Feasibility Study on WASTE TO ENERGY CONVERSION in Six Municipalities in Bangladesh

Sustainable and Renewable Energy Development Authority (SREDA)
Power Division
Ministry of Power, Energy & Mineral Resources

Supported by
Development of Sustainable Renewable Energy Power Generation Project (SREPGen)

Feasibility Study on

WASTE TO ENERGY CONVERSION

in Six Municipalities in Bangladesh

Md. Helal Uddin
Chairman
Sustainable & Renewable Energy Development Authority (SREDA)
Power Division

Message

Environment efficient waste disposal is a significant challenge for a country like Bangladesh to overcome. The urban population of the country is generating on an average 0.56 kg per person Municipal Solid Waste (MSW) everyday especially in the major municipalities and city corporation areas. The current waste management capacity of the 334 municipalities and city corporation is still limited. Thus, a good amount of waste is left undisposed, causing significant environment and health hazard for the inhabitants living in the urban areas.

Government of Bangladesh has formed SREDA as the nodal agency to promote renewable energy and energy efficiency. Waste to energy is regarded as the renewable form of energy and with appropriate technologies waste can be treated for the generation of workable energy like electricity and heat. Since its inception, SREDA has taken many initiatives to facilitate the generation of energy from the MSW. In this regard, SREDA has been playing an active role in sensitizing the municipalities along with the city corporation management to go for the waste to energy generation, which will not only reduce the volume of waste disposed at the landfill but will also address the environment pollution as well as help reducing Green House Gas (GHG) emission in a sustainable manner.

I am happy that SREPGen, UNDP has come forward and assembled a good team of experts and consultant in this area to conduct this feasibility study on waste to energy conversion in six municipalities of Bangladesh to resolve the ongoing waste management issues. The municipalities were selected based on quantitative criteria including number of inhabitants and volume of waste generated every day and qualitative criteria like flooding risk, road infrastructure, population density, climatic context, electrical network and industrial sector etc. In this phase of this study, Mymensingh, Cox's Bazar, Sirajganj, Dinajpur, Habiganj and Jessore were selected for the comprehensive feasibility study for waste to energy conversion. This study recommended several "waste to energy" options like thermal conversion mainly through gasification and non-thermal conversion of waste using the technology like anaerobic digestion as the most suitable mitigation measures in the context of the selected municipalities. It also suggested the need of an enabling policy to encourage the stakeholders for the generation of energy from MSW.

At last I would like to thank SREPGen, UNDP and GEF for their support especially project stuffs for their sincere efforts to conduct this feasibility study on the selected municipalities. I wish with our collective efforts, we will able to take these findings forward for the development of suitable projects in the targeted municipalities.

Md. Helal Uddin

Sudipto Mukerjee
Country Director, UNDP Bangladesh

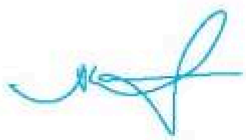
Message

Waste management is a major challenge to many municipalities in developing country like Bangladesh. This is mainly due to rapid increase of waste generation, the associate cost of waste management as well as the lack of understanding about the different stages of waste management, which affects the entire handling system and prospect of energy generation from waste. The daily estimated waste generation in Bangladesh is above 23,000 tons of which the share of organic portion is high.

Sustainable and Renewable Energy Development Authority (SREDA) has been created as a nodal organization of the Government to promote and foster the renewable energy development in Bangladesh both in public and private sectors. In connection with this,the feasibility study has been initiated by the Sustainable and Renewable Energy Developmentproject of UNDP-GEF in association with SREDA. The feasibility is conducted to identify the prospective energy solution from waste in six municipalities-Mymensingh, Cox's Bazar, Sirajganj, Dinajpur, Habiganj and Jessore. A European firm (ECOREM) supported us to conduct the study. Required data and information from selected site was collected by interviewing with a number of respondents from different stakeholders includes official from Municipalities, professional, NGO's, social workers and households. The team was not only assessed the daily waste generation but also evaluated the site condition whether waste-to-energy (W2E) generation plant can be operated without any disturbance in future. Furthermore, financial analysis of all the possible W2E generation technology in terms of pay-back period was carried out by the experts.It is my immense pleasure to know that this study covers all the aspects that are needed to take decision about W2E generation project in the said municipalities.

