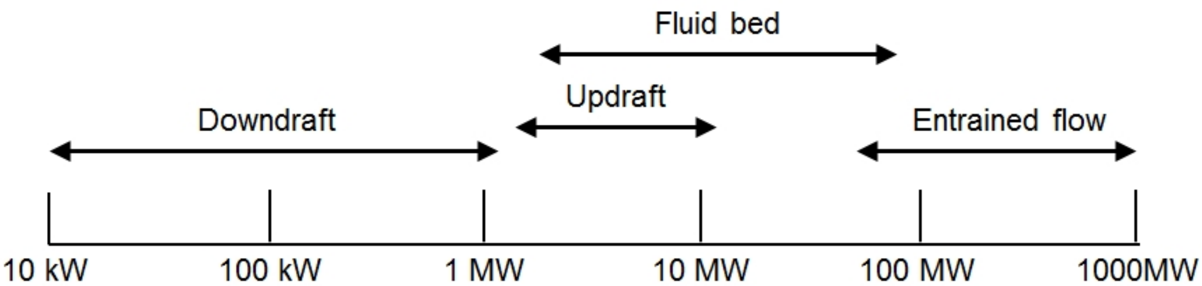


Figure 12: Range of applicability for biomass gasifier types. Adapted from [22]

P3: gas-based generator (gas cleaning and burning)

Refer to Section 4.1.3.2, P3: gas-based generator.

P4: Anaerobic digestion

Refer to section 4.1.3.3, P2: anaerobic digestion.

P5: Post-treatment

Refer to section 4.1.3.3, P4: post treatment.

4.1.4.4 Outputs and Potential Environmental Hazards

Out1: emissions into air

Emissions from pre-processing of AIW are minimal and are hence not considered.

Out2: residuals

Residuals of gasification technologies are tar, char and oil as described under P2: gasification. Char can be compacted into briquettes and create another revenue stream for the business. Briquetting processes are covered in section 4.1.1.3, P3 briquetting. The post-treatment of tar and oil would be too cumbersome for the business operator and would need to be collected, safely stored and then disposed of at an appropriate location, which usually there is a fee for.

Out3: noise

Noise will not be covered as part of the technology assessment, but is covered by the environmental and health assessment**.**

Out4: emissions into air

Refer to section 4.1.3.2, P3: gas-based generator.

Out5: noise

Noise will not be covered as part of the technology assessment, but is covered by the environmental and health assessment.

Out6: biogas

Refer to section 4.1.3.4, Out1: biogas.

Out7: electricity

Refer to section 4.1.3.4, Out4: electricity.

Out8: emissions into air

Refer to section 4.1.3.4, Out5: emissions into air.

Out9: sludge

Refer to section 4.1.3.4, Out6: sludge.

Out10: effluent

Refer to section 4.1.4.2, In4: effluent.

Out11: liquid effluent

Refer to section 4.1.3.4, Out8: liquid effluent.

Out12: dewatered solids

Refer to section 4.1.3.4, Out9: dewatered solids.

4.1.4.5 Technology Score Card

The technology score card in Table 18 compares three different anaerobic digestion processes. A technology score card for gasification was not created due to the wide range of technologies and operation modes. For the assessment of anaerobic digestion processes, refer to section 0.

Table 18: Technology score card for anaerobic digestion.

Requirements	Single Stage	Multi-Stage	Batch
Land	1	2	3
Skilled Labor	2	3	1
Water	2	2	2
Electricity	1	2	1
Climate	1	1	1
Supply + Support Chain	2	3	1
Environmental	1	1	3
Capital	2	3	1
O&M	1	3	1
Risk of failure (lack of robustness)	1	2	3

4.1.4.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

The application of anaerobic digestion in peri-urban and rural areas has been successful, but similar as for Kampala, as described in the “Waste Supply and Availability” report, most AIW and AM is not produced within urban Hanoi (for the definition of urban Hanoi refer to the “Waste Supply and Availability” report) [2].

Similar to anaerobic digestion, gasification would only make sense if applied in the peri-urban and rural areas, where the AIW is produced.

Kampala

As described in the “Waste Supply and Availability” report [1], most AIW is not produced within the boundaries of Kampala, but in the surrounding areas. This results in high transportation costs, if produced electricity is utilized within the city boundaries. Gasification does not seem to be a well-established technology in Kampala. The only existing information reports a 160 million USD project on the construction of a biomass gasification plant within a collaboration agreement between Taylor Biomass Energy and Uganda’s Sesame Energetics Limited. This agreement was signed in 2011 and is supposed to generate 40 MW of power, using 1000 tons of MSW per day. The electricity will be used by the coffee and manufacturing industries, but no information exists about the status of construction of this facility [23]. A small-scale gasification project was implemented in Mukono District, outside Kampala, producing 10 kW of electricity per day. This system was assessed in detail within the health and environmental impact assessment [24].

The “Waste Supply and Availability” report furthermore revealed that animal manure within the boundaries of Kampala is produced at around 1800 farms, which include breeding sheep, goats, cattle, pigs and poultry [24]. Around 58,492 tons of animal manure is produced per year and 59% remain unused, while the main application is the use as a fertilizer/soil conditioner (32%) and biogas being applied 1% of the time. Farms are mostly small-scale at the household level, which concludes that a large scale application of anaerobic digestion is difficult due to collection and transport logistics. Ugachick, a large scale farm, lies outside the boundaries of Kampala and slaughters 120,000 chickens per week. No information exists about the current use of produced animal manure.

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.1.5 **Model 3: Onsite energy generation from agro industry and livestock waste**

Business model 3 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Mumias Sugar Company/Kenya
2. Case Study Nyongara Biogas Plant/Kenya
3. Case Study Thai Biogas Energy Company/Thailand
4. Case Study Shri Someshwar Sahkari Sakhar Kharkhana (SSSSK)/India

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.5.1 Brief description

Business model 3 is based on the fermentation and distillation of MSW, specifically sugar cane bagasse. The endproduct of distillation is ethanol, which is the first revenue stream of the business. In addition, as in business model 2b, animal manure is also used for the production of biogas and electricity. The ethanol is sold to petroleum and pharmaceutical companies, while the electricity is fed to into the grid. The technical assessment focuses on the fermentation and distillation processes, as anaerobic digestion is explained in detail in section 4.1.3 and 4.1.4. **Figure 13** shows the flow diagram of the business model.

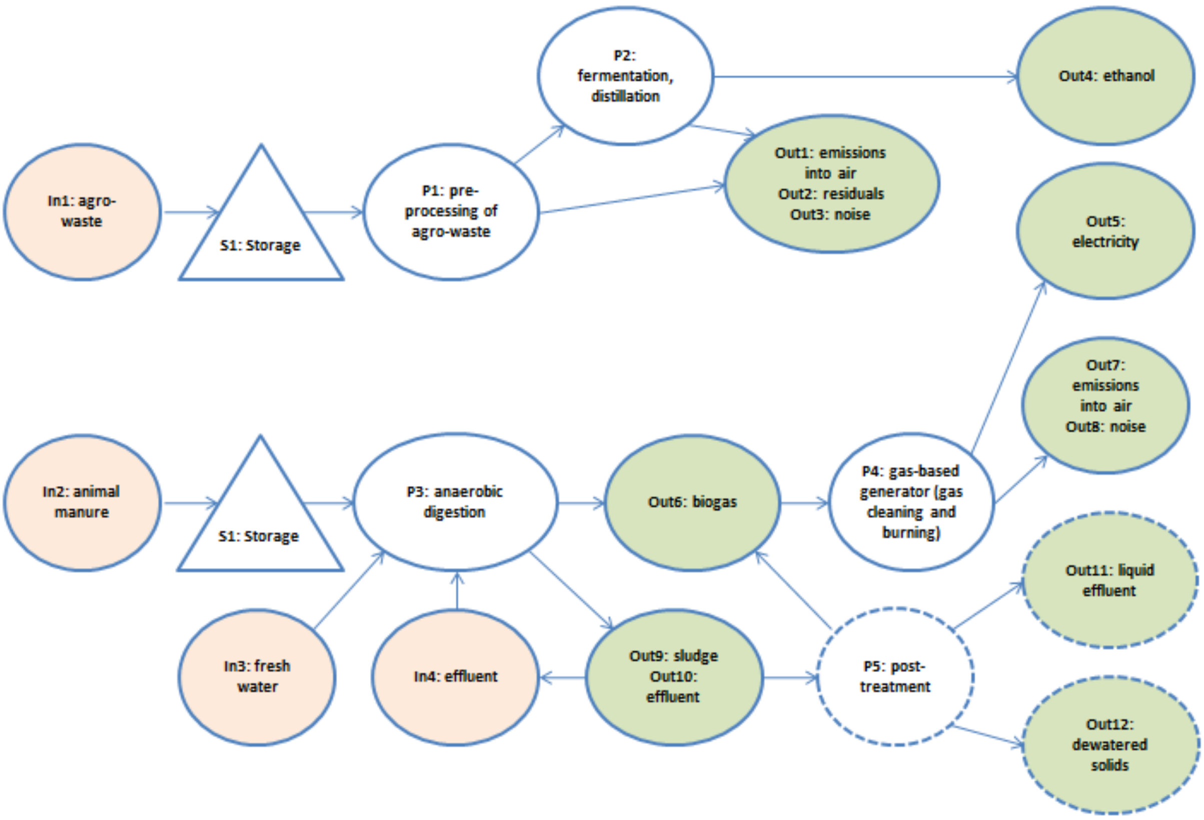


Figure 13: Flow diagram for business model 3.

4.1.5.2 Inputs

In1: AIW (primarily sugar cane bagasse)

Sugarcane consists of a stem and straw. The sugarcane straw is divided into three different components, which are fresh leaves, dry leaves and tops. The stems are milled to obtain sugar cane juice, which is subsequently used for the production of sugar or ethanol. Bagasse is the residual of the sugarcane stem. Both sugarcane bagasse and straw can be used for ethanol production.

In2: animal manure

Refer to Section 4.1.4.2, In2: animal manure.

In3: water

Refer to Section 4.1.4.2, In3: water.

In4: effluent

Refer to Section 4.1.4.2, In4: effluent.

4.1.5.3 Processes

P1: pre-processing of AIW

As the business model requires sugarcane bagasse as the input product, the pre-processing is already covered within the company that utilizes the sugarcane. Bagasse is a by-product and pre-processing is covered under P2: fermentation, distillation.

P2: fermentation, distillation

In order to understand the process of the conversion of sugarcane bagasse into ethanol, a general understanding of chemical, biological and physical processes is required. The business requirements for skilled labor are high and operation and maintenance is complex.

Sugarcane bagasse and straw are chemically composed of cellulose, hemicellulose and lignin. Converting the biomass into ethanol requires a couple of different steps, each depending on whether the cellulose, the lignin or the hemicellulose is broken down. Steps included are pretreatment of biomass, enzymatic hydrolysis of cellulose, fermentation of hexose/pentose sugars and finally the recovery of ethanol. A wide range of technologies and processes exist for the pre-treatment of sugarcane bagasse, the development of enzymes for enhanced cellulose/hemicellulose saccharification and suitable technologies for the fermentation of hexose and pentose sugars. Pretreatment technologies can be categorized into four types [25]:

- Physical (mechanical)
    - Processes include: milling, pyrolysis, microwave
- Physiochemical
    - Requires a high control of operation conditions because reactions occur at high temperature and pressure
    - Processes include: steam explosion or hydrothermal
    - Ammonia fiber explosion
    - CO_2 explosion
    - Hot water (under high pressure)

- Chemical pretreatments
    - Acid pretreatment
    - Alkaline pretreatment
    - Oxidative delignification
    - Ozonolysis
    - Organosolv
    - Wet oxidation
- Biological
    - Alternative to chemical pretreatment, fungi are employed for biological pretreatment

Followed by the pretreatment, the enzymatic reaction of the cellulosic fraction follows. Several types of processes can be applied for these reactions. Microorganisms are most commonly used for the fermentation of sugars into ethanol. Yeast is the preferred choice for fermentation and the sugars are converted to produce ethanol and CO_2.

The required last step to produce a high quality endproduct is the distillation of ethanol. It is the highest energy consuming process during the ethanol production but is necessary as the final medium is composed by water and ethanol. Conventional distillation processes cannot be applied because ethanol-water forms a non-ideal mixture system. Therefore three steps have to be applied: distillation, rectification and dehydration [25].

P3: anaerobic digestion

Refer to Section 4.1.4.3, P4: anaerobic digestion.

P4: gas-based generator (gas cleaning and burning)

Refer to Section 4.1.3.3, P3: gas-based generator

P5: post-treatment

The covered lagoon bioreactor is a large lagoon with anaerobic conditions, long retention times and a high dilution factor. Reactors used for the treatment of animal manure have an influent of 0.5 to 2% TS. They are not heated, perform well at ambient temperatures and have retention times of 30 to 45 days or longer, depending on the size. The captured biogas can be used to produce electricity and heat by using a CHP unit (more detail see Section 4.1.3.3, P3: gas-based generator).

4.1.5.4 Outputs and Potential Environmental Hazards

Out1: emissions into air

Emissions of concern for the production of ethanol are: particulate matter, volatile organic compounds and hazardous air pollutants (HAPs). These are released during fermentation and distillation as well as from storage tanks. Scrubbers and thermal oxidizers have to be implemented for mitigation. More details on emission control are covered in section 4.1.1.4, Out2: emissions into air. The application of emission control technologies for different parameters is presented in the same section in Table 13.

Out2: residuals

Both, the sugar cane stem and straw can be used for the production of ethanol. The milled sugar cane stems are the residual of the production of sugar can bagasse. The remaining material is minimal and can be disposed of off-site.

Out3: noise

Noise plays a role for the health impact assessment but the potential measurable impact on the environment is of minor influence.

Out4: ethanol

Ethanol is the endproduct of the fermentation and distillation processes. It is flammable and therefore needs to be stored safely in distance to any source of ignition.

Out5: electricity

Electricity will be fed into the grid for revenue generation.

Out6: biogas

Refer to section 4.1.3.4, Out1: biogas.

Out7: emissions into air

Refer to section 4.1.3.2, P3: gas-based generator.

Out8: noise

Noise plays a role for the health impact assessment but the potential measurable impact on the environment is of minor influence.

Out9: sludge

Sludge that is produced during the anaerobic digestion processes requires post-treatment. The goal of RRR based businesses should be full resource recovery from all endproducts, and disposal at landfills is not advocated. In any case, the effluent and sludge have to comply with local regulations and post-treatment technologies have to be implemented. Post-treatment processes are covered in section 4.1.3.3, P4: post-treatment.

Out10: effluent

Refer to section 4.1.3.2, In3: effluent.

Out11: liquid effluent

Refer to section 4.1.3.4, Out8: liquid effluent.

Out12: dewatered solids

Refer to section 4.1.3.4, Out9: dewatered solids.

4.1.5.5 Technology Score Card

A technology score card for distillation and fermentation was not created as this business model refers to large scale industrial plants. This makes the assessment and comparisons between existing technology solutions difficult.

4.1.5.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

As of the pre-selection of cities for feasibility testing, presented in Table 10, Hanoi was not selected for testing of this business model.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

In Lima, this business model refers to the production of electricity from livestock waste (manure) given the low availability of agro-industrial waste. Biogas generation from manure (via anaerobic digestion) is well established in Peru and anaerobic digestion applications exist in the peri-urban settings of Lima.

Different technological option may be employed according to the scale of the plant. For example, simple PVC digesters may be used for small applications given their low capital requirement and ease to operate while commercial multi-stage digesters may be employed for large producers, which may justify a higher capital investment and a more technologically complexity. A big poultry farm situated in La Chira owns a big commercial anaerobic digester for heat and electricity recovery.

Therefore, the livestock model is technically feasible and no technology transfer is required.

4.1.6 **Model 4: On-site energy generation in enterprises providing sanitation services**

Business model 4 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Sulabh International Social Service Organization/India
2. Case Study Umande Trust TOSHA / Kenya
3. Case Study Rwanda/Nepal/Philippines ICRC Prison Biogas

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.6.1 Brief description

The aim of business model 4 is to provide sanitation services to communities as a provision of public toilets. Blackwater and brownwater is collected in an anaerobic digester, biogas is generated and either used internally for lightning and cooking or bottled, stored and sold to businesses and surrounding communities. The flow diagram is presented in Figure 4.

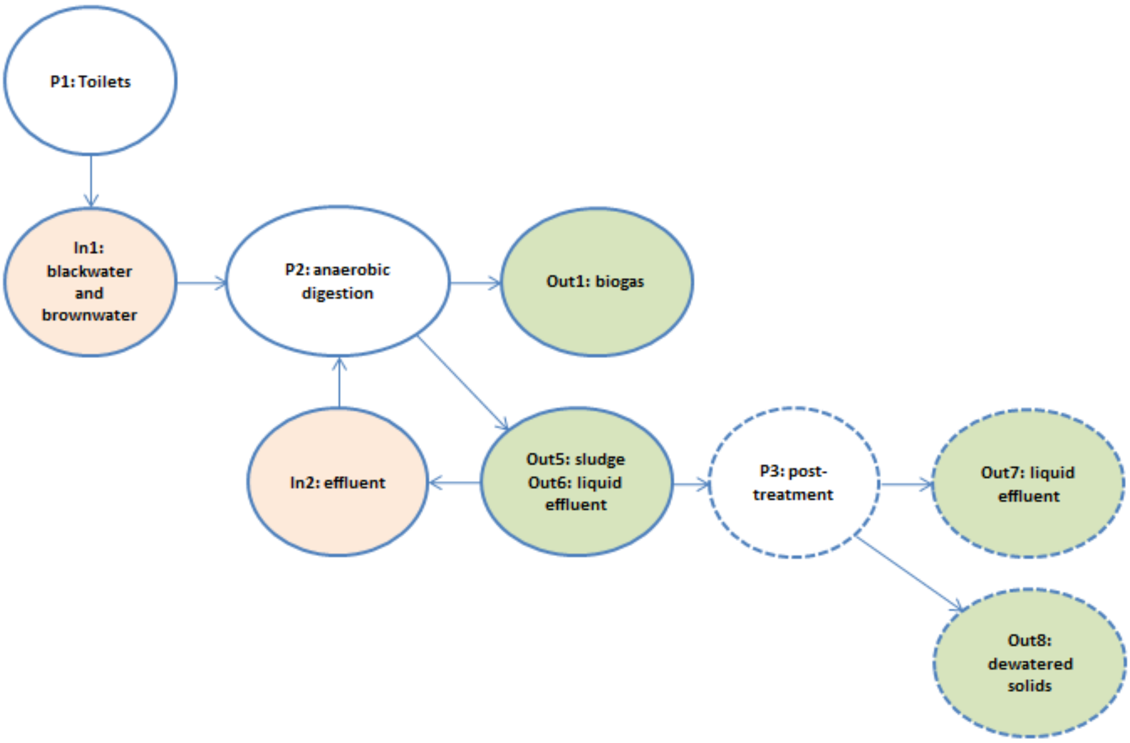


Figure 14: Flow diagram for business model 4.

4.1.6.2 Inputs

In1: blackwater and brownwater

Blackwater is the mixture of urine, feces and flush water along with anal cleansing water and/or dry cleansing material and is the output of pour flush and flush toilets. Brownwater, on the other hand, is the output of urine-diverting flush toilets and does not contain urine. Anal cleansing water and dry anal cleansing material may also be included in brownwater [19]. Blackwater and brownwater have different characteristics, which influences the anaerobic digestion processes. Brownwater contains fewer nutrients, while blackwater contains more due to the urine, and a potentially higher amount of flush water.

In2: effluent

The production of effluent is continuous and therefore provision for its storage, use and/or transport away from the site needs to be considered. For this, infrastructure needs to be put in place, which requires space, and trained labor has to be onsite. If reclamation for agriculture is a resource recovery option for the implementing business, appropriate post-treatment technologies need to be implemented that allow safe use of the effluent. Inactivation of pathogens in anaerobic digestion is limited and needs to be compliant with quality/safety requirements as per given reuse scenario.

4.1.6.3 Processes

P1: toilets

The business model requires the installation of toilets with a connection to an anaerobic digester. Depending on the user interface that is applied, output products with different characteristics will be generated. According to Tilley, et. al (2014), the following user interfaces could be applied for a biogas reactor: the implementation of anaerobic digestion

- Poor Flush Toilet
- Urinal
- Urine-Diverting Flush Toilet

Urine diverting flush toilets are only adequate when there is a use for the collected urine. Use of urine requires storage to make it safe for use in agriculture and is difficult to transport due to its liquid nature. This increases transport costs and the need for space. More information on the use of urine in agriculture is provided in section 4.3.4: Model 18: Urine for agricultural production. The accumulating blackwater and brownwater will be treated in an anaerobic digester.

P2: anaerobic digestion

The principle of anaerobic digestion remains the same as for the other business models that apply this technology as their core process (compare section 4.1.3.3, P2: anaerobic digestion). However, anaerobic digesters implemented for the treatment of blackwater and brownwater, are most suitable and commonly implemented as single stage systems based on wet fermentation under mesophilic conditions and operated continuously.

P3: post-treatment

Refer to section 4.1.3.3, P4: post-treatment.

4.1.6.4 Outputs and Potential Environmental Hazards

Out1: biogas

Biogas is the endproduct of anaerobic digestion and used as a source of light or cooking fuel onsite. Another revenue stream is selling of biogas to businesses and nearby communities. This requires bottling and storing of biogas onsite, which increases the requirements for space. Depending on scale and the volume of produced biogas, an alternative scenario would be to install a gas-based generator and produce electricity. For more details, refer to section 4.1.3.3, P3: gas-based generator (gas cleaning and burning).

Out2: sludge

Refer to section 4.1.3.4, Out6: sludge.

Out3: effluent

Refer to section 4.1.6.2, In2: effluent

Out4: liquid effluent

Refer to section 4.1.3.4, Out8: liquid effluent.

Out5: dewatered solids

Refer to section 4.1.3.4, Out9: dewatered solids.

4.1.6.5 Technology Score Card

The technology score card in Table 19 shows the requirements for single stage anaerobic digestion of blackwater and brownwater. For this business model only one technology is assessed, as this is the most commonly implemented solution.

Land requirements are medium, as space needs to be available for the construction of the anaerobic digester and storage of biogas, in addition to the toilet facilities.

Requirements for skilled labor are low, as the installed technology is simple and does not require skilled labor for operation and maintenance.

Water is not required, as the installation of pour flush toilets provides enough water to keep the moisture at the required level for wet fermentation anaerobic digestion processes.

Electricity is not required, as the technologies are not entailing moving parts. Electricity required for lightning (e.g. inside the toilet facilities) can be substituted by the generated biogas.

Climate requirements are low as the temperature in tropical climates does not decrease to critical conditions for mesophilic anaerobic digestion.

Requirements for the supply and support chain are low, as spare parts for the anaerobic digester are not required.

The potential environmental impact is low, as long as the anaerobic digester is operated appropriately. There is a risk for explosion if leakages exist and ignition sources should be kept separate from the bottled biogas, as it is flammable.

The capital costs are medium, as the construction of toilet facilities and the anaerobic digester requires high investment costs. However, these investment costs are comparatively low compared to the installation of conventional sewer-based sanitation. Wastewater infrastructure does not only require high investment costs, but also has high operating costs.

Operation and maintenance requirements are low, as the process is simple to operate and requires little maintenance, other than regular desludging and the cleaning of the toilet facilities.

Risk of failure is ranked medium, as blackwater and brownwater does not have the optimal characteristics for anaerobic digestion processes. An alternative model could include the addition of organic solid waste (e.g. kitchen waste) as another input to the anaerobic digester.

Table 19: Technology score card for single stage anaerobic digestion.

Requirements	Single Stage
Land	2
Skilled Labor	1
Water	0
Electricity	0
Climate	1
Supply + Support Chain	1
Environmental	1
Capital	2
O&M	1
Risk of failure (lack of robustness)	2

4.1.6.6 City context

Bangalore

The technological choice at the core of this business model is toilets followed by an anaerobic digester (which may be also followed by a gas generator). This type of configuration is not new in India given the presence of many communal toilets that recover energy for internal use under the form or gas or electricity (e.g. the Sulabh case). Therefore, technological transfer is not required given the existing experiences and local know how.

Hanoi

The "Waste Supply and Availability" analysis has identified 1481 public toilets in Hanoi, of which all are flush toilets connected to a septic tank with an overflow into the sewer. In four of the nine urban districts of Historic Hanoi (for the definition of Historic Hanoi refer to the Waste Supply and Availability report) [2], the collected faecal sludge is transported to the Cau Dien composting plant where it is discharged into settling tanks. The liquid effluent is partly reused to maintain moisture of the compost heaps.

No information is available on public toilets being connected to an anaerobic digester. However, septic tanks are also applying anaerobic digestion as a primary treatment step, but biogas is not captured. This is due to the construction of septic tanks, which are generally rectangular and not suitable for the capture of biogas.

The demand for public toilet facilities for sanitation provision is expected to be relatively low in urban Hanoi, as sanitation coverage for households is almost 100%. The high number of public toilets, especially in the districts of Historic Hanoi, shows that toilet facility provision as a public service (e.g. for tourists) is well covered.

Kampala

The “Waste Supply and Availability” report identified 533 public toilets for Kampala [1]. The majority of these toilets are ventilated improved pit (VIP) latrines with overall 363 toilet facilities. 73 have been identified as Ecosan toilets, 71 as pour flush and 24 as water borne systems, connected to a sewer. No information about toilets being connected to anaerobic digesters was available. Public toilets are managed and emptied by KCCA, the Kampala Capital City Authority. Implementing a public toilet service in Kampala would require the acquisition of land where people are lacking sanitation services. These are informal settlements (“slums”), which are densely populated without open or available land. Upgrading existing infrastructure bares the same situation, where there is often no space for the installation of an anaerobic digester. Currently, public toilets are emptied by KCCA and to some minor extent by private emptying service providers. The collected faecal sludge is transported to the recently commissioned Lubigi faecal sludge treatment plant, which applies a combination of settling-thickening tanks for solid-liquid separation, unplanted drying beds for further treatment of the solid fraction and waste stabilization ponds for co-treatment of the liquid fraction with wastewater.

From a technical perspective, biogas production from blackwater and brownwater is low when comparing it to anaerobic digestion of organic solid waste. Therefore, bottling and selling of biogas for revenue generation may not be sufficient for financial viability. Collecting fees from users for revenue generation is a possible option but have to be affordable for low-income households in informal areas of Kampala.

Lima

During the final stakeholder workshop in Lima, this business model regarded unfeasibly on not considered for implementation, as no public toilets exist in Lima.

4.1.7 **Model 5: Power capture model – agro-industrial effluent to energy**

Business model 5 is based on the same business cases as business model 3. Refer to section 4.1.5 for more information.

4.1.7.1 Brief description

Business model 5 has the same technology processes as business model 3, but coverts yare into ethanol and electricity instead of sugar cane bagasse. Yare is a by-product that is created during the production of Casabes (flat bread) from the Cassava root. It is a milky toxic liquid, high in cyanide and used by tribes in Venezuela. Innovative technologies have been developed to produce electricity from yare through fermentation and distillation. The use of yare instead of sugar cane bagasse does not affect the technical feasibility or the city context besides the availability of the waste product. Therefore, for technical analysis refer to model 3.

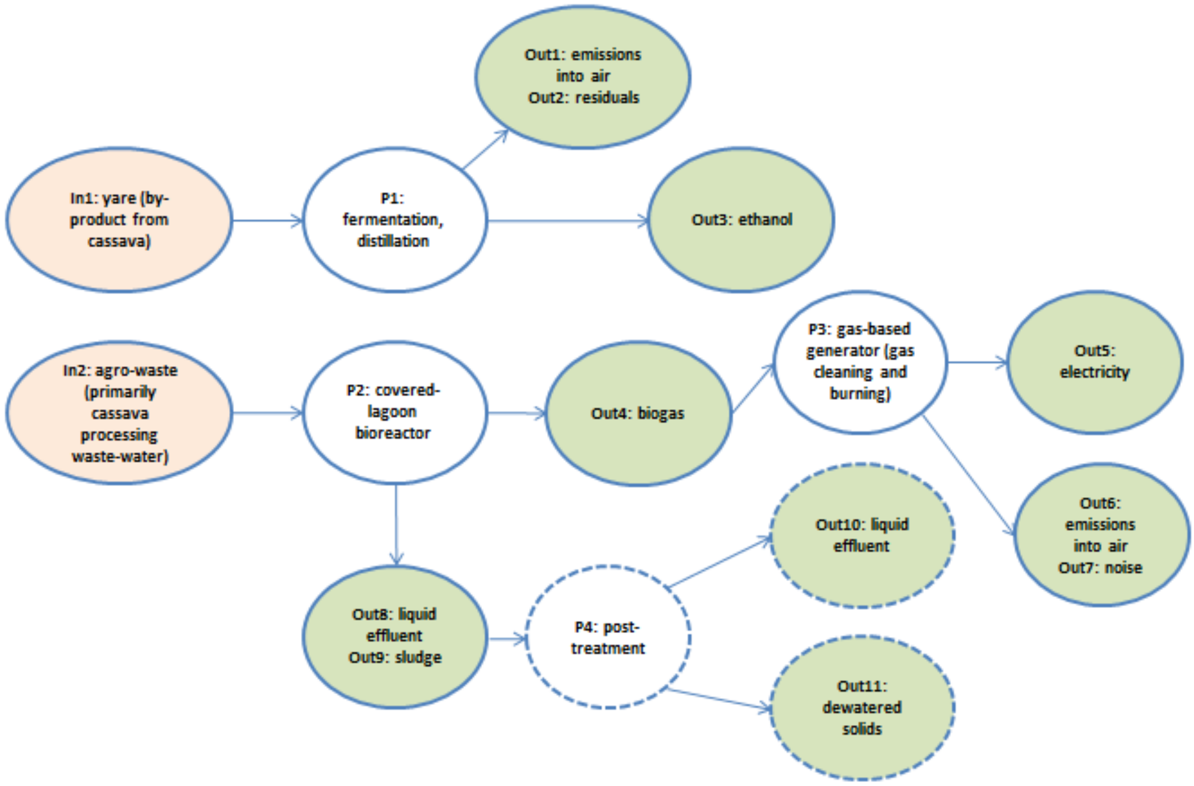


Figure 15: Flow diagram for business model 5.

4.1.8 **Model 6: Power capture model – livestock waste to energy**

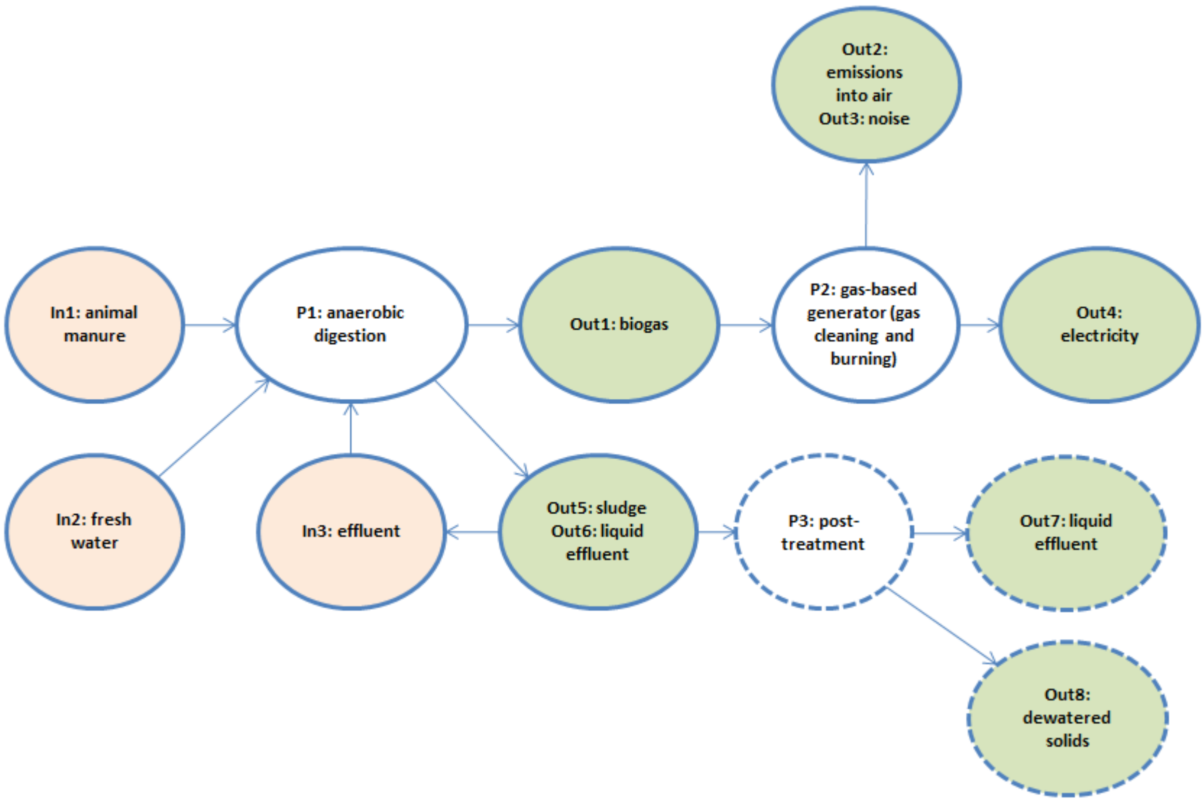
Business model 6 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Cidelsa/Peru
2. Case Study Sadia/Brasil
3. Case Study SuKarne/Mexico
4. Case Study CasaBlanca/Peru

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.8.1 Brief description

Business model 6 has the same technology processes as business model 2a and 2b. It is based on anaerobic digestion of AM to produce biogas and recover energy. What is different from the other business models is that revenues are not created from feeding electricity into the grid but rather from carbon emission reduction certificates. This model does not have any special technical requirements other than more careful monitoring and documentation of operations to assert the waste amount treated for verification of the reduced emissions. Hence, detailed analysis on inputs, outputs and processes is not reported here, and the technology score cards and city context remain the same. For more information refer to model 2a and 2b.



4.1.8.2 Inputs

Refer to section 4.1.4.2.

4.1.8.3 Processes

Refer to section 4.1.3.3.