From the outcomes of this study it is clear that the most suitable options for W2E conversion are anaerobic digestion process for producing biogas and next comes gasification to get the thermal energy. I strongly believe, these proposed technologiescan have significant contribution to generate power if Integrated Waste Management System (IWMS) combining with power generation system is introduced in the country. I hope the Government of Bangladesh will provide their continuous support in this regard.

Finally, I would like to thank SREDA, UNDP Bangladesh, GEF and project staff for their sincere effort. I also express my cordial thanks to Mr. Siddique Zobair, Member (Additional Secretary) for his guidance during the whole feasibility study period.



Sudipto Mukerjee

Md. Taibur Rahman
Project Manager, SREPGen, UNDP Bangladesh

Message

Bangladesh is facing a serious waste management challenges. Unplanned urbanization associated with lack of awareness among people regarding proper waste disposal have left the country increasingly overburdened with Municipal Solid Waste (MSW). In 2015, waste generation in Bangladesh amounted to around 23,688 tons per day according to Waste Concern database on Municipal Solid Waste (MSW), which means that an average person in Bangladesh disposed of 204 kg of waste in that year.

SREPGen Project of UNDP/GEF in association with Sustainable and Renewable Energy Development Agency (SREDA) has initiated this study to identify the viable waste to energy generation measures in the six municipalities of Bangladesh to not only address the MSW management challenges but also to produce energy out of it. Accordingly, a team of veteran experts in this fieldled by Dr. Walter Mondt and Dr. Stefan Helsen, Eng. Diane Lippens, Eng. Marian Renkensof a Belgium based firm "Ecorem" were selected to conduct this feasibility study. The team paid several site visits in the selected municipal areas and talked with a number of stakeholders from public and private agencies, NGOs, social worker, households and development professionals. They have collected primary data on the waste generated every day from the municipalities and assessed the site conditions in terms of their accessibility to road and utility network for power evacuation, flood and other climatic condition that can hamper future operation on the waste to energy conversion facilities. They have also carried out a rigorous financial analysis on each of the waste to energy generation options in terms of financial returns for the municipalities. This study has been guided by a review team led by Mr. Siddique Zobair, Member (Additional Secretary), SREDA. I express my gratitude to that review team also.

Gasification and anaerobic digestion (AD) of MSW are considered as the emerging and sustainable technologies to treat waste for energy generation in Bangladesh. These are also particularly suitable options to avoid significant land acquisition and high moisture content of the MSW. This is an initial feasibility study and it suggested an in-depth study to firm up assumptions like the actual volume of generated wastes, cost of social and environmental mitigations and necessary capital and overhead to run this type of facility in Bangladesh. This will also be useful to derive the cost of a pilot project to be implemented in the near future in any of the municipalities. UNDP Bangladesh and GEF are committed to continue its utmost support in this regard to scale up the most suitable technology propagation.

I express my heartfelt thanks to SREDA management, the team of experts who conducted this study successfully, the review team and all concerned. We are hopeful that this study will trigger some pilot initiative of the suggested waste to energy mitigation options in the selected municipalities and scale up programme in near future.

Md. Taibur Rahman, PhD

Study Review Panel

Chairperson

Mr. Siddique Zobair
Member (Energy Efficiency & Conservation) SREDA

Members

Mr. Sheikh Reaz Ahmed
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Director, Sustainable Energy
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Mr. Arif M Faisal
Program Specialist
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Executive Summary

Bangladesh is the ninth most populous country and twelfth most densely populated country in the world. The urban population growth rate is approximately 3%. With this population growth, there is an increasing problem of waste management particularly in the larger cities.

A comprehensive feasibility study on waste to energy conversion was undertaken in six municipalities in Bangladesh in order to resolve the ongoing waste management issue. The total works were carried out in several step by step actions including work plan, selection of municipality, data analysis (both primary and secondary sources), conversion technologies, evaluation of appropriateness of technology in each municipality and recommendation of pilot model development.

On the basis of quantitative criteria including number of inhabitants and qualitative criteria including flooding risk, road infrastructure, population density, climatic context, electrical network and industrial sector etc., Mymensingh, Cox's Bazar, Sirajganj, Dinajpur, Habiganj and Jessore were selected for the comprehensive feasibility study for waste to energy conversion.

The primary data were collected through the distribution of questionnaires on waste management practices currently developed in their Municipality, in which the local authorities were involved. There is a lack of consistency and reliability between primary data collected by the local authorities and the secondary official data source. As such, recommendations were prepared to underline the importance of implementing systems for data recovery and follow-up.