4.1.8.4 Outputs and Potential Environmental Hazards

Refer to section 4.1.3.4.

4.1.8.5 Technology Score Card

The technology score card for anaerobic digestion technologies is evaluated in Section 4.1.4.5.

4.1.8.6 City context

Bangalore

For the feasibility of anaerobic digestion of animal manure in Bangalore, refer to Section 4.1.4.6

Hanoi

For the feasibility of anaerobic digestion of animal manure in Hanoi, refer to Section 4.1.4.6.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.1.9 **Model 7: Generator model**

Business model 7 is based on the following case studies, which are available in “Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse.” [5]

1. Case Study ETAVENCA/Venezuela
2. Case Study Ecobiosis/México

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.1.9.1 Brief description

After the pre-selection of business models it was decided to not test this model in the four cities (compare Table 10). For the description of anaerobic digestion processes refer to business model 2a, 2b and 3 in section 4.1.3, 4.1.4 and 4.1.5, respectively. The main difference of this business model is the use of kitchen waste instead of MSW, AIW or AM. If appropriately separated at source, kitchen waste is an ideal input material for anaerobic digestion with low impurities. The biogas reactor and use of biogas for cooking or electricity is implemented onsite.

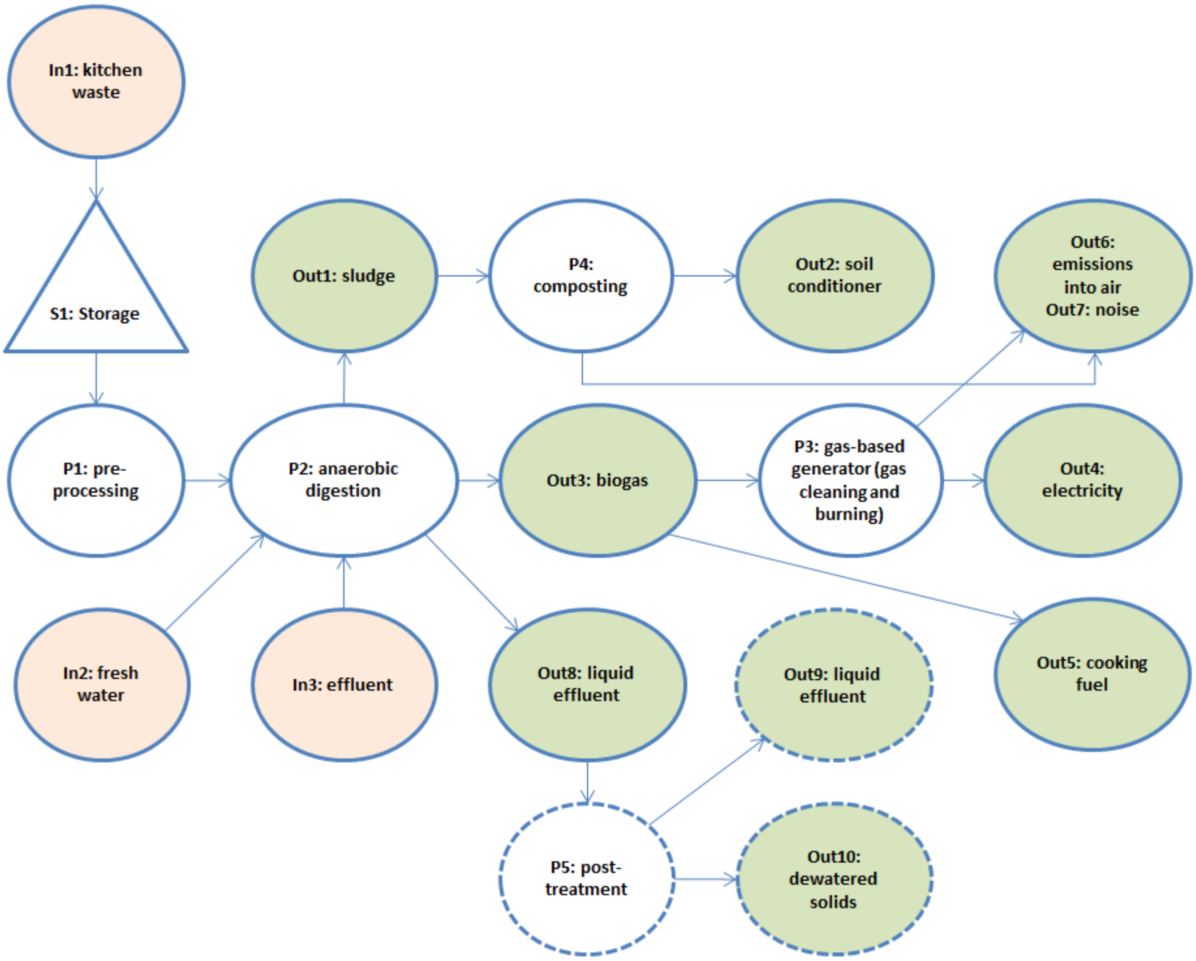


Figure 16: Flow diagram for business model 7.

4.2 **Business models for wastewater recovery**

4.2.1 **Model 8a: Phyto-remediative wastewater treatment and fish production (small scale)**

Business model 8a is based on the following case studies, which are available in “Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse.” [5]

1. Case Study Agriquatics/Bangladesh
2. Case Study Terraqua Barranca/Peru
3. Case Study Waste Enterprisers/Ghana

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.2.1.1 Brief description

Business model 8 aims at producing fish with duckweed harvested from wastewater ponds. The business model is based on duckweed ponds, feeding into fish ponds (aquaculture) with the endproduct of fish and treated wastewater effluent. The company Agriquatics has a pre-described technology set-up, which the business model uses as the core technology. It includes chemical treatment and disinfection of the final wastewater effluent, which allows discharge into the environment. The flow diagram in Figure 17 simplifies these processes and focuses on the output products. The focus of the technology assessment lies on the description of duckweed and fish ponds for wastewater treatment to provide background knowledge and identify the risk of failure.

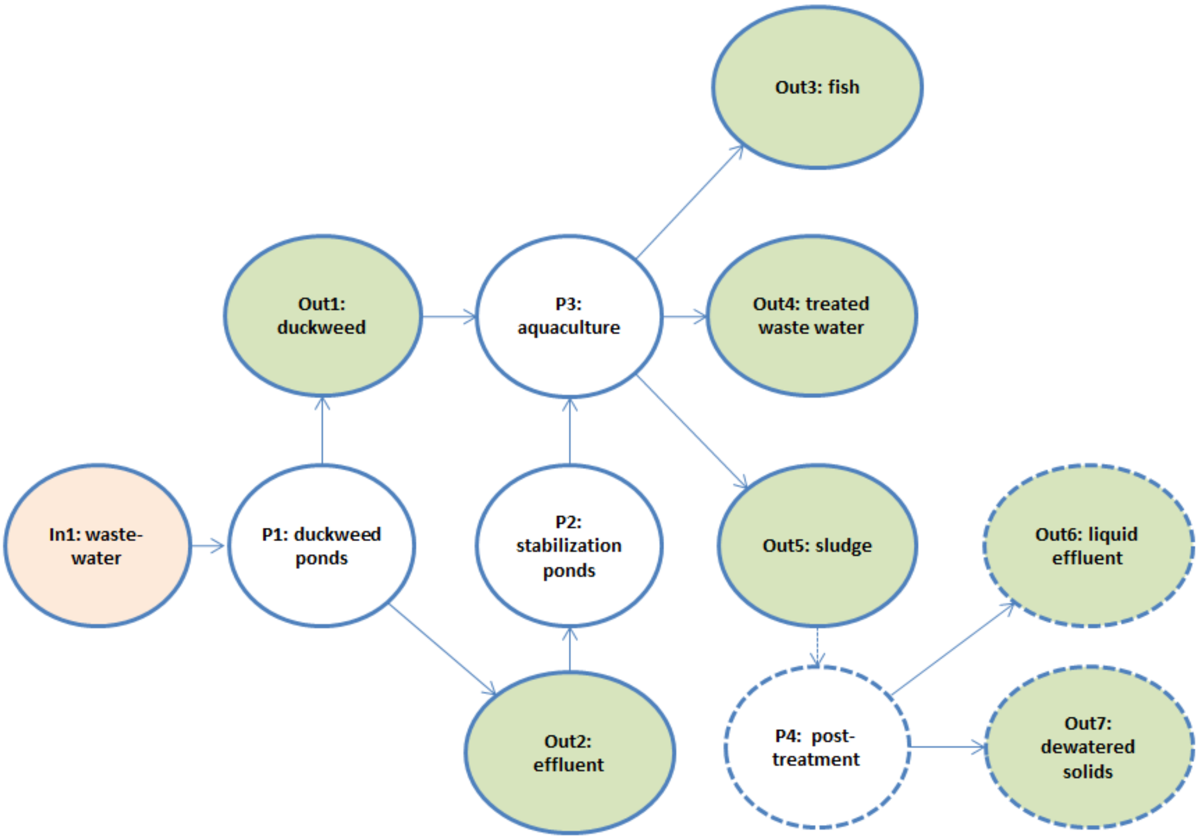


Figure 17: Flow diagram for business model 8.

4.2.1.2 Inputs

In1: Wastewater

Wastewater from hospitals is the input of the business model. It can contain pharmaceuticals and disinfectants, as well as pathogens and antibiotic resistant bacteria in high concentrations [26]. This can be problematic as pharmaceuticals and other micro-pollutants from the hospital wastewater could bio-accumulate in the duckweed and/or fish. Until further research is conducted on the potential for bio-accumulation in duckweed, if it is used for food production it should only be grown on wastewaters with extremely low concentrations of pharmaceuticals, and constant monitoring is required to ensure that the endproduct complies with health regulations for consumption. If the business model is implemented for wastewater from municipal sources, it needs to be assured that only domestic wastewater reaches the treatment plant. Sources of industrial wastewater can contain heavy metals and other pollutants, which can accumulate and make the endproduct not safe for consumption.

All incoming wastewater should undergo a pre-treatment step to remove the settleable fraction of pathogens, settleable solids and floating material. Pre-treatment is furthermore important to release organically bound nitrogen and phosphorous through microbial hydrolysis, as the availability of NH_4^+ and *o*-PO_4^{3-} is suggested to be the limiting step for production of duckweed [27].

P1: duckweed ponds

As with any treatment infrastructure, the treatment goal will define the design of the duckweed ponds. It is important to decide whether the goal is to produce duckweed for harvesting and as a feed for aquaculture or if the goal is high quality effluent. Important design parameters are [27]:

- Batch (small scale) or plug-flow system (large scale)
- Type and quantity of wastewater
- Hydraulic retention time
- Water depth (shallow for duckweed harvesting, deeper for high quality effluent)
- Organic loading rate

Another important design aspect of duckweed ponds is the protection against wind, which inhibits plant growth. This can be achieved by floating grid systems. There needs to be easy access to the ponds to remove and harvest the duckweed. Harvesting plays a major role in the treatment efficiency and nutritional value of the plants. Younger plants show a better nutrient profile and higher growth rate than older plants. After harvesting an almost complete cover should remain on the pond surface to ensure enough duckweed for reproduction of younger plants [27].

To compare duckweed ponds for the treatment of wastewater with similar wastewater treatment technologies, Table 20 highlights the main differences compared to waste stabilization ponds (WSP). WSPs are more robust and the requirements for labor in general and especially skilled labor are much lower. Duckweed treatment systems require a sophisticated level of management to operate and maintain the system adequately.

Table 20: Comparison between waste stabilization ponds and duckweed treatment systems [27].

Criterion	WSP	Duckweed
Robustness	- Extremely robust - High ability to absorb organic and hydraulic shocks	- High BOD loads need appropriate pre-treatment
Labor requirements for operation and maintenance	- Low labor requirements - Unskilled, but supervised labor is sufficient - Simple operation and maintenance	- Highly labor intensive - Requires skilled labor - Sophisticated management necessary
BOD removal efficiency	>90%	>90%
Nutrient removal efficiency	N_{tot}: 70-90%, P_{tot}: 30-50%	N_{tot} and P_{tot}: >70%

Alternative uses for duckweed include feed for animals and possibly even humans, due to its low fiber content and nutritional value. It can also be used as a soil conditioner via direct land application or composting [27].

P2: stabilization ponds

WSPs are implemented for the treatment of liquid effluent from the duckweed ponds. There are three types of ponds, which can be used individually, or linked in a series for improved treatment. Different types are (1) anaerobic, (2) facultative and (3) aerobic ponds with different treatment and design characteristics [19]. Table 20 compares WSPs and duckweed ponds for some selected parameters.

P3: aquaculture

Duckweed as fish feed is a widespread application and it can be fed fresh or in combination with other feed components. Commonly used polycultures are: Chinese and Indian carp species and tilapias, grass carp (*Ctenopharyngodon idella*) and silver barb (*Puntius gonionotus*). However, pisciculture (aquaculture of fish) requires a high degree of skill, combining know-how and experience. The balance between fish density, feed and fertilizer inputs is important and sufficient amounts of dissolved oxygen have to be maintained for high fish yields. The combination of duckweed and pisciculture makes the system more complex as interdependencies between availability and quality of duckweed and fish growth exist [27].

P4: post-treatment

The final effluent of duckweed and aquaculture ponds has to be in line with local regulations. Accumulated sludge in the duckweed and fish ponds needs to removed and treated appropriately. Drying beds can be used to dewater the sludge and then possibly compost it with other organic waste. The final product has to be analyzed for heavy metals and organic toxins to ensure it meets the established standards for agriculture [27]. For more information on post-treatment refer to section 4.1.3.3, P4: post-treatment.

4.2.1.3 Outputs and Potential Environmental Hazards

Out1: duckweed

Duckweed is fed to fish ponds, which are described above under 4.2.1.2, Inputs.

Out2: effluent

Effluent of the duckweed ponds is fed to WSPs, which is described above under 4.2.1.2, Inputs.

Out3: fish

Fish is the endproduct and main value proposition of the business model. For fish grown on wastewater, regulations have to be fulfilled to ensure that it is safe for consumption.

Out4: treated wastewater

Wastewater treated to tertiary level is one output of the business model. For the definition of tertiary level treated wastewater, refer to section 4.2.3.3, “wastewater treatment”. Treating wastewater to this level requires the implementation of appropriate technologies, which increases the capital and operational costs of the business. There is a potential risk of environmental pollution with pathogens, heavy metals, organic substances and nutrients, if the treatment infrastructure is not operated and maintained adequately.

Out5: sludge

The post-treatment of accumulated sludge from duckweed ponds is described above under 4.2.1.2, Inputs.

Out6: liquid effluent

Refer to section 4.1.3.4, Out8: liquid effluent.

Out7: dewatered solids

Refer to section 4.1.3.4, Out9: dewatered solids.

4.2.1.4 Technology Score Card

As duckweed ponds and aquaculture are established technologies, no technology score card was created for this business model. A more detailed description of the Agriquatics solution, including a case description can be found on: http://www.agriquatics.com/Case_Studies.html. A comparison between duckweed ponds and WSPs is presented in Table 20

4.2.1.5 City context

Bangalore

This BM requires ponds (e.g. waste treatment ponds) for the cultivation of ducked and/or fish. Although in Bangalore WSP treatment options do not exist, the presence of about 200 lakes within the city and their connection to WWTP (they are the final receptors of the treated effluent) makes this model technically viable. This would require that the benefits of duckweed/aquaculture (external to the treatment plant boundary) are recognised and internalised in the wastewater treatment business for profit or cost recovery.

Aquaculture itself is not a technical challenge as it is very simple and requires very low capital (e.g. USD 2000-5000) [28]. Production may be calculated assuming: a stocking density of 4 fish/m^2 for catfish; 2 cultivation seasons/year and a 65% survival rate. Regular water quality checks may be necessary to ensure the overall sustainability of the model.

Local knowledge on fishing exists given the presence of fishermen communities in Bangalore lakes, which are licenced by local authorities.

Hanoi

Use of wastewater for aquaculture is a well-established system in Hanoi. It is mainly based on farmer's experience and also utilizes animal manure. In 1995, Than Tri District, south of urban Hanoi, was producing 10% of the total fish supply for Hanoi city. However, it can be assumed that these practices are not under safe conditions and that the used wastewater is of mixed domestic and industrial source. To implement a business model, similar to Agriquatics, requires institutional involvement as the city has developed master plans for the expansion of the wastewater treatment infrastructure until 2050. These analyses will be covered by the institutional analysis of the RRR project.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

Aquaculture examples already exist in the region and in Lima, in particular. Therefore, knowledge transfer is not required. The presence of treatment plants based on WSP technologies make the implementation of this business model viable in the city. This is particularly true in the Southern area of the city where there is the majority of pond based WWTPs.

4.2.2 **Model 8b: Phyto-remediative wastewater treatment and fish production (large scale)**

Business Model 8b applies the same technology principle as business model 8a with the difference of treating wastewater on large scale rather than small scale. Both business models implement duckweed and fish ponds and produce wastewater treated to tertiary level. Large scale implementation has an influence on all requirements listed in section 2.4. The overall increase in complexity of large scale implementations not only increases the requirements for land, capital and skilled labor, but also have to be in line with the overall sanitation and wastewater infrastructure plans in the implementing city. Small-scale implementation, on the other hand, can be performed by stand-alone businesses treating wastewater of institutions, hotels, schools, prisons, etc.

4.2.3 **Model 9: Treated wastewater for irrigation/fertilizer/energy – Cost recovery**

Business model 9 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study As-Samra/Jordan (with box on carbon/Bolivia)
2. Case Study St. Martin Wastewater Treatment Plant/Mauritius
3. Case Study Okhla Sewage Treatment Plant/India
4. Case Study Mexico AqWise

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.2.3.1 Brief description

This business model compromises all modules of a conventional wastewater treatment plant with limited nutrient removal. It includes all resource recovery products consisting of water, energy and nutrients. The core value addition is reclamation of treated wastewater for agriculture, dewatered solids for soil conditioner in agriculture and energy recovery through anaerobic digestion, as presented in Figure 18. The core treatment includes wastewater treated to secondary level with further pathogen removal, if required; wastewater sludge drying and co-composting with MSW; and wastewater treatment technologies based on anaerobic treatment processes. Capital costs for implementation of such treatment infrastructure is the main constraint for this business model, unless the related investment costs of 1.5-230 million USD are covered through other mechanisms. Therefore, the business model requires that the feasibility study cities have existing infrastructure, which employs adequate treatment mechanisms that provide outputs, treated to the required levels for reclamation of water for irrigation, dewatered sludge as soil conditioner for agriculture and recovery of energy from anaerobic digestion. Existing infrastructure can be upgraded, so that it delivers the required outputs. This implies that the implementing business either enters a private-public partnership (PPP) with the local institution responsible for wastewater treatment, or that the institution itself implements the required treatment mechanisms.

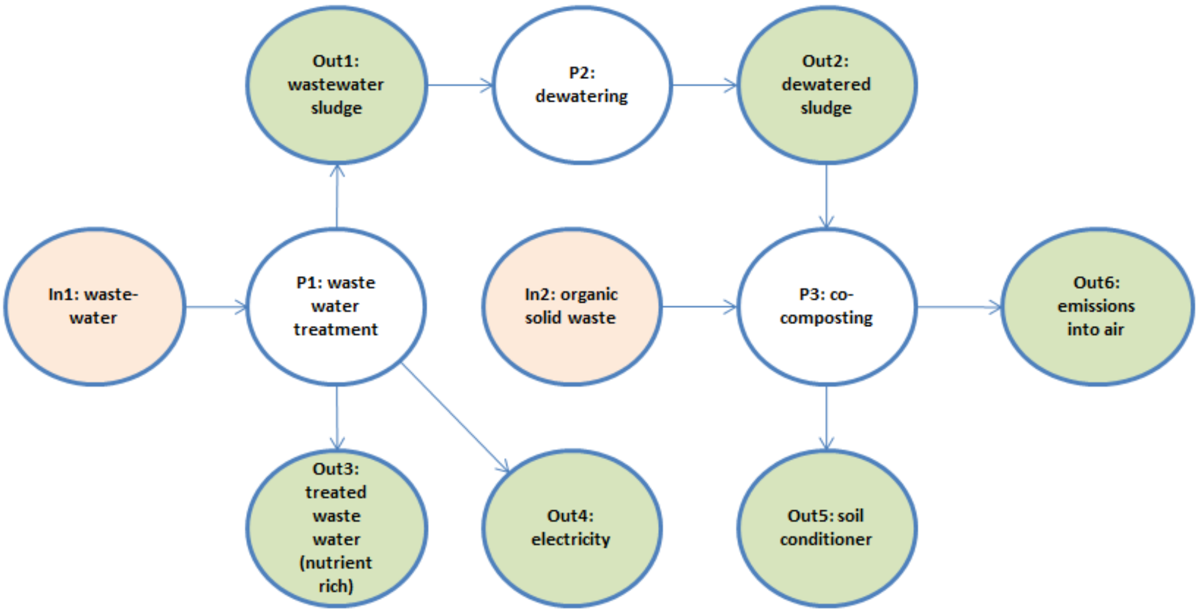


Figure 18: Flow diagram for business model 9.

4.2.3.2 Inputs

In1: wastewater

The incoming wastewater is of municipal sources and can be comprised of domestic and industrial wastewaters. Laboratory analyses have to be implemented to characterize and monitor the influent characteristics. Important parameters amongst others are chemical oxygen demand, nutrients, and heavy metals. Especially if industrial wastewater is included with domestic wastewater, there is a possible risk of contamination with heavy metals and other pollutants that could accumulate in the settled wastewater sludge. If not treated appropriately they could also be present in the final effluent, which poses an environmental risk. Only if influent characteristics are well understood, adequate treatment structure can be implemented that suits the goal of treatment for the intended resource recovery option and furthermore ensures an effluent safe for discharge into the environment.

In2: organic solid waste

For the requirements on organic solid waste as an input for co-composting, refer to section 4.3.1.3, which describes all relevant processes.

4.2.3.3 Processes

P1: wastewater treatment

For the recovery of nutrients and energy, and the reclamation of water for irrigation, several treatment steps have to be implemented that suit the goal of treatment. Using treated wastewater for irrigation requires the effluent to be safe for handling and effective pathogen reduction to the required level (for more information refer to “Health and Environmental Impact Assessment” report. This furthermore highly depends on the type of crop to be irrigated and the irrigation technology (drip irrigation vs. manual irrigation). Similarly, soil conditioner produced from dewatered wastewater sludge in combination with organic solid waste has to comply with local regulations that make it safe for use and handling. An additional environmental risk exists, as heavy metals can accumulate in the settled wastewater sludge and contaminated solid waste of domestic sources.

Levels of treatment that can be achieved are taken from [29] as follows:

- Preliminary treatment
  - Removal of wastewater constituents such as rags, floatables, grit, and grease that may cause maintenance or operational problems
- Primary treatment
  - Removal of a portion of suspended solids and organic matter from wastewater
- Advanced primary treatment
  - Enhanced removal of suspended solids and organic matter from wastewater. Typically accomplished by chemical addition or filtration
- Secondary treatment
  - Removal of biodegradable organic matter and suspended solids. Disinfection is also typically included in the definition of conventional wastewater treatment
- Secondary with nutrient removal
  - Removal of biodegradable organics, suspended solids, and nutrients (nitrogen, phosphorous, or both nitrogen and phosphorous)
- Tertiary
  - Removal of residual suspended solids usually by granular medium filtrations or microscreens. Disinfection is also typically a part of tertiary treatment. Nutrient removal is often included in this definition
- Advanced
  - Removal of dissolved and suspended materials remaining after normal biological treatment when required for various water reuse applications

Recovering energy through anaerobic digestion requires infrastructure that produces and captures the biogas and converts it into electricity. For the design of anaerobic wastewater treatment, [29] defines the following parameters:

- Flow and loading variations
  - Can upset the balance between acid fermentation and methanogenesis
- Organic concentration and temperatures
  - Preferred temperatures are between 25 to 35°C and the COD concentrations should not be lower than 1300 mg/L
- Fraction of non-dissolved organic material
  - The composition of particulate and soluble fractions greatly affects the type of anaerobic reactor and its design
- Wastewater alkalinity
  - Alkalinity influences the pH, which is required to be maintained at or near neutral. Concentrations typically required are between 2000 to 4000 mg/L $CaCO_3$

- Nutrients
    - Addition of phosphorous and nitrogen might be required for biomass growth as many industrial wastewater lack sufficient nutrients
- Macronutrients
    - Trace metals, such as iron, nickel, cobalt and zinc are important to stimulate methanogenic activity
- Inorganic and organic toxic compounds
    - Detailed analysis are needed to ensure that a chronic toxicity does not exist for anaerobic wastewater treatment
- Solids retention time
    - Fundamental parameter for operation and design of all anaerobic processes
- Expected methane gas production
- Treatment efficiency needed
    - Effluent from anaerobic processes is high in suspended solids and anaerobic processes alone cannot achieve secondary treatment levels that are required to comply with local regulations. Some form of aerobic post-treatment of the effluent is needed.
- Sulfide production
    - Can be present in high concentrations in industrial and domestic wastewaters
- Ammonia toxicity
    - Can be of concern for wastewaters having high concentrations of ammonium or proteins and/or amino acids
- Liquid solids separation
    - Efficient separation can enhance the treatment performance

Other important parameters include flow and loading variations as variable flows and organic loads can upset the balance between acid fermentation and methanogenesis in anaerobic processes.

Technologies applying anaerobic treatment of wastewater are:

- Anaerobic suspended growth processes
- Anaerobic sludge blanket processes
- Attached growth anaerobic processes
- Other anaerobic treatment processes (covered anaerobic lagoon, membrane separation anaerobic treatment process)

The choice of technology highly depends on all the mentioned parameters above. As described before, in depth characterization studies and the definition of specific goals for wastewater treatment are inevitable for the choice and design of the technology

Treating municipal wastewater has to be part of a larger sanitation master plan and strategy, led and directed by local authorities. This will influence the feasibility of the business model in itself, as the required endproducts have to be available. Important issues to consider when implementing infrastructure for wastewater treatment are:

- Constant supply of energy, due to the need of constant aeration for aerobic treatment

- The availability of local manufacturers for the mechanical/spare parts that are needed for the treatment process.
- Highly skilled personnel: plant manager and operators need experience, or need to be able to acquire experience in other similar facilities in the city or region

P2: dewatering

The dewatering of wastewater sludge has similar concerns to the dewatering of faecal sludge. For a detailed description refer to section 4.3.1.2, In2: faecal sludge.

P3: co-composting

Co-composting wastewater sludge with organic solid waste is similar to co-composting of dewatered faecal sludge with organic solid waste. For a detailed description, refer to section 4.3.1.3, P3: co-composting.

4.2.3.4 Outputs and Potential Environmental Hazards

Out1: wastewater sludge

Potential environmental hazards for wastewater sludge include contamination with heavy metals, which is described above.

Out2: dewatered sludge

The use of dewatered sludge for co-composting is described in section 4.3.1.3, P3: co-composting.

Out3: treated wastewater (nutrient rich)

The treated effluent of the wastewater treatment facility has to be nutrient rich, if reuse in agriculture for the reclamation of nutrients is implemented. The treatment technologies have to be designed accordingly (i.e. limited nutrient removal, e.g. waste stabilization ponds). If the treated effluent is used for the reclamation of water for other irrigation purposes (e.g. parks, forestry), local regulations for nutrient removal have to comply. The same accounts for pathogen reduction, which is covered in the "**Out4: electricity**

Electricity, produced from biogas, will be used internally for cost-recovery.

Out5: soil conditioner

The endproduct of the business model is a soil conditioner and should not be labelled as a fertilizer as typical nitrogen contents remain around 1-2 %. Additional supplement of nutrients, such as nitrogen, phosphorous and potassium to the product, can help qualify the endproduct as a fertilizer and is typically called fortified compost.

Out6: emissions into air

Gaseous emission from the compost heap will consist mainly of water vapor and CO_2. If sufficient aeration cannot be ensured, pockets of anaerobic conditions will occur in the compost heap. This might then lead to methane and nitrous oxide emissions, both important greenhouse gases. Under normal and careful operating conditions these emissions are negligible.

Emissions generated during the conversion of biogas into electricity are covered in P3: gas-based generator "Emissions" in section 4.1.3.3 and in section 4.1.1.4, Out2: Emissions into air.

4.2.3.5 Technology Score Card

Table 21 compares some of the most widely implemented wastewater treatment technologies. The technologies are grouped into intensive and extensive treatment. Extensive treatment options, such as WSPs, anaerobic lagoons, phyto-depuration and floating aquatic plants require more land but less energy and skilled labor, while intensive technologies, such as activated sludge, extended aeration, trickling filters, rotating biological contactors, UASB's and aerated lagoons require less land but more energy and skilled labor.

Extensive technologies, and particularly floating aquatic plant and phyto-depuration technologies are more affected by the climate than intensive technologies. Wind and ambient temperature can have a significant effect on plant growth and anaerobic digestion processes.

The requirements on the supply and support chain for intensive wastewater treatment technologies is higher than for extensive technologies. This is due to the fact of moving parts and high technical complexity.

If the implemented technologies are designed appropriately for the goal of treatment, the potential environmental impact, regarding the effluent quality is not applicable. This is regardless the fact the intensive technologies require energy, while some extensive technologies (i.e. WSPs, anaerobic lagoons) release green-house-gases, such as CH_4.

Capital costs are higher for intensive technologies, if the cost of land is not considered. Intensive technologies are based on more complex infrastructure, such as pumps, sensors and moving parts, which highly influences the investment costs. For extensive technologies the acquisition of land in urban areas is costly due to high land requirements per m^3 of treated wastewater.

Operation and maintenance requirements are higher for intensive technologies, which has the same reasons as for capital costs, skilled labor and the supply and support chain. In summary, the risk of failure of simple extensive technologies is lower than for intensive technologies, with the exception of phyto-depuration and floating aquatic plant technologies which rank the same as activated sludge and extended aeration technologies, due to high skilled labor requirements.

Table 21: Technology score card for common wastewater treatment technologies.

	Intensive						Extensive			
	Activated sludge	Extended Aeration	Trickling Filters	Rotating Biological Contactors	UASB	Aerated Lagoons	WSPs	Anaerobic Lagoons	Phyto-depuration	Floating Aquatic Plants
Land	2	2	1	1	1	2	3	3	3	3
Skilled Labor	3	3	3	3	3	2	1	2	2	2
Water	0	0	0	0	0	0	0	0	0	0

Electricity	3	3	1	3	1	2	1	0	0	0
Climate	1	1	1	0	0	2	2	2	3	3
Supply + Support Chain	3	2	3	3	3	2	1	1	2	1
Environmental	0	0	0	0	0	0	0	0	0	0
Capital	3	2	3	3	3	2	1	2	1	1
O&M	3	3	2	3	2	2	1	1	1	1
Risk of failure (lack of robustness)	2	2	3	3	3	2	2	1	2	2

4.2.3.6 City context

Bangalore

In Bangalore, there are at least four WWTPs that are based on anaerobic processes and from which biogas can be captured and converted into electricity. Therefore, energy production from wastewater treatment (or carbon emission reduction from an anaerobic treatment system UASB, via electricity production of biogas) is feasible. In this case, gas generators or CHP are required as additional equipment to upgrade the existing WWTP into energy producers.

Furthermore, the solids produced in the WWTP (aerobic and anaerobic), after being dewatered, are finally disposed to land without any recovery. Therefore, there is the scope to process the sludge for energy recovery. Energy recovery from sludge is usually carried out with anaerobic digestion and may recover a substantial percentage of the WWTPs energy requirements.

For wastewater irrigation, technology will depend very much on the quality required by the demand and the reuse applications. In principle, there is plenty of secondary and tertiary treated wastewater that could be potentially reused. Necessary irrigation infrastructure may be built to distribute the wastewater.

Hanoi

Similar to Kampala, a sanitation and wastewater infrastructure planning for the next decades until the year of 2050 exists. The “Waste Supply and Availability” have identified that the effluent of the existing wastewater treatment plants is in line with local water quality standards for discharge into the environment [2]. Reclamation of water for nutrient recovery might therefore not be feasible due to the increased nutrient removal in the treatment processes. Furthermore, farmers are already using nutrient rich river water downstream of the urban drainage system, which is in competing use if wastewater reclamation was to be implemented.

None of the existing treatment plants includes anaerobic treatment capturing biogas for electricity generation. Therefore, required infrastructure would need to be implemented if cost-recovery through anaerobic digestion is a potential revenue stream. No information exists on the current management of wastewater sludge. Co-composting of wastewater sludge and organic waste is technically feasible but requires all process steps that would need to be implemented in any composting facility.

Kampala

Reclamation of waster from treating wastewater has shown low feasibility based on the “Waste Supply and Availability” report [1]. Ongoing projects are increasing the wastewater infrastructure, including treatment plants and sewer networks. Even though urban agriculture is practiced widely, business orientated reclamation of wastewater in urban areas is not manageable due to the scattered organization of urban farmers. Large-scale farming activities are located far away from urban areas, where wastewater infrastructure is not planned to be implemented, which would require the treated wastewater to be piped long distances. Wastewater technologies that are planned to be implemented include elements such as anaerobic digestion for the production of biogas and electricity.

In Kampala, dewatered sludge has already been used by farmers, collecting it at the Bugolobi wastewater treatment plant. Regulations and frameworks are needed for the implementation of such activities, as the wastewater sludge might be contaminated with heavy metals and pathogens. Co-composting of wastewater sludge and organic waste is technically feasible but requires all process steps that would need to be implemented in any composting facility.

Lima

In Lima, there are three WWTPs that are based on anaerobic processes and from which biogas can be captured and converted into electricity. Therefore, energy production from wastewater treatment (or carbon emission reduction from an anaerobic treatment system UASB, via electricity production of biogas) may be feasible.

Furthermore, the solids produced in the WWTP (aerobic and anaerobic), after being dewatered, are finally disposed to land without any recovery. Therefore, there is the scope to process the sludge for energy recovery. Energy recovery from sludge is usually carried out with AD and may account to a substantial percentage of the WWTPs energy requirements.

For wastewater irrigation, technology will depend very much on the quality required by the demand and the reuse applications. In principle, there is plenty of secondary and tertiary treated wastewater that could be potentially reused. Necessary irrigation infrastructure may be built to distribute the wastewater.