Forecasting of future volume of waste production was extrapolated by regression analysis considering population growth rate and consumption

pattern due to seasonal variation as the multification factor in each municipality. It is worthy to mention that after analysis of the primary data, notable difference to the scientific literature have been identified (in particular waste quantity, waste composition, etc.). The work of the consultant therefore mainly consisted in interpreting the data using reliable published secondary data sources.

There are two types of technology around the world for waste to energy conversion which include :

- Thermal conversion (incineration, gasification, pyrolysis, plasma arc gasification, etc.)
- Non-thermal conversion (anaerobic digestion, landfill gas recovery)

The end-use consumption such as electricity, gas, heat, compost etc. is one of the most important parameters that influence the choice of the energy recovery system.

The merit and demerits of both technologies have been elaborately addressed in the study. Gasification and anaerobic digestion (AD) are considered to the emerging and sustainable technologies.

Advantages of gasification technology include great reduction in waste volumes and its ability to process a variety of waste streams, small land size requirement and with output energy of heat and electricity. A major disad vantage of this technology is the requirement of a constant supply of waste feedstock with less than 30% moisture content. Thus, a rotary dryer is needed to remove the moisture from wet feed stock which would result in 20–30% self-consumption. On the contrary, biochemical conversion techniques (anaerobic digestion) can digest wet biodegradable waste like wood and vegetables, has a low Lower Heating Value (LHV) with output energy of biogas, compost and landfill. The major disadvantages of anaerobic digestion include the need for vast land area and cost of sanitation. However, both technologies (gasification and anaerobic digestion) are technically sustainable.

Large cities where land acquisition is troublesome, gasification technology is recommended. In those cities where availability of land is not an issue and end use consumption is primarily bio-gas (cooking & transport), compost and landfill etc., anaerobic digestion technology is recommended. However, a composite module (integration of both technologies) is suggested in a mixed situation.

A financial analysis has been exercised in each city separately with and without environmental cost and revenue into consideration. Actual cost estimation for pilot project with regards to Bangladesh became difficult due to limited time and was estimated based on experience gained in Europe. Due to the limitation of cost estimation of commercial project, developing a decision making financial business model proved difficult. A practical approach of cost estimation using more local resources is highly recommended. In order to do so, a small scale demo project using both technologies (gasification and anaerobic digestion) would need to be undertaken. Based on the result of demo project, a sustainable financial model should be developed comprising of soft loan, grant and owner's equity. The Life Cycle Cost (LCC) with Net Present Value (NPV), Internal Rate of Return (IRR) and Pay Back Period (PBP) are to be formulated to evaluate the financial viability of the commercial project.

This is the critical time for GOB to make appropriate policies for waste management. Electricity generation from municipal solid waste (MSW) is the most environmental friendly solution for this existing issue. UNDP and SREDA are encouraged to take a primary role in establishing our proposed solution.

The overall result of this study is considered as a major step forward in the development of sustainable solutions to address the huge solid waste challenge in Bangladesh. National, regional and local authorities, institutes, NGOs and research organizations, as well as international donors, have shown their involvement and commitment throughout the study. It is therefore of utmost importance to sustain this collaboration with the development of a pilot plant in one or more of the selected municipalities. Mymensingh and Cox's Bazar municipalities can be considered as high priority for piloting.

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Abbreviation

ADB	Asian Bank of Development
AD	Anaerobic Digestion
SREDA	Sustainable Renewable Energy Department Authority
SREPGen	Sustainable Renewable Energy & Power Generation
RfP	Request for Proposal
WTE	Waste-to-Energy
Inh.	Inhabitants
IRR	Internal Rate of Return
LGED	Local Government Engineering Department
LHV	Lower Heating Value
LSP	Large Scale Plant
MGSP	Municipal Governance & Services Project
NPV	Net Present Value
HW	Highway
HV	High Voltage
RHD	Road Highway Department
ToR	Term of Reference
NWPGCL	North Western Power Generation Company Ltd
MATI	Motivation, Awareness, Training and Implementation
PBP	Pay Back Period
SBSU	Sheora Bohumukhi Samaj Kalyan Unnayan Sangsta
TUS	Trinomul Unnayan Sangsta
SSP	Small Scale Plant
PSA	Preliminary Storage Area
CBM	Compressed Bio-methane
PGR	Population Growth Rate