4.2.4 **Model 10: Untreated wastewater for irrigation and groundwater recharge**

Business model 10 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Groundwater Recharge in Bangalore/India
2. Case Study Mezquital Valley/Mexico
3. Case Study Drarga/Morocco
4. Case Study Pakistan (auctioning/ Chakera) and India auctioning
5. Case Study Glen Valley Farms/Botswana

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.2.4.1 Brief description

As business model 10 utilizes untreated wastewater for irrigation, a major restriction is the crop selection based on the wastewater quality. The WHO "Guidelines for the safe use of Wastewater, Excreta and Greywater", extensively describe the limitations, environmental and health concerns for this type of application [30]. As of the Health Risk and Environmental Impact Assessment undertaken within the feasibility analysis, this business model is not recommended for implementation [24]. A wide set of mitigation measures would need to be implemented to make this business model feasible.

The business model additionally requires the implementation of drainage systems and pumping stations to transport the wastewater from the source to the application. In case this is not already in place, which depends on the location of the enduser and therefore the market demand assessment, this business model shows very low feasibility from the technical perspective and it was therefore not analyzed in further detail.

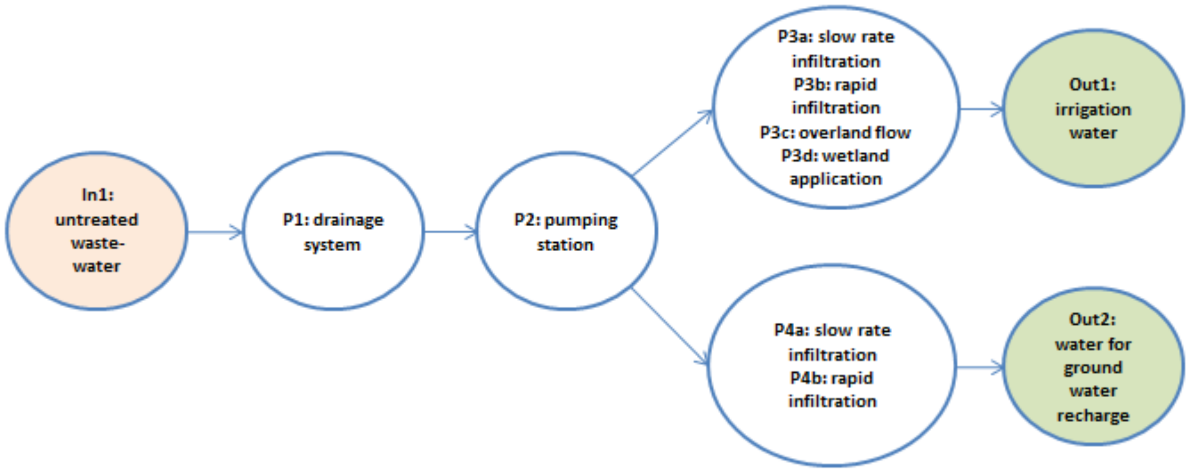


Figure 19: Flow diagram for business model 10.

4.2.5 **Model 11: Wastewater and drinking water exchange (water exchange – irrigation and drinking water)**

Business model 11 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Iran
2. Case Study Spain
3. Case Study Bolivia

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.2.5.1 Brief description

The input of this business model requires wastewater treated to secondary level, including pathogen removal. The treated wastewater has to comply with local regulations and standards described in the "WHO Guidelines for the safe use of Wastewater, Excreta and Greywater" [30]. Similar to business model 10, Section 4.2.4, it requires the implementation or availability of drainage systems, pumping stations or infrastructure for other means of transport (trucks), which may create high capital costs. Other capital costs include: transmission, pumping, storage, field preparation, distribution, recovery and land.

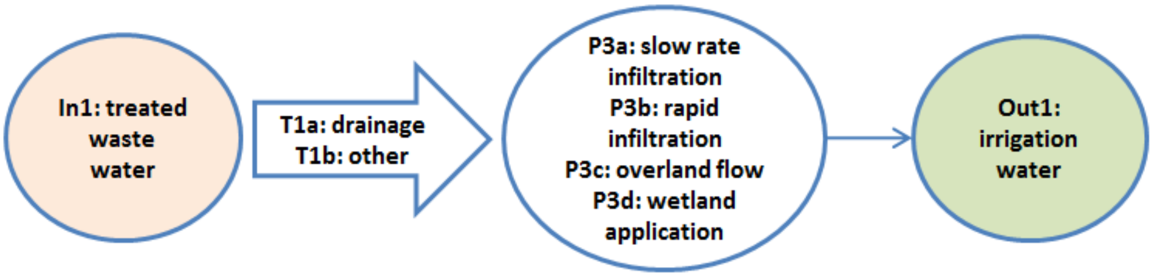


Figure 20: Flow diagram for business model 11.

4.2.5.2 Inputs

In1: treated wastewater

Wastewater for irrigation has to be in line with the "WHO Guidelines for the safe use of Wastewater, Excreta and Greywater" [30]. The implementing business relies on partnerships with the local water and sanitation entity, which is responsible for providing wastewater that complies with these standards.

T1a: drainage

The availability of drainage systems is a core requirement for the feasibility of this business model. The feasibility is more likely in cities, which already have existing and sufficient infrastructure, as high capital costs for implementation of such would be a major obstacle for the business.

T1b: other

Other means of transport, such as trucks, can be a feasible option if the location for irrigation is in close distance to the wastewater treatment infrastructure.

4.2.5.3 Processes

P3a: slow rate

Slow rate infiltration is the controlled application of wastewater treated to secondary level to a vegetated land surface. In partially treated wastewater, the nutrients and water contribute to the growth of a wide variety of crops. The wastewater infiltrates and percolates from the vegetated soil surface and flows through the plant root zone and soil matrix. Standard irrigation methods, such as sprinkler or drip application are used to distribute the water to agricultural fields. To ensure appropriate hydraulic conditions, soil and groundwater characteristics as well as the slope of the land have to be analyzed in detail before the process can be implemented [31].

P3b: rapid infiltration

Rapid infiltration systems apply wastewater in in shallow basins constructed in deep and permeable deposits of highly porous soils. The application can be by flooding. The process can treat a much larger volume of wastewater on a much smaller land area than slow rate infiltration. Rapid infiltration is more suitable for groundwater recharge purposes and where the groundwater table is relatively shallow, the use of underdrains allows control of groundwater mounding and recovery of renovated water. Failure of rapid infiltration processes occurs when site evaluation is not properly evaluated. Primary design considerations for site selection are: soil depth, soil permeability, and depth to groundwater. These and other characteristics also account for designing slow rate infiltration processes. Once a suitable site has been selected, the following characteristics also have to be taken into account: hydraulic loading rates, nitrogen loading rates, organic loading rates, land area requirements, hydraulic loading cycle, infiltration system design and groundwater mounding [32].

P3c overland flow

Overland flow systems are suitable in areas with relatively impervious solids. The wastewater is released onto gently sloping terraces cover with water tolerant grasses. At the bottom, the water is collected in a drainage ditch and can be discharged if complying with local regulations for the discharge of treated wastewater into water bodies [33].

P3d: wetland application

The application of wastewater to wetland systems is typically described by the position of the water surface and/or the type of vegetation grown. Most systems are free water surface systems where the surface is exposed to the atmosphere. Another possible option is subsurface flow wetlands, which are specifically designed for the treatment or polishing of wastewater and are typically constructed as a bed or channel containing appropriate media. The main advantage compared to free water surface application is the decreased risk of public contact and reduced odor [34].

4.2.5.4 Outputs and Potential Environmental Hazards

Out1: irrigation water

Selling treated wastewater for irrigation is the main revenue of this business model. In addition to that, fresh water saved from irrigating with wastewater can be another revenue source.

4.2.5.5 Technology Score Card

No technology score card was developed as the choice of technology highly depends on the local soil conditions at the identified enduser.

4.2.5.6 City context

Bangalore

Technically speaking groundwater recharge from WWTP is already happening in Bangalore. In fact, the treated wastewater that it is discharged into the lakes infiltrates in the groundwater and replenishes the aquifer. This is an existing benefit that the business model may need to recognize.

Schemes for the enhancement of groundwater recharge (e.g. increasing the infiltration rate) may be implemented through recharge wells installations. This technical alternative may require further analysis given the risk to create a faster way for contaminants (e.g. nitrates) to reach the aquifer (eliminating filtering capacity).

A promising option for groundwater recharge in Bangalore may be done via the replenishment of city tanks, which dried due to the high development and water abstraction in the city, and which may act as reservoirs and medium for treated wastewater to recharge into the ground. Geographical location of ‘tanks to target’ will be an important and crucial factor to consider.

Hanoi

As of the pre-selection of cities for feasibility testing, presented in Table 10, Hanoi was not selected for testing of this business model.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.2.6 **Model 12: Wastewater treatment for carbon emissions reduction**

Business model 12 is based on the following case studies, which are available in “Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse.” [5]

1. Case Study As-Samra/Jordan (with box on carbon/Bolivia)
2. Case Study St. Martin Wastewater Treatment Plant/Mauritius
3. Case Study Okhla Sewage Treatment Plant/India
4. Case Study Mexico AqWise

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.2.6.1 Brief description

The business model is based on conventional wastewater treatment, including anaerobic digestion technologies. The biogas is used for electricity production and either used onsite or fed into the grid. The value addition of the business model is carbon emissions reduction. As previously described, the business model requires highly skilled labor for operation and maintenance of the system. The design and implementation require highly skilled labor, with a background specifically in wastewater engineering.

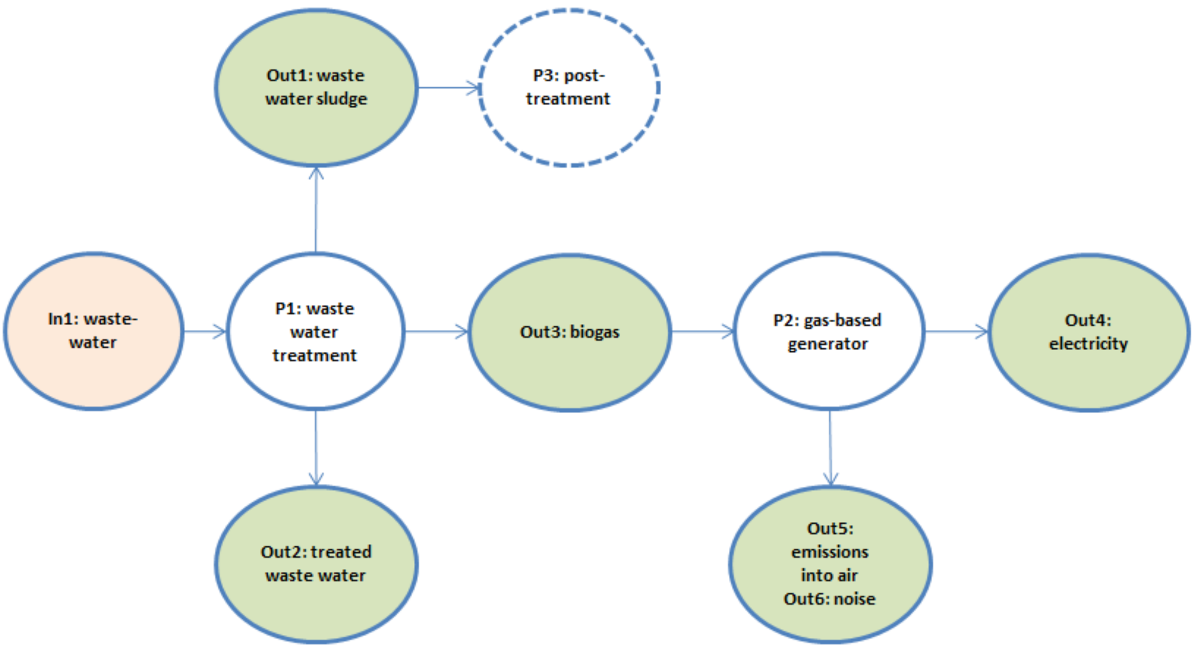


Figure 21: Flow diagram for business model 12.

4.2.6.2 Inputs

In1: wastewater

Refer to section 4.2.3.2, In1: wastewater.

P1: wastewater treatment (including anaerobic digestion)

Refer to section 4.2.3.3, P1: wastewater treatment.

P2: gas-based generator (gas cleaning and burning

Refer to section 4.1.3.3, P3: gas-based generator.

P3: post-treatment

Refer to section 4.1.3.3, P4: post-treatment

4.2.6.3 Outputs and Potential Environmental Hazards

Out1: wastewater sludge

Wastewater sludge from anaerobic digestion requires the implementation of post-treatment technologies. Solid-liquid separation can provide dewatered sludge, which could be co-composted with organic solid waste. The dewatering of wastewater sludge has similar concerns to the dewatering of faecal sludge. For a detailed description refer to section 4.3.1.2, In2: faecal sludge. Co-composting wastewater sludge with organic solid waste has similar concerns to co-composting of dewatered faecal sludge with organic solid waste. For a detailed description, refer to section 4.3.1.3, P3: co-composting.

Out2: treated wastewater

Pathogen reduction and nutrient removal in wastewater technologies for anaerobic digestion is limited. Therefore, the implementation of post-treatment is necessary. The choice of technology depends on the intended enduse, has to provide effluent compliant with local regulations and should be in line with the “WHO Guidelines for the safe use of Wastewater, Excreta and Greywater”, if irrigation for agriculture could be a viable option [30].

Out3: biogas

In this business model biogas is converted to electricity using a gas-based generator.

Out4: electricity

The produced electricity can be used onsite to reduce the energy requirements or sold and fed into the grid for revenue generation.

Out5: emissions into air

Emissions into air are covered under P3: gas-based generator “Emissions” in section 4.1.3.3 and in section 4.1.1.4, Out2: Emissions into air.

Out6: noise

Noise will not be covered as part of the technology assessment, but is covered by the environmental and health assessment

4.2.6.4 Technology Score Card

For anaerobic treatment of wastewater, no technology score card was created, as the technology choice highly depends on the wastewater characteristics which has a major influence on the requirements listed in section 2.4.

4.2.6.5 City context

Bangalore

This business model was moved and integrated into business model 9. Refer to section 4.2.3.6.

Hanoi

As of the pre-selection of cities for feasibility testing, presented in Table 10, Hanoi was not selected for testing of this business model. The city context for wastewater treatment for Hanoi is described in section 4.2.3.6.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model. The city context for wastewater treatment for Kampala is described in section 4.2.3.6.

Lima

This business model was moved and integrated into business model 9. Refer to section 4.2.3.6.

4.2.7 Model 13a: Wastewater treatment for irrigation (profit and social responsibility

Business model 13a is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Drarga/Morocco
2. Case Study Pakistan (auctioning/ Chakera) and India auctioning
3. Case Study Glen Valley Farms/Botswana

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.2.7.1 Brief description

Business model 13a has the same revenue streams as business model 11, which is the use of treated wastewater for irrigation purposes. The technology principle is the same and described in section 4.2.5.3. The main difference of this business model is that the wastewater used for irrigation is also treated by the business itself. Wastewater treatment is covered in section 4.2.3.3, P1: wastewater treatment. The detailed assessment is covered in the outlined sections. The implemented technology has to provide an effluent with limited nutrient removal if recovery of nutrients is planned to be implemented.

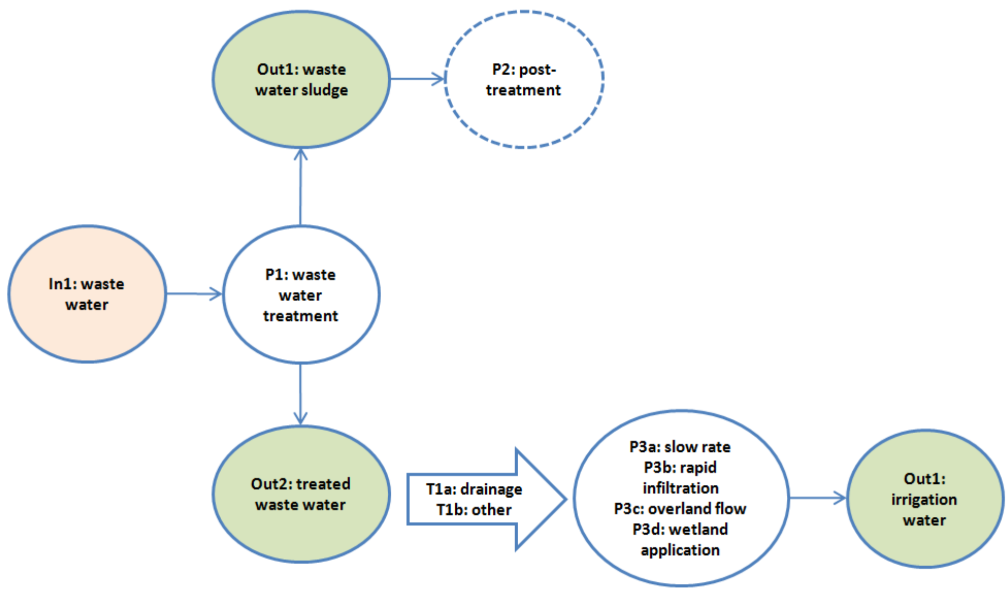


Figure 22: Flow diagram for business model 13a.