Glossary

Administrative Tire	Source : (Bangladesh Bureau of Statistic, 2018)
Zila	Zila (Bengali word of District) is a mid-level administrative unit comprising of several upazilas/ thanas and having Zila Parishad institution
Upazila	Upazila (Bengali word of Sub-district) is a rural administrative unit comprising of several unions and having Upazila Parishad
Mauza	Lowest administrative unit having a separate jurisdiction list number (J.L No) in revenue records. Every mauza has its well-demarcated cadastral map. Mauza should be distinguished from local village since a mauza may consist of
Ward	Smallest administrative urban geographic unit comprising of mahallas and having ward council institution.
Mahalla	Lowest urban geographic unit
Urban Area	Smallest administrative urban geographic unit comprising of mahallas and having ward council institution.
Paurashava/ Municipality (PSA)	Includes paurashavas incorporated and administered by local government under Paurashava Act, 2009.
Town	Urban area having population less than 100,000

1. Background

Bangladesh is one of the most densely populated countries in the world with about 161 million people living on 147,570 km² of land. It is also mostly agrarian with about 70% of its population living in rural areas. The development challenges imposed by such a high population density and the related environmental threats are huge, but with the impact of climate change, the challenges grow bigger.

Bangladesh is urbanizing at a rapid pace. Since its independence in 1971, the urban population has grown at an average annual rate of 6% against the overall national growth of 2.2%. As a result, the urban population has increased six times, as compared to the rural population. From a total of 20.8 million urban population in 1991, the country's urban population increased to 28.6 million in 2001, which is expected to reach 89.5 million by 2030. Approximately 28.4% of the total population living in urban areas is impoverished. By 2020, it is estimated that the poor will comprise 40 - 60% of the urban population. The increase of impoverished people in urban areas is resulting in the growth of slums in large cities. These demographic changes have increased the public and environmental health challenges in urban areas. High urban density in Bangladesh has resulted in high concentration of waste production, with negative effects when treated properly.

This feasibility study has only focused on the use of municipal waste as a base for energy production. It looked into the possibilities from municipality waste to identify suitable conversion technologies and evaluated the existing framework conditions to set up a waste-to-energy plant.

1.1 Overall Objective of The Project

One of the potential sources of renewable energy in Bangladesh is the transformation of waste to energy (WTE).

The waste generation rate in 336 municipalities (paurashavas+city corporations) of Bangladesh varies from 0.25 to 0.56 kg per person per day, and more than 70% of the waste are organics, with high moisture content and low caloric value.

Besides, it is important to note that all these municipalities are responsible to manage the waste produced in their territory but most of current systems show a limited efficiency. However, the lack of space for disposal of solid waste is often a challenge for the municipalities.

Based on these different elements, the generation of energy by treating these wastes with appropriate technologies is an alternative solution to the waste management issues in some municipalities of Bangladesh.

For this purpose, the SREPGen Project has prepared a feasibility study in six municipalities for waste to power generation and to elaborate the detailed specifications and to design a pilot power plant. In this feasibility study, the overall objective is to look into the opportunities and possible techniques for energy conversion of municipality waste in a representative sample of municipalities throughout the country. Based on the local waste and energy specific data, several options of WTE conversion were compared. The following items have been discussed: technical description of possible process, financial description, operational elements (logistical elements, business model, social elements, employment, etc.) and regulatory aspects (policy recommendations, etc.).

As such, the task of the consultant consisted of advising the client with the best practices in the implementation of the project, and specific technical issues, etc.

1.2 Specific Objectives of The Study

This consultancy and study assignment consists of data collection, detailed analysis, designing services, providing best business model and presenting workshops.

To achieve the proposed objectives of the TOR, a number of sub-actions are defined:

Project Implementation
Action 1: Start of the study
Action 2: Selection of municipalities;
Action 3: Detailed analysis of data;
Action 4: Generic discussion of energy conversion options;
Action 5: Evaluation of solutions for each of the municipalities;
Action 6: Development of best possible business model for piloting;

Project Management
Reporting/deliverables;
Attending workshops.

The "end product" of this Study is the development of brief project documents for possible WTE projects in six municipalities. These documents will be useful for the preparation of technical specifications and tenders for the demonstration of projects. In all of the project documents, much attention is given to the following items which are very important to guarantee a successful implementation:

Preconditions :
Supply of waste streams (quantity and constant daily supply)
Pre-treatment and purification of waste treatment
Presence energy demand (heat, gas or electricity)

Sustainability :
Environmental aspects on the sites and its vicinity
Socio-economic conditions
Operation and maintenance of the plant

2. Action 1 : Project Intiation

All information related to the work plan and the details of the mission have been discussed in close cooperation with the client. Moreover, the mission started with the signature of the contract on July 4th, 2016.

As mentioned in the contract conditions, the international key staff and national supporting staff were mobilized from that date.

Figure 1: Bangladesh Division Map

3. Action 2: Selection of Municipality

A long list of suitable municipalities have been prepared.

The SREPGen Project mission is to develop renewable energy resources in Bangladesh. As this study looks into the possibility to reuse waste as source of energy, it was important to capture a nationwide picture of the WTE potential.

Twelve municipalities have been preselected by the consultant on several features, allowing for a significant representation for Bangladesh. After validation, six paurashavas amongst the twelve have been selected by the client to perform the further tasks.

The analysis and assessment of the suitability of the potential municipalities for the installation of a WTE facility has been conducted whilst taking into account aspects such as logistical elements, environmental aspects, and the specific socio-economic situation.

Table 1 : Name of Paurashava based on Results from the elimination analysis

1	Mymensingh	17	Brahmanbaria
2	Tarabo	18	Bogra
3	Faridpur	19	Pabna
4	Narsingdi	20	Nawabganj
5	Savar	21	Sirajganj
6	Kishoreganj	22	Naogaon
7	Bhairab	23	Dinajpur
8	Tangail	24	Saidpur
9	Jamalpur	25	Jessore
10	Kaliakoir	26	Jhenaidaha
11	Tongi	27	Satkhira
12	Sreepur	28	Kushtia
13	Chandpur	29	Pirojpur
14	Noakhali	30	Mathbaria
15	Feni	31	Swarupkathi
16	Cox's Bazar	32	Jhalokathi

With the outcome of the workshop, the selection of the paurashavas has been based on two elimination criteria (city's category and population) and six qualitative criteria (flooding risk, road infrastructure, climate, electricity grid, presence of industries and population density). Note that the spatial distribution has not been considered as a criterion, but has been taken into consideration along the selection process.

3.1 Analysis by Elimination Criteria

To perform this analysis, the scope of analyzed cities had to be reduced to those presenting the highest potential and the best conditions. For this, two elimination criteria were taken into consideration :

- City's category : Only A-type and B-type Paurashavas are included into the selection process
- Population : Cities whose population exceeds 100,000 inhabitants are considered

After applying these two criteria and based on geographical distribution, 32 cities have been preselected for the second step. They are presented below.

In order to respect the spatial distribution throughout the country and the proportion of city per division as obtained above, the qualitative selection process for the selection of the twelve cities has been based on the following elements :

- Preselection of 3 Cities in the Dhaka Division
- Preselection of 2 Cities in the Rajshahi Division, the Chittagong Division and the Khulna Division
- Preselection of 1 City in the Rangpur Division, the Barisal Division and the Sylhet Division

3.2 Qualitative Criteria

Several criteria have been examined in this analysis: flooding risks, road infrastructure, density, climate, electrical infrastructure, etc. Contrary to the previous analysis, these criteria have been appreciated in function of each specific context and the analysis has been conducted at the scale of each division in a way as to respect as much as possible the principle of equal geographic distribution on the whole country.

3.2.1 Presentation Of The Qualitative Criteria

Flooding risks	As majority of Bangladesh's territory is situated in flood risks zones, flooding represents a strategic issue for both the population and the infrastructure. Because WTE plants are expensive investments, they require to be protected against such natural disasters. As a consequence, the consultant has given preference to municipalities outside of flood sensitive s (in particular for the demonstration phase).
Road Infrastructure	A WTE installation should be easily accessible for both construction phase and operating phase (maintenance, etc.). As a consequence, cities with good quality road infrastructures have been favored.
Population density	This is considered because it reflects the concentration of waste in the territory (in general, the higher the population density, the more important the waste generation will be in the area). Note: the production rate per municipality was not available when this part of the report was developed. Therefore, the population density was used to give an estimation of the waste generation potential.
Climatic context	To guarantee a fair distribution over the different climatic and geographical regions, the selection process aims to shortlist municipalities within different climatic areas. The consultant has tried to select cities in such a way as around 50% present a dry climate, and around 50% present a wet climate.
Electric Network	The installation of WTE plants is seen as a strategic element for the development of a sustainable renewable energy system for Bangladesh. It may be important that some new developed energy system could be connected (at low cost) to the national grid system. Therefore, the selection process will consider municipalities in close proximity to the national grid system. On the other hand, the implementation of a WTE facility in paurashavas currently deprived of energy plants or HV lines could be an asset for the development of the municipalities.
Industrial Sector	Industries can be involved in WTE process as a biowaste supplier and/or an energy consumer. It is therefore proposed to consider some municipalities that hold a relevant industrial areas nearby such as sugar industry, tobacco industry, etc.