4.2.7.2 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

As of the pre-selection of cities for feasibility testing, presented in Table 10, Hanoi was not selected for testing of this business model.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

"This business model was moved and integrated into business model 9. Refer to section 4.2.3.6."

4.2.8 **Model 14: Wastewater treatment via hedging and matchmaking of futures contracts for commoditized treated wastewater**

Business model 14 is based on the following case studies, which are available in “Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse.” [5]

1. The Business Model of Prana Sustainable Water/Switzerland

After the pre-selection of business models it was decided not to test this model in the four feasibility study cities (see Table 10), so it is not evaluated here.

4.3 Business models for nutrient recovery

4.3.1 Model 15: Centralized large-scale compost production for carbon emissions reductions

Business model 15 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study IL&FS Waste Management Services, Okhla /India
2. Case Study Waste Concern/Bangladesh
3. Case Study A2Z Waste Management/India
4. Case Study Karnataka Compost Development Corporation Ltd/India

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.3.1.1 Brief description

Business model 15 focuses on the co-composting of faecal sludge together with organic municipal solid waste to produce a soil conditioner, as illustrated in Figure 23. Although addition of faecal sludge to organic solid waste increases the nutrient content of the final compost product, it nevertheless should not be labeled as a fertilizer as typical nitrogen contents remain around 1-2 %. Additional supplement of nutrients such as nitrogen, phosphorous and potassium) to the product can help qualify the endproduct as a fertilizer and is typically called fortified compost. Given that faecal sludge is utilized as a feedstock for the composting process, this business model requires special attention to process parameters of composting which insure inactivation of viruses, bacteria and parasites and thus avoid any health risk by pathogenic compost. Inactivation of pathogens can be achieved by high temperatures for a defined period of time during the composting process. This business model specifically considers a revenue stream from carbon emission reduction certificates. Considering this aspect does not need any special technical requirement other than a more careful monitoring and documentation of operations to assert the waste amount treated, and control of some specific composting parameters (e.g. oxygen content in the composting windrow) for verification of the reduced emissions.

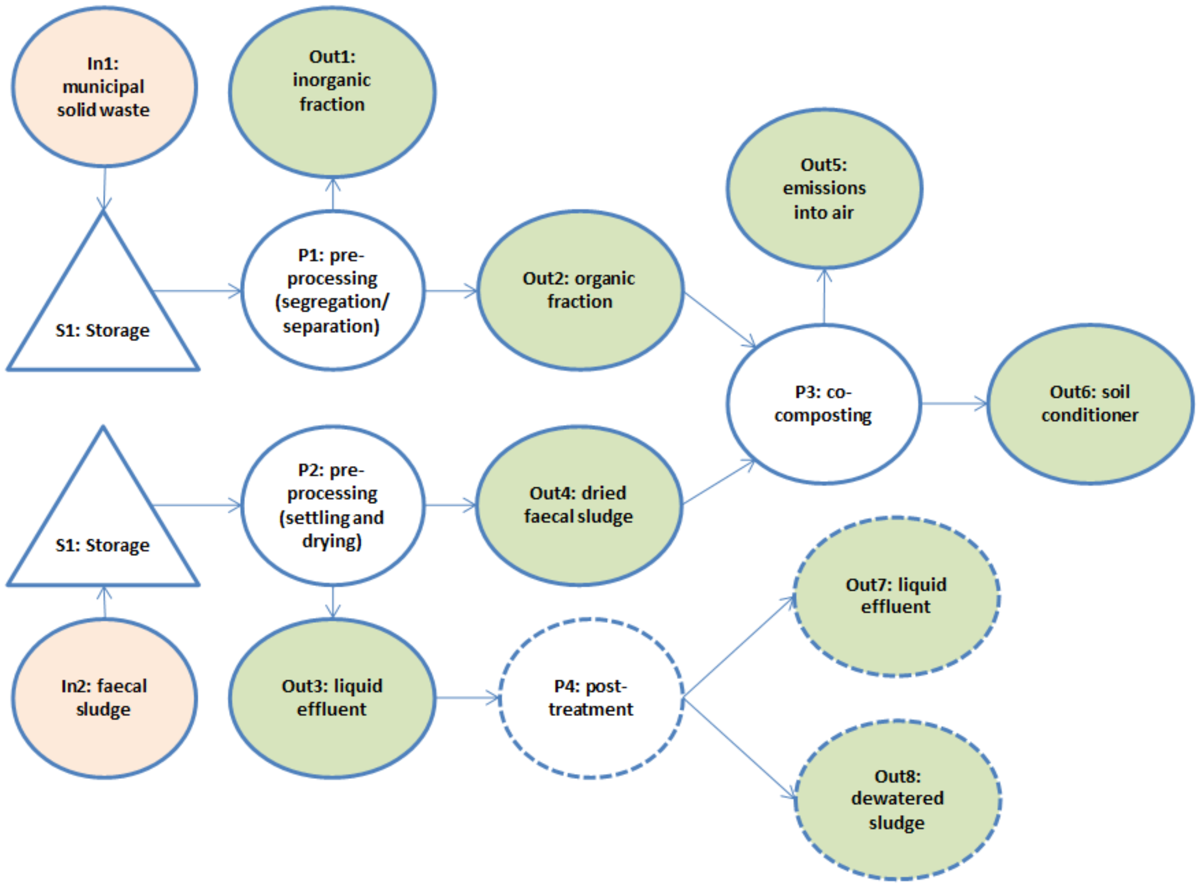


Figure 23: Flow diagram for business model 15.

4.3.1.2 Input materials

In1: municipal solid waste

Incoming MSW can be segregated at source, or derive from specific sources with a high organic solid waste fraction. In both cases the composting facility will receive a more or less pure organic solid waste fraction which can directly be further processed or needs only little further manual sorting. If mixed waste with varying content of inorganic material arrives at the treatment facility, inorganic impurities will affect the final product negatively. Figure 23 shows varying risks of contamination depending on different input solid waste streams. Mixed household waste ranks highest in risk of contamination with a resulting low final quality of the soil conditioner. To avoid loss of quality of the final product, pretreatment by sorting of waste is a recommended step before composting.

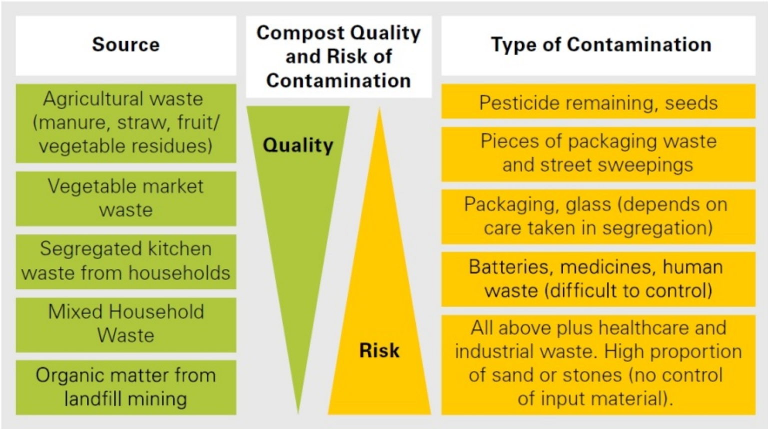


Figure 24: Sources of waste, compost quality and risk of contamination. Taken from [14]

In2: faecal sludge

The second input material and source or organic matter in the co-composting process is faecal sludge. Faecal sludge from septic tanks or public toilets typically has a total solids content of about 5%, thus consisting mainly of water. When faecal sludge is used as an input for co-composting, the sludge first needs to be thickened and dewatered so that the mixture of solid waste and sludge can be maximized without compromising the composting process requirements of a water content between 40-60%. As pretreatment steps for faecal sludge, settling-thickening tanks combined with unplanted drying beds are treatment technologies to use to obtain effluent from settling tanks, dewatered sludge and liquid effluent from drying beds. Settling-thickening tanks result in settled solids at the bottom of the tank while scum floats at the top. Baffles installed at the inflow of the tank reduce turbulence and thus enhances the settling process [18]. Settling and thickening of FS can also be achieved with Imhoff Tanks. Imhoff Tanks have the advantage of requiring less space as they are built as vertical tanks and one tank only is necessary. The Imhoff Tank enables anaerobic digestion of the settled sludge, thus also generating some biogas which can be captured and utilized to reduce fuel needs or provide a revenue source if sold. The drawback of the Imhoff Tank compared to settling thickening tanks is that it requires more skilled labor for operation and maintenance and has slightly higher costs [18].

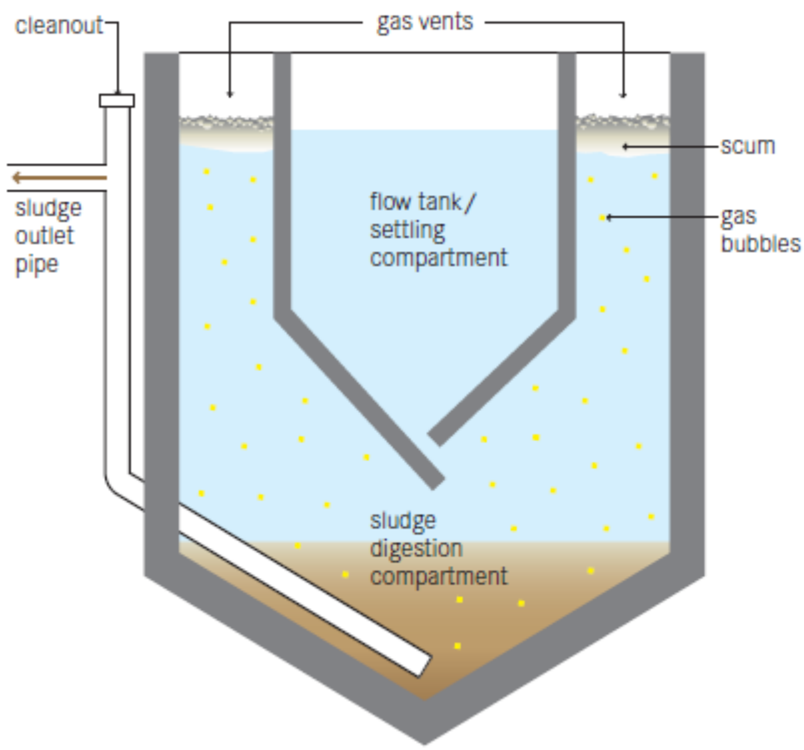


Figure 25: Cross-section of an Imhoff Tank. Taken from [19].

Pretreatment of faecal sludge by all technologies results in thickened sludge and liquid effluent. This effluent may contain pathogens and typically has high pollution loads and therefore requires further treatment before discharge into the environment or enduse.

A second step of pretreatment, after settling and thickening, is the use of unplanted drying beds. The dewatering of FS on drying beds follows two principles, the removal of free water, and bound water. Free water percolates as leachate through a sand and gravel bed, while bound water is removed through evaporation. Depending on the final desired water content in the sludge and the respective local climate factors the process of dewatering can last several days to several weeks [18]. Shortening the time for dewatering is of utmost importance as it affects performance capacity of the drying beds and thus the land footprint of the required pretreatment area. Sludge from settling-thickening or Imhoff tanks has already undergone some dewatering, and when it is applied on drying beds is advantageous in increasing the dewatering efficiency.

Up to date details on technologies for dewatering of faecal sludge are explained in more detail in the recently published book, Faecal Sludge Management: Systems Approach to Implementation and Operation [18].

4.3.1.3 Processes

P1: pre-processing (segregation/sorting)

Special care should be taken to ensure good sorting of the solid waste fraction as all impurities introduced into the composting process would affect the final compost quality. If left in the input material, inorganic materials may then leach into the surrounding material during the composting process and contaminate large volumes of the final product. Examples of hazardous materials are batteries (e.g. contamination of heavy metals) or solvents (e.g. contamination of persistent organic compounds). Sorting of the waste stream before composting is necessary, independent of the waste source. When using relatively pure organic solid waste streams from vegetable markets, or agroindustry the sorting effort is rather small, whereas it is large when using a mixed solid waste stream. Manual sorting is labor intensive but can achieve a good result if done carefully. A conveyor belt can ease the manual sorting process but the drawback is that it is subject to maintenance and requires power supply to operate. With manual sorting, workers must wear protective gear as they are in close contact with the waste. Mechanical sorting equipment typically is capital and power intensive and often does not achieve a lesser degree of sorting compared to manual sorting.

P2: pre-processing

As described in the chapter on faecal sludge as input material, faecal sludge pretreatment consists of settling, thickening and dewatering to decrease the water content and increase the total solids concentration being applied in the composting process.

P3: co-composting

An added value of co-composting, which describes the process of co-treating faecal sludge and organic solid waste, is the higher nutrient value of the final product. This is because excreta and urine in faecal sludge contain higher nitrogen and phosphorous values compared to organic solid waste. On the other hand, organic solid waste is typically high in carbon. The combination of these two materials thus results in an ideal carbton to nitrogen ratio (C/N ratio), as well as a suitable moisture level for the composting process. Another main benefit of the composting process is the high operating temperature that derives from the bacterial activity during the composting process. Typically a well-managed compost heap achieves thermophilic conditions (>50 degrees Celsius) thereby inactivating pathogens as well as weed seeds. [18]. After a phase of thermophilic aerobic degradation that requires a sufficient supply of oxygen, a maturation phase follows, which stabilizes the compost. Operation of a co-composting plant in Kumasi, Ghana has shown that two months were necessary to produce a stable compost that complied with the WHO guidelines of 1 Ascaris egg/g TS [35]. As the composting process requires a moisture content of 40 to 60% and a suitable C/N ratio, it is critical that dewatered faecal sludge and incoming organic waste are characterized and monitored prior to mixing of the two waste streams [18]. A study at the same plant in Kumasi concluded that market solid waste is preferable to household solid waste as it contains less inorganic material and therefore requires less sorting. A mixing ratio between organic solid waste and faecal sludge of 2:1 was determined as favorable, whereby the faecal sludge was pretreated and dewatered to a moisture content of 80% whereas the organic solid waste had a moisture content of between 50-60%. A turning frequency of the compost heap of 10 days is recommended to allow aeration during turning as well as an improvement of the structure in the compost heap thus allowing better oxygen diffusion into the heap [35]. The C/N ratio of the final product shows that a mature and stable product can be achieved under these circumstances.

The co-composting procedure

Step 1: Sorting

As MSW is delivered to the composting site, it is sorted manually or mechanically into the different fractions such as biodegradable organic material, recyclables and rejects. Even though manual sorting requires more labor, the impurities can be sorted more effectively and costly mechanical equipment that requires maintenance and power supply does not need to be installed. Workers must wear protective gear as they are in close contact with the waste.

Step 2: Mixing

Pre-treated faecal sludge with a moisture content of about 80% or less (a consistency which can easily be shoveled) is mixed with the sorted solid waste. Mixing can be achieved with manual labor and simple tools such as shovels. A suitable C/N ratio between 25:1 and 40:1 is suitable for the biological degradation of organic waste as they are essential for growth and cell division of the microorganisms. Woody yard waste is typically high in carbon whereas faecal sludge is relatively high in nitrogen. Mixing these two fractions can obtain the suitable C/N ratio. A mixing ratio between solid waste and FS of 2:1 was determined as favorable and the C/N ratios of the final product confirm that a mature and stable product was achieved. The ideal mixture of wastes has to be determined on case to case basis using trials [2].

Step 3: Piling the waste

After mixing the two waste fractions, the material is then loosely heaped to a maximum height and width of 1.6 meters. The length of the heap (called windrow) is not critical but should not be less than 2 meters. The size of heap should be large enough so that heat can build up and be retained to thus achieve pathogen inactivation. If the heap is too big, the load affects the structure inside the heap thus hindering passive diffusion of oxygen into the center of the heap, a prerequisite for aerobic degradation. Within 24 hours the bacterial communities will multiply and consume the oxygen and moisture in the pile and at the same time generate heat. Temperatures typically increase rapidly in the first few days to value between 55 and 65°C, which is the optimum for aerobic composting. To ensure that aerobic degradation can continue a sufficient supply of oxygen must be ensured.

Step 4: Turning of windrows (oxygen, temperature and moisture control)

Aeration structures at the center of the heap can help supply the composting process with oxygen. Triangular tunnels constructed with local materials placed in the center of the heap is one alternative of passive aeration. Turning of the windrows also enhances oxygen supply. In the first weeks of the process it is recommended that the heap be turned 3 times weekly as temperatures easily may reach up to 70°C. Temperatures above 70°C should be avoided as they will inhibit microbial activity. In such cases, turning can be an appropriate measure to cool the heap. After the first 2 weeks temperatures the turning frequency can be reduced to weekly turning and after 3 weeks the temperature will decrease further into the mesophilic range (45 to 50 °C). The pile can then be turned every ten days. High temperatures and microbial activity during the thermophilic phase will lead to moisture losses. When moisture levels fall below 40 % additional water must be added to the heap with each turning. The moisture content should be maintained ideally between 40 and 60% [2].

Step 5: Maturing

After about 5-6 weeks of composting the temperature of the pile typically falls below 50°C and the maturation phase starts. The material is characterized by a soil like color. Mesophilic microorganisms become active and further stabilize the immature compost within approximately 15 days. Turning is no longer necessary and only little watering is required if the piles are very dry. After a total of about 8 weeks the mature compost material is characterized by a dark brown color, an earthy smell and a crumbly texture [2].