3.2.2 Pre-selection of 12 Municipalities

Based on the qualitative criteria evaluation, 12 Cities have been pre-selected and proposed to the Client as listed in Table 2 (see Annex 2 for details).

Table 2: Proposition of selected cities

N°	City	Division	Cat.	Pop.	Flood risks	Road Infra.	Density	Rainfall	Climate	HV/E	Industry
1	Mymensingh	Dhaka	A	258,040	L	N	2,969	W		VS /	I
2	Tangail	Dhaka	A		M		2,290	D		Ed	
3	Sreepur	Dhaka	A	167,412	L	N	5,99			VS	I
4	Chandpur	Dhaka	A	159,02 1	L	R	2,71	W		V	I
5	Cox's Bazar	Chittagong			L		3,36	W		S	
6	Sirajganj	Rajshahi	A	158,91 3	S	R	3,477	D		V	I
7	Naogaon	Rajshahi			L		2,643			S	
8	Dinajpur	Rangpur	A	186,72 7	L	N	2,74	D		(Ed)	
9	Jessore	Khulna	A	201,79 6	L	N	3,679	D		VS	
		Khulna			M		3,222			Ed	
10	Pirojpur	Barisal	A	60,056	M	R	2,11	W			
11	Habiganj	Sylhet	A	69,512	M	R	2,66	W			

Legend

Flooding	Road	Pop. Dens	Rainfall	Climate		Electric grid	Industry
Low	National	2,000 < X ≤ 3,785	< 200 cm	SE	W	V : HV line	I : Favorable Industrial Context
Medium	Regional	> 3,785	> 200 cm	NE	SW	S : Substation	
Severe				NN	SC	Ed / Ec : PP in the district/city	
				NW		() : planned	

3.2.3 Selection of 6 Municipalities

A workshop was organized on 31 August 2016, during which the results of the inception report were presented. Issues on waste-to-energy (WTE) were discussed, and valuable remarks and suggestions were communicated in order to be incorporated in the final version of the inception report or later in the interim report. All the observations were summarized and added in minutes of the meeting, available in Annex 1.

On the basis of the final version of the inception report, the client has selected the following six municipalities among the twelve presented:

- Mymensingh, Dhaka Division
- Cox's Bazar, Chittagong Division
- Sirajganj, Rajshahi Division
- Dinajpur, Rangpur Division
- Jessore, Khulna Division
- Habiganj, Sylhet Division

Figure 2: Pilot Municipalities – Source (Department of Peacekeeping Operations, 2004)

4. Action 3 : Detailed analysis of data

This section has been divided into three parts. First, general information on each paurashava has been described. Then, a focus has been made on information related to waste, for example the composition and the production of waste in each paurashava. Finally, the energy context has been studied in order to analyze needs and opportunities regarding the production of energy through waste.

This detailed study has been based on secondary data, such as literature, scientific articles, records from municipalities, etc.

4.1 General Information

4.1.1 Objective

The objectives of this section is to capture a general overview of the situation on each paurashava regarding the geographic position, the administrative dependence, the climate, the population, the infrastructure, the economic situation and the education level.

4.1.2 Methodology

As mentioned in the introduction, the Consultant has prepared this section on two major sources of data.

Initially, questionnaires had been prepared by the consultant and sent to each local council (template available in Annex 3). It is important to highlight that the involvement of local authorities is at utmost important for the success of the analysis, as well as the accuracy of data collected. Results from the questionnaire were awaited by the local partner, and further analyzed by the consultant in order to map the current status on waste management and to define a profile of each paurashava.