Step 6: Sieved

The final mature compost can then be sieved to obtain the required particle size, which depends on the customer requirements. Sieving can help remove still remaining inorganic particles in the compost. The coarse rejects form sieving can be added to the fresh incoming waste. Sieving can be performed using a flat frame sieve operated with manual labor or using mechanical rotating drum sieves.

Step 7: Storage and bagging

Depending on the marketing and sales strategy, the final compost product can be either stored and sold in bulk or else be packaged in bags of different volumes. The moisture content should be below 40% before bagging and the final product should be stored in a dry and sheltered location.

P4: post-treatment

Refer to section 4.1.3.3, P4: post-treatment

4.3.1.4 Outputs and Potential Environmental Hazards

Besides the final compost product, other outputs of the composting process are: waste rejects from the sorting process, effluent from faecal sludge pretreatment, gaseous emission from the composting process and leachate form the compost heap.

Out1: inorganic fraction

The amount of waste rejects will depend on the quality of the incoming raw material. This fraction needs storage and transport to a designated recycling facility or a solid waste discharge site (ideally a sanitary landfill).

Out2: organic fraction

The organic fraction will be used for the co-composting process with dried faecal sludge.

Out3: liquid effluent

Effluent from faecal sludge pre-treatment will comprise the main volume of the delivered sludge and needs further treatment before discharge or enduse. Treatment of effluent can follow typical wastewater treatment steps.

Out4: dewatered faecal sludge

Dewatered faecal sludge will be used for the co-composting process with the organic fraction of the MSW.

Out5: emissions into air

Gaseous emission from the compost heap will consist mainly of water vapor and CO_2. If sufficient aeration cannot be ensured, pockets of anaerobic conditions might occur in the compost heap. This might then lead to methane and nitrous oxide emissions, both important greenhouse gases. Under normal and careful operating conditions these emissions are negligible.

Out6: liquid effluent

When moisture is not well controlled, leaching of water out of the heap might occur. This polluted leachate must then be collected and should not be discharged into the environment without treatment. Storage of leachate and then use for watering the compost heap when it is too dry is considered a good solution that avoids the need for leachate treatment. Workers on a composting site should wear protective equipment such as gloves, shoes and facemasks to avoid workers health related risk when in contact with waste. This is especially important during compost turning when dust and fungi spores are airborne and may negatively affect the respiratory system.

Out7 soil conditioner

The endproduct of the business model is a soil conditioner and should not be labeled as a fertilizer as typical nitrogen contents remain around 1-2 %. Additional supplement of nutrients, such as nitrogen, phosphorous and potassium to the product, can help qualify the endproduct as a fertilizer and is typically called fortified compost.

4.3.1.5 Technology Score Card

The business model described here comprises an aerated windrow composting process as the main technology option.

Even though windrow composting is the most frequent applied technology in low- and middle-income countries, the technology score card below compares the windrow composting approach with three other well-known composting technology approaches. Windrow composting was further divided between static and turned windrow systems.

The static windrow composting approach relies on forced aeration, which means the blowing of air into the compost heap instead of turning the heap as in the case of the turned windrow system. Forced aeration systems require a slightly more complex infrastructure (e.g. the blowers and the piping system), and a continuous supply of power (e.g. electricity or fuel) to operate the aerators. Furthermore, the higher level of sophistication in equipment at a facility with forced aeration will also require a solid and stable supply and support chain, slightly more skilled labor, more investment capital, and higher operation and maintenance expenditures. On the other hand, the turned windrow systems will require more labor for turning, (although less skilled labor) and is less capital intensive. In large facilities where many windrows need continuous turning, a simple mechanical turning device might be required to improve turning efficiency.

Vermi-composting has a higher land requirement than the normal composting approaches as worms can only be fed daily with thin layers of waste to avoid heat build-up and unfavorable conditions for the worms. In-vessel technologies need less space than windrow composting given the increase space efficiency of a closed reactor. The same is valid for inclined step grades, which make use of the topography to limit the use of space.

Highly skilled labor is required for all technologies besides the windrow technologies, due to less moving parts and skills that are needed for operation and maintenance.

All technologies require water to keep the moisture level at required levels, but the requirements are low for all technologies and not expected to differ between technologies.

Inclined step grades and vermi-composting have less electricity requirements compared to the other technologies, whereas forced-aerated composting will have an increased energy requirement as the process depends on blowers aerating the windrows.

Table 22: Technology score card for composting technologies.

Requirements	Aerated (Static) Windrow	Aerated (Turned) Windrow	In-Vessel	Inclined Step Grades	Vermi-composting
Land	3	3	1	2	3
Skilled Labor	1	1	3	3	3
Water	1	1	1	1	1
Electricity	3	2	3	1	1
Climate	2	2	1	2	3
Supply + Support Chain	2	1	3	3	2
Environmental	1	1	1	1	1
Capital	2	1	3	3	2
O&M	3	1	3	2	2
Risk of failure (lack of robustness)	1	1	3	2	3

4.3.1.6 City context

Bangalore

Bangalore has a long tradition in composting. The city hosts two of the largest composting plants in India: Karnataka Compost Development Corporation (KCDC) (operating successfully since 1974) and Terra Firma. Both plants process sorted and mixed MSW and produce different quality compost (low-quality, enriched and vermin-compost). The core technological option employed by both plants is open windrow composting, with manual and mechanical (with front end loaders) turning, which is followed by motorised sieving and bagging (crushing is performed for the high quality compost only). KCDC also employs vermicomposting (box) for a small quantity of sorted/high content organic waste.

Therefore, despite the high land requirement, turned windrow composting (and vermicomposting) is a high viable option for this BM in Bangalore. This is corroborated by the fact that large-scale plants and possible power cuts (frequent during peak summer time in Bangalore), hardly justify the employment of energy intensive technologies such as in vessel composting or static piles.

Furthermore, the local knowledge of the process is well known and no technological transfer is required.

Cost estimates for composting at different scales are reported in Zhu et al. (2008) and are described in the table below [36].

Infrastructure required	Population[a] Under 50,000[b]	Up to 100,000	Up to 200,000
Disposal site, including landfill area (acres)[c]	20 + 15	25 + 20	30 + 25
Compound wall or barbed-wire fencing	Cost depends on materials used.		
Internal and peripheral roads	Rs 2.00 lakhs[d]	Rs 3.00 lakhs	Rs 5.00 lakhs
Green belt along the boundary	Rs 0.50 lakhs	Rs 0.75 lakhs	Rs 1.50 lakhs
Weigh bridge	Rs 5.00 lakhs	Rs 5.00 lakhs	Rs 7.50 lakhs
Control room as office and laboratory	Rs 3.00 lakhs	Rs 4.00 lakhs	Rs 5.00 lakhs
Concrete yard with drains:			
Area (cubic meters)	6,000	12,000	18,000
Cost	Rs 45.00 lakhs	Rs 80.00 lakhs	Rs 120.00 lakhs
Shed for processing machinery with space for storing and bagging	Rs 15.00 lakhs	Rs 25.00 lakhs	Rs 40.00 lakhs
Processing machinery (such as rotary screens with conveyor belts)	Rs 30.00 lakhs	Rs 50.00 lakhs	Rs 80.00 lakhs
Processing equipment	Rs 10.00 lakhs (1 tractor with accessories)	Rs 25.00 lakhs (1 medium payloader and 1 tractor with accessories)	Rs 65.00 lakhs (1 heavy-duty payloader, 2 medium payloaders, and 1 tipper)
Vehicle shed	Rs 0.50 lakh	Rs 0.50 lakh	Rs 1.00 lakh
Leachate tank			
Capacity (liters)	20,000	35,000	50,000
Cost	Rs 0.50 lakh	Rs 1.00 lakh	Rs 2.00 lakhs
Water supply (excluding bore well cost) and lighting	Rs 1.00 lakh	Rs 1.50 lakhs	Rs 2.00 lakhs
Generator with panel board			
Capacity (horsepower)	25	50	100
Cost	Rs 6.00 lakhs	Rs 7.50 lakhs	Rs 8.50 lakhs
Total	Rs 118 lakhs	Rs 203.25 lakhs	Rs 337.5 lakhs

Source: Karnataka Compost Development Corporation 2006.

Note: The estimates given are for treating unsegregated municipal solid waste. A reduction can be expected up to 30 to 40 percent if the waste is segregated.

a. Although 25 tons per day of waste is expected to be generated for a population of 50,000, provision is made to treat garbage up to 50 tons per day (that is, up to 100,000 population). Similarly, for a population up to 100,000 and 200,000, provision is made to treat up to 100 tons per day and 200 tons per day, respectively.

b. Vermicomposting is recommended for towns having a population under 50,000.

c. Value of site is not included.

d. 1 lakh equals 100,000 rupees.

Hanoi

Similar to Kampala, the availability of MSW in Hanoi is not the constraining factor, but rather the fact that it is not source separated. However, Hanoi has an existing and functioning composting facility in Cau Dien (see more details "Waste Supply and Availability" report) [2]. The composting facility receives market and restaurant waste from four urban areas. This highly decreases the sorting efforts necessary at the facility. Nevertheless, the facility does not make any profits due to the fact that the treatment costs are higher than the revenues that can be created from the endproduct. A functioning business model could increase the profitability of the composting facility. The composting plant also receives faecal sludge from public toilets, of which the liquid part is used to maintain the moisture in the composting piles. Technically, this cannot be considered as co-composting since the solid fraction of the faecal sludge is still disposed of at one of the landfills.

From the technical perspective, composting in Hanoi is only feasible if more source-separation initiatives can be implemented that secure a consistent input quality. The 3R (Reduce, Reuse, Recycle) initiative was implemented by the Japan International Cooperation Agency (JICA) in 2007 to promote source separation at the household level, but it was reported that these efforts have stopped (for more information refer to the "Waste Supply and Availability" report) [2].

Kampala

The "Waste Supply and Availability" analysis revealed that Kampala currently produces 2358 t MSW/d of which 60% remain uncollected in illegal open dumps and 40% are transported to the Kiteezi landfill north of the city. None of the collected waste is source separated. Although the waste is characterized by a high organic fraction (70% to 90%), the remaining inorganic fraction is considered to be problematic. Waste arriving at the landfill also contains medical and industrial waste. Manual sorting at the landfill would therefore be a hazardous practice. The alternative of mechanical sorting would highly increase the complexity of a composting facility without necessarily significantly improving the input quality and respectively the final compost product. Considering these facts, the final endproduct from composting activities of mixed or mechanically sorted MSW would tend to be of low quality, potentially not fulfilling local regulations for compost quality. One option could be to target specific waste collection trucks arriving from certain waste generators (e.g. vegetable markets) where the organic fraction is assumed to be very high and the contamination levels low. This however implies that these trucks can be clearly identified and can be diverted from the normal landfill discharge pathway.

Using faecal sludge for co-composting not only complicates the business model in terms of health concerns but also complicates the logistics of the business model in the case of Kampala. In May 2014, the first large scale faecal sludge treatment plant (i.e. Lubigi) was commissioned in Kampala with a design capacity of 400 m^3/d. There are currently no plans for enduse of the dewatered faecal sludge as the main design objective for Lubigi was to provide an appropriate place for the discharge of faecal sludge for emptying and transport companies. The dewatered sludge from Lubigi will be transported to Kiteezi landfill for discharge.

Therefore a co-composting facility could be implemented at the Kiteezi landfill, as the location also receives the dewatered faecal sludge. If trucks that solely deliver market waste to the Kiteezi landfill can be identified and diverted from discharging into the landfill, then, co-composting with faecal sludge might be feasible. Another feasible option is to arrange a special PPP agreement with KCCA, which focuses on the collection and management of MW from selected markets and also transports dried faecal sludge form Lubigi to the site of co-composting.

Looking at composting from a technology perspective, case studies around low- and middle-income countries have shown to be successful if an effective organizational structure was implemented. This includes that these facilities had shown a strong leadership and skilled, motivated and continuously trained staff [37]. This shows that for the implementation of composting projects it is not so much the complexity of the technology that makes a project successful or prone to failure, but rather the enabling environment.

A World Bank project implemented various composting facilities in Kampala in between 2011 and 2013. One of the project sites was visited during the prefeasibility studies of the RRR project but was not operational. The main reasons for failure where the distance of the facility to the city centre and therefore high transportation costs, and also the high impurities of the MSW.

Lima

There is currently no existing large scale composting plant in Lima. However, compost is technically feasible Windrow turned composting may be the most feasible technology given the low energy requirement, the land availability in the outskirt of the city. Also it is good given the low labor cost in the city (and the possibility to create jobs).

4.3.2 **Model 16: Decentralized multi-partnership community based model**

Business model 16 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Nawacom/Kenya

The business case provides a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.3.2.1 Brief description

Business model 16 has the same technological principle as business model 15. The main difference is the scale of operation and the input material. Business model 16 is a community based small-scale facility and faecal sludge is not included as an input material.

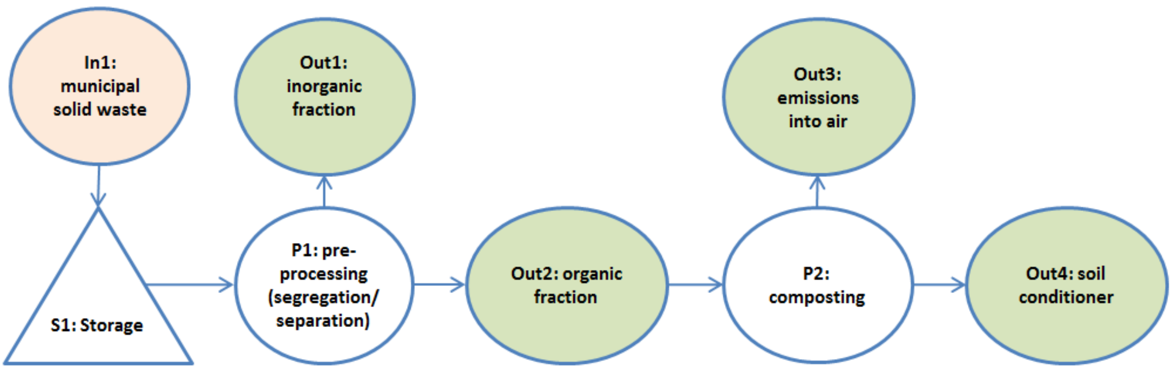


Figure 26: Flow diagram for business model 16.

4.3.2.2 Inputs

In1: municipal solid waste

In this case, the input material is source-separated organic solid waste from households or market waste from a market surrounding the community that is implementing the facility. This implies that a strong community involvement, public awareness and participation exist.

4.3.2.3 Processes

P1: pre-processing (segregation/separation)

Even though the input material is practically purely organic, some manual sorting needs to be implemented to ensure the highest input quality.

P2: composting

Refer to section 4.3.1.3, P3: co-composting. The addition of faecal sludge is not implemented in this model.

4.3.2.4 Outputs and Potential Environmental Hazards

The outputs and potential environmental hazards are covered in section 4.3.1.4.

4.3.2.5 Technology Score Card

The technology score card for composting technologies is described in section 4.3.1.5. and will not be listed individually here.

4.3.2.6 City context

Bangalore

Refer to Hanoi, as the city context for Bangalore is the same.

Hanoi

The city context for composting activities is described in Section 4.3.1.6. However, this model refers to small scale community based composting rather than centralized large scale composting. This decreases the technical complexity and but requires strong community engagement and source-separation of household waste which has shown to be unsuccessful in Hanoi. Awareness raising campaigns would be needed for successful implementation. Additionally, very limited space in urban Hanoi decreases the feasibility of this business model. It is also required to work closely with state-owned companies, cooperatives and joint stock companies that are currently responsible for the collection of MSW in Hanoi.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.3.3 **Model 17: High quality branded/certified organic fertilizer from faecal sludge and municipal solid waste**

Business model 17 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study EcoProducts/Ghana
2. Case Study Fortifer/Ghana
3. Case Study DeCo! Farming/Ghana
4. Case Study EcoHoldings/Kenya
5. Case Study TerraFirma/India

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies.

4.3.3.1 Brief description

Business Model 17 has the same technology set-up as business model 15, but includes the addition of nitrogen, phosphorous and potassium to the final compost so that it can be branded and sold as fertilizer. Fortifying the compost with nutrients does not affect the technical feasibility or the city context other than a slight increase in production complexity, the need for good supply chains, and the need for regular analysis to ensure a high quality fertilizer. Therefore, detailed technical analysis is not presented here for this model.

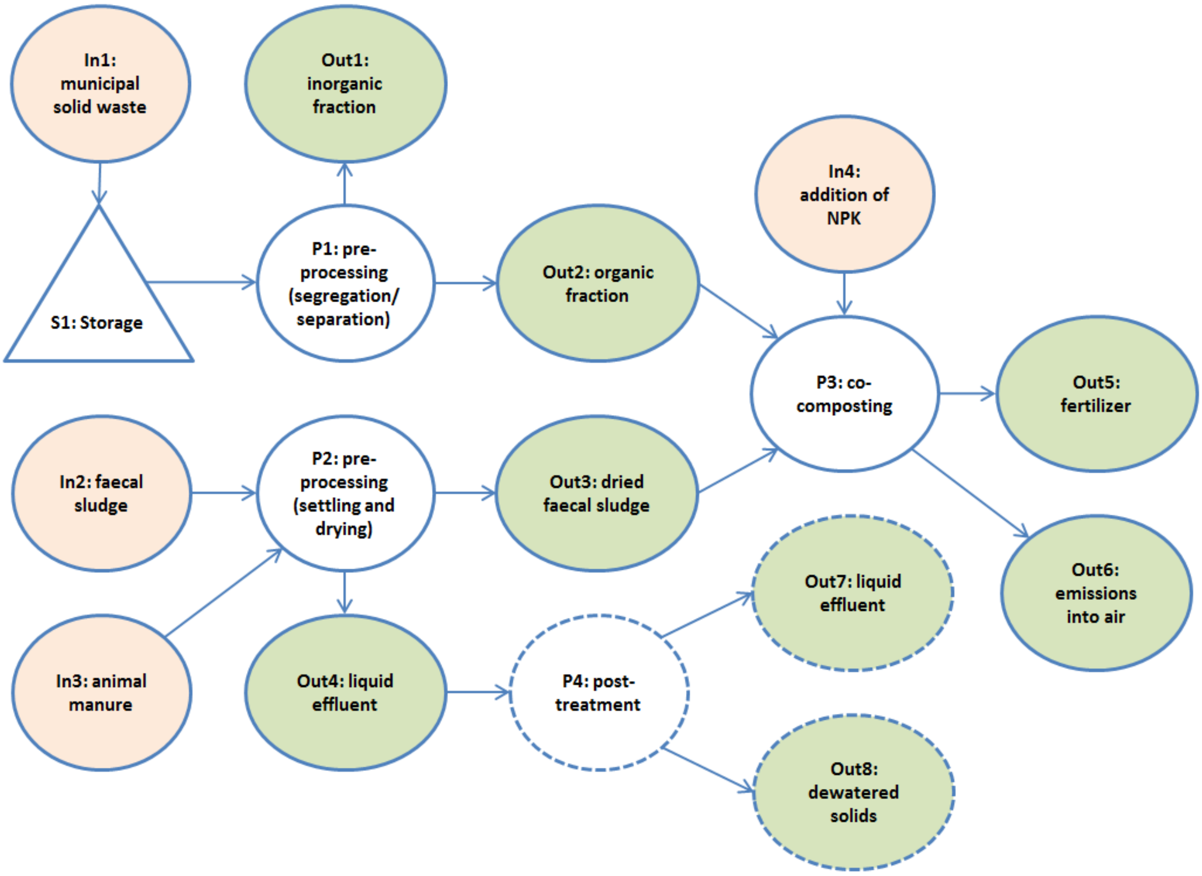


Figure 27: Flow diagram for Business Model 17.

4.3.3.2 Inputs

Refer to business model 15, section 4.3.1.2.

4.3.3.3 Processes

Refer to business model 15, section 4.3.1.3

4.3.3.4 Outputs and Potential Environmental Hazards

Refer to business model 15, section 4.3.1.4.

4.3.3.5 Technology Score Card

Refer to business model 15, section 4.3.1.5.

4.3.3.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

Refer to business model 15, section 4.3.1.6

Kampala

Refer to business model 15, section 4.3.1.6

Lima

The core technology at the heart of this business model is similar to other compost-based nutrient recovery business model (windrow composting). However, extra processing is required to increase compost quality for better 'marketability'. The extra processing depends on the final product quality required, which is affected by the market. The following scenario may be considered:

- Pelletized compost: it is feasible given the diffusion of pellet machines for wood chips in Peru and technology transfer is not required;
- Faecal sludge co-composting (enrichment) is not feasible in Lima given the low availability of FS in the city;
- Nutrients (nitrogen, phosphorous, potassium) addition (e.g. inorganic fertilizers or manure) may be performed without machinery (simple addition). Preferably nitrogen enrichment should be done at the end of the composting process to avoid nitrogen losses, while phosphorous addition could be done at the beginning of the process.

4.3.4 Model 18: Urine for agricultural production

Business model 18 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Ouagadougou Community/Burkina Faso
2. Case Study Ostara

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies. The business model was deemed not feasible as there are no existing large-scale implementations of urine diverting dry toilets (UDDTs). However, a brief overview is presented here of the use of urine in agriculture.

4.3.4.1 Brief description

For this business model, urine is collected from UDDTs and treated for pathogen removal by storage. It requires existing infrastructure, unless it is planned as part of the implementing business to build urine diversion toilets.

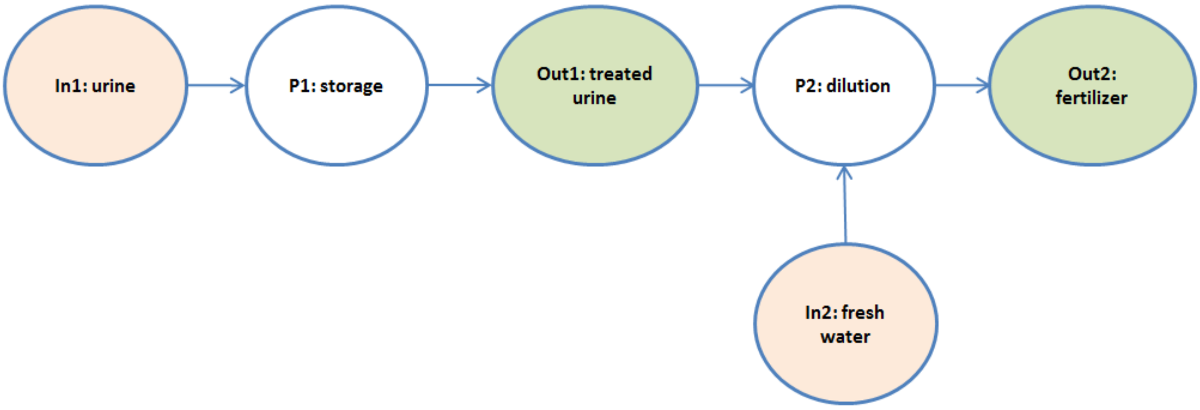


Figure 28: Flow diagram for Business Model 18.

4.3.4.2 Inputs

In1: urine

Urine contains the majority of nutrients that are excreted by the human body. The composition varies depending on diet, gender, climate, and water intake, but roughly 88% of nitrogen, 61% of phosphorus and 74% of potassium, excreted from the body, is contained in urine.

In2: fresh water

Depending on the application of urine, fresh water might be needed for dilution, as a high ammonia concentration can "burn" crops.

4.3.4.3 Processes

P1: storage

Urine should be stored for at least three months to be safe for agricultural application at the household level and if used for crops that are not eaten by the urine producer itself for a period of six months [19].

P2: dilution

Due to its high pH and ammonia, urine should not be applied directly to plants. The correct dilution ratio depends on the soil and the type of vegetables the urine is applied to, while a water to urine mix of 3:1 has shown to be an effective dilution for most vegetables. Furthermore, urine can be mixed undiluted into soil before planting of vegetables or poured into furrows. For this, a significant distance away from the roots of the plants is needed and furrows should be covered immediately.

Application rate

It can be assumed that 1 m^2 of crop land can receive 1.5 l of urine per growing season, but the optimal application rate depends on the nitrogen demand and tolerance of crop on which it will be used, in addition to the nitrogen content of the liquid and the rate of ammonia loss during application. Some crops that grow well with urine include: maize, rice, millet, sorghum, wheat, chard turnip, carrots, kale, cabbage, lettuce, bananas, paw-paw, and oranges.

4.3.4.4 Outputs and potential Environmental Hazards

Out1: treated urine

Urine stored for a sufficient amount of time can be used in agriculture. Depending on the nutrient characteristics it might require to get diluted with fresh water before application.

Out2: diluted urine

Even diluted, urine might have an offensive smell which and social acceptance might be difficult. The use might be less accepted in urban or peri-urban areas than in rural areas where houses and crop land are kept separate. Large scale application in agriculture requires the urine to get transported, which is costly as urine is heavy and difficult to transport. Additionally there is a risk of soil salinization if the soil is prone to the accumulation of salts.

4.3.4.5 Technology Score Card

As there is only one process described, no technology score card was developed for the treatment of urine.

4.3.4.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

The feasibility of implementing the use of urine in agriculture in Hanoi is low, as there are no existing urine diversion toilets and agricultural land is far from urban Hanoi. Furthermore, sanitation coverage in urban Hanoi (for the definition of urban Hanoi refer to the “Waste Supply and Availability” report) is almost 100%, which implies that there is no need for the implementation of toilet infrastructure [2].

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.3.5 **Model 19: Sustainable sanitation service delivery via compost production from faecal sludge**

The business model has the same technological principle as business model 15, combined with business model 18. The main difference is the provision of sanitation services and therefore the implementation of onsite sanitation infrastructure.

4.3.5.1 Brief description

Refer to section 4.3.1.1. and 4.3.4.1.

4.3.5.2 Inputs

Refer to section 4.3.1.2. and 4.3.4.2.

4.3.5.3 Processes

Refer to section 4.3.1.3. and 4.3.4.3.

4.3.5.4 Outputs and Potential Environmental Hazards

Refer to section 4.3.1.4. and 4.3.4.4.

4.3.5.5 Technology Score Card

Refer to section 4.3.1.5.

4.3.5.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

Refer to section 4.3.1.6. and 4.3.4.6

Kampala

Refer to section 4.3.1.6. and 4.3.4.6

Lima

As of the pre-selection of cities for feasibility testing, presented in Table 10, Lima was not selected for testing of this business model.

4.3.6 Model 20: Informal re-use of faecal sludge for agricultural production (faecal sludge collection service and on-farm use)

The business model is not yet available for assessment, but has the same technological principle as business model 15. A detailed assessment can be performed when detailed information about the business model becomes available, however, this model would need to be implemented with great caution, as treatment for pathogen reduction is not part of the model.

4.3.7 **Model 21: Municipal solid waste collection service and low-cost organic fertilizer**

Business model 21 is based on the following case studies, which are available in "Business Model and Business Case Catalogue: Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse." [5]

1. Case Study Balangoda Compost Plant/Sri Lanka
2. Case Study Nawalapitiya Environmental Preservation Center/Sri Lanka
3. Case Study Greenfield Crops/ Sri Lanka
4. Case Study Mbale Municipal Composting Plant/ Uganda

The business cases provide a holistic overview of the business, while the technical assessment focuses on the description and assessment of the technologies

4.3.7.1 Brief description

This business model is not yet available for assessment, but has the same technological principle as business model 15. For more details refer to section 4.3.1.1.

4.3.7.2 Inputs

Refer to section 4.3.1.2.

4.3.7.3 Processes

Refer to section 4.3.1.3.

4.3.7.4 Outputs and Potential Environmental Hazards

Refer to section 4.3.1.4.

4.3.7.5 Technology Score Card

Refer to section 4.3.1.5.

4.3.7.6 City context

Bangalore

As of the pre-selection of cities for feasibility testing, presented in Table 10, Bangalore was not selected for testing of this business model.

Hanoi

As of the pre-selection of cities for feasibility testing, presented in Table 10, Hanoi was not selected for testing of this business model.

Kampala

As of the pre-selection of cities for feasibility testing, presented in Table 10, Kampala was not selected for testing of this business model.

Lima

Refer to section 4.3.1.6.

5. **Overall conclusions**

The technical assessment analyzed the potential of RRR treatment technologies to be implemented within the context of the four feasibility study cities. Potential environmental risks and major technological obstacles were identified. At this stage of the assessment, the technical feasibility of the business models cannot be judged in detail, as information on facility scale, specific location in the city and market demand is not available. Required treatment infrastructure can only be clearly defined after the market demand of endproducts and the corresponding specific goal of treatment is determined. This would also include detailed laboratory analysis of the waste to be treated, so that treatment technologies can be selected and designed accordingly. This was not available within the scope of this report, given the size and complex waste management infrastructure of the feasibility study cities. Based on this limited level of technical detail, the technology assessment gives an overview of treatment options for each RRR business models and city. It identifies potential environmental hazards of outputs (e.g. emissions from gasification) and proposes mitigation measures to avoid these hazards (e.g. scrubbing). The developed technology score cards rank technology options based on requirements such as land, electricity and operations and maintenance. Feasibility of a treatment technology depends strongly on the enabling environment (i.e. institutional, legal and political concerns), supporting such an implementation. The technology assessment therefore cannot be regarded as a stand-alone component, but is highly dependent on other components of the feasibility analysis. The technology score cards can be used as guidance for the decision-making process, as the implementing business can use them to identify the constraints certain technologies have.

Conclusions directly related to the business model and the feasibility for implementation are incorporated into the “City Context” sections and furthermore summarized in the executive summary.

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8. Annexure

8.1 Annex 1: Revised business model names and numbering

Table 23: Revised business model names and numbering.

RRR Business Models		**Kampala**	**Hanoi**	**Bangalore**	**Lima**
ENERGY	New Names of Business Models				
Model 1: Dry-fuel manufacturing c. Agro-waste --> Briquettes d. Municipal solid Waste --> Briquettes	**Model 1:** Dry Fuel Manufacturing a) Agro-industrial Waste to Briquettes b) Municipal Solid Waste to Briquettes	**X** **-**	**X** **-**	**X** **-**	**X** **-**
Model 2: Independent Power Producer/ Private power developer c. Agro-waste --> Electricity d. MSW --> Electricity	**Model 2:** Energy Service Companies at Scale a) Agro-Waste to Energy (Electricity) b) Municipal Solid Waste to Energy (Electricity)	**X** **-**	**X** **-**	**-** **-**	**-** **-**
Model 3: Onsite Energy Generation (Agro-waste to Biogas, Electricity, Carbon credit)	**Model 4:** Energy Generation from own Agro-industrial waste	**-**	**-**	**-**	**X**
Model 4: Onsite Energy Generation in Enterprises Providing Sanitation Service	**Model 6:** Onsite Energy Generation by Sanitation Service Providers	**X**	**X**	**X**	**X**
Model 5: Power capture model (Agro-industrial effluent to energy)	**Moved to Model 4:** Energy Generation from own Agro-industrial waste	**-**	**-**	?	**-**
Model 6: Power capture model - Livestock waste to energy	**Model 3:** Manure to Power	**-**	**X**	**X**	**-**
Model 7: Generator model*	**Model 5:** Biogas from Food Waste	**-**	**-**	?	**-**
New Model	**Model 7:** Emerging Technology Model				

WASTEWATER					
Model 8: Phyto-remediative wastewater treatment and fish production a. Wastewater treatment and fish production – small scale **b.** Wastewater treatment and fish production – large scale	**Model 17:** Beyond Cost Recovery: the Aquaculture example	**-**	**X**	**X**	**X**
Model 9: Treated wastewater for irrigation/fertilizer/energy - *Cost recovery*	**Model 16:** On Cost Savings and Recovery	**X**	**X**	**X**	**X**
Model 10: Untreated wastewater for irrigation and groundwater recharge	**Model 19:** Informal to Formal Trajectory in Wastewater Irrigation b) Incentivizing safe reuse of untreated wastewater **Model 18:** Groundwater recharge	**X**	**-**	**X**	**-**
Model 11: Wastewater & drinking water exchange *(water exchange – irrigation and drinking water)*	**Model 20:** Inter-sectoral Water Exchange	**-**	**-**	**X**	**-**
Model 12: Wastewater treatment for carbon emissions reduction	**Moved to Model 16:** On Cost Savings and Recovery	**-**	**-**	**X**	**X**
Model 13: Wastewater treatment for irrigation *(profit and social responsibility)* c. Sale of treated wastewater for irrigation d. Sale of advanced treated wastewater for other uses	**Model 19:** Informal to Formal Trajectory in Wastewater Irrigation a) Sale/Auctioning wastewater for irrigation	**-**	**-**	**?**	**X**
Model 14: Wastewater treatment via hedging & matchmaking of futures contracts for commoditized treated wastewater	**Model 21:** Hedging and Matchmaking for Futures Contract	**-**	**-**	**-**	**-**
NUTRIENTS					
Model 15: Centralized large-scale compost	**Model 8:** Large-Scale Composting for Revenue Generation	**X**	**X**	**X**	**X**

production for carbon emissions reductions (MSW --> Compost)					
Model 16: Decentralized multi-partnership community based model (MSW --> Compost)	**Model 9:** Subsidy-free Community Based Composting	**-**	**X**	**X**	**-**
Model 17: High Quality Branded/Certified Organic Fertilizer from Faecal Sludge and MSW	**Model 11:** High value Fertilizer Production for Profit	**X**	**X**	**X**	**X**
Model 18: Urine for Agricultural Production (Urine--> Organic Fertilizer)	**Model 14:** Urine and Struvite Use at Scale	**-**	**X**	**-**	**-**
Model 19: Sustainable Sanitation Service Delivery via Compost Production from Faecal Sludge	**Model 13**: Compost Production for Sanitation Service Delivery	**X**	**X**	**-**	**-**
Model 20: Informal reuse of faecal sludge for agricultural production (FS collection service and on-farm use)	**Model 15**: Outsourcing Fecal Sludge Treatment to the Farm	**-**	**-**	**X**	**-**
Model 21: MSW collection service and low-cost organic fertilizer*	**Model 10**: Partially subsidized Composting at District Level	**-**	**-**	**-**	**X**