Because many data as requested in the questionnaire were not be available, the consultant proceeded with a literature review, allowing to at least estimate some figures and make assumptions based on reliable national or regional information.

4.1.3 Mymensingh

Localization and Administrative Situation

Mymensingh, which is located on the banks of the Old Brahmaputra River, is a city in the north-central part of Bangladesh, in the Dhaka Division. It is the main city of the Mymensingh District (4396 sq. km).

Mymensingh paurashava, which occupies 21.73 sq.km, is sub-divided in 21 wards (Geocode from 01 Ward No - 01 to 21–Ward No. 21). The Mayor of the paurashava is Mr Akmtaiqui Alom. Hereafter is presented a map of the district and the paurashava.

Climate

The city is situated in the south-central climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 12°C to 33.3°C and by an annual average precipitation of 2174 mm.

Figure 3 : Situation of Mymensingh - (LGED, 2010)

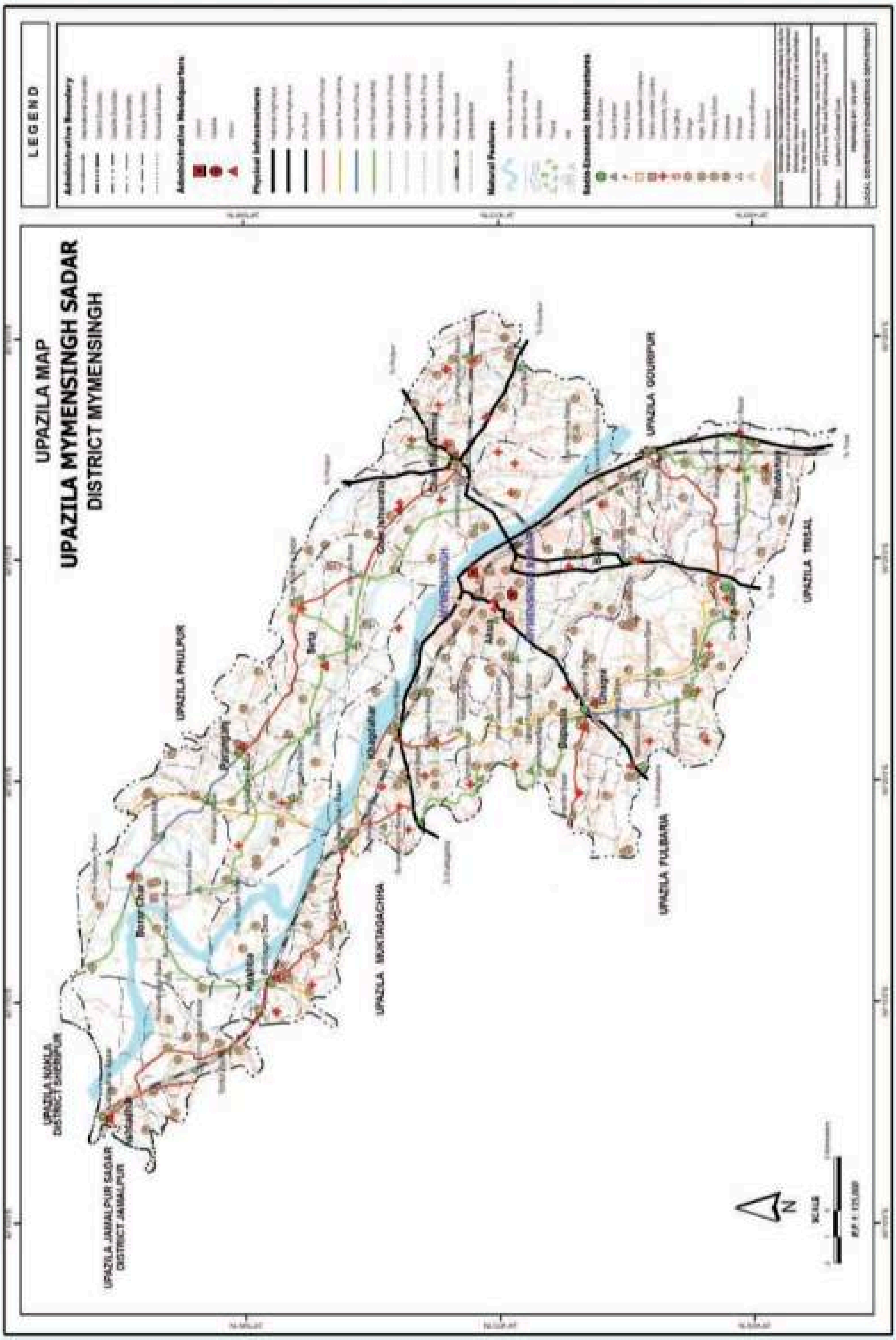
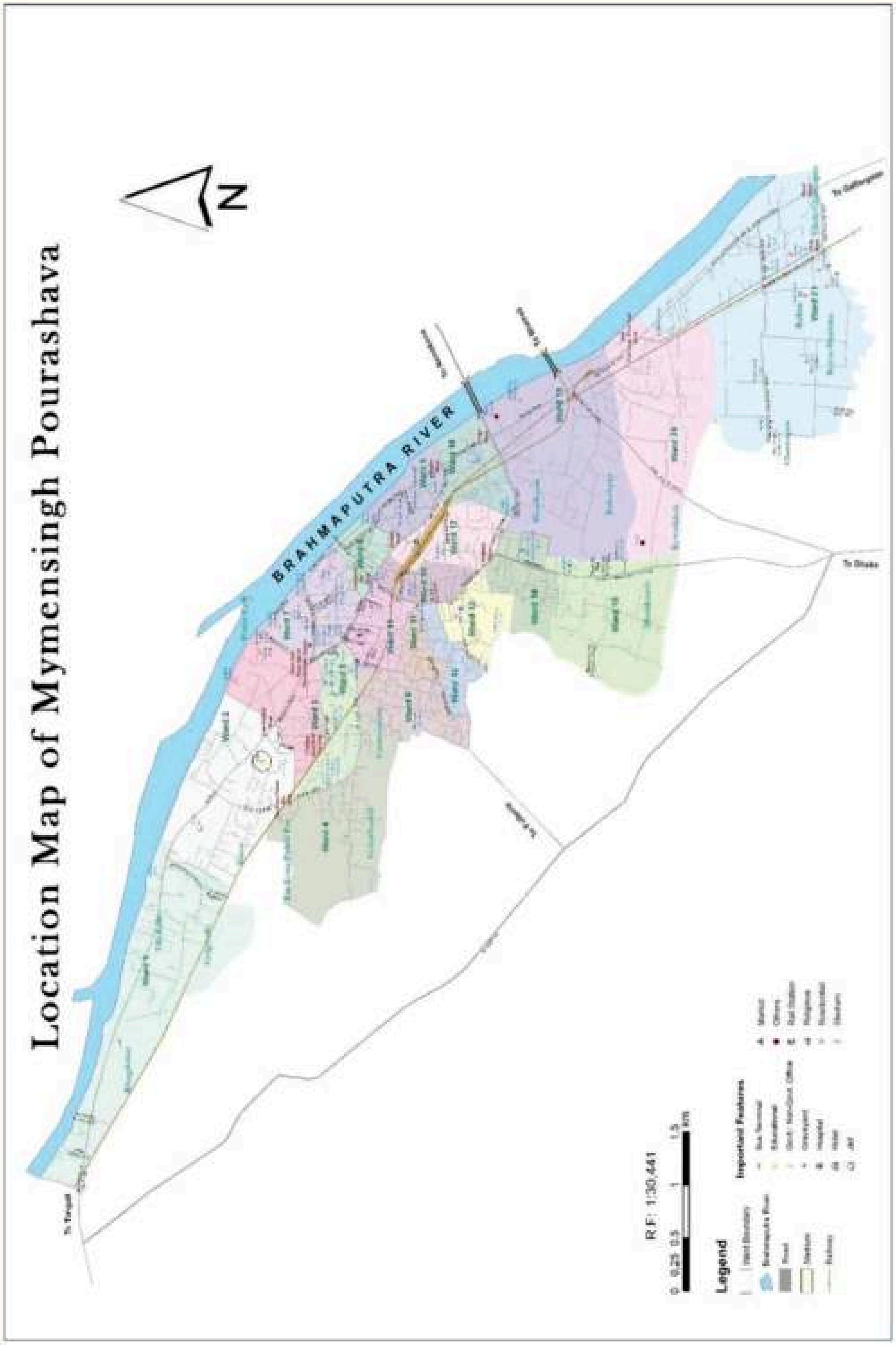


Figure 4 : Map of Mymensingh Paurashava



Population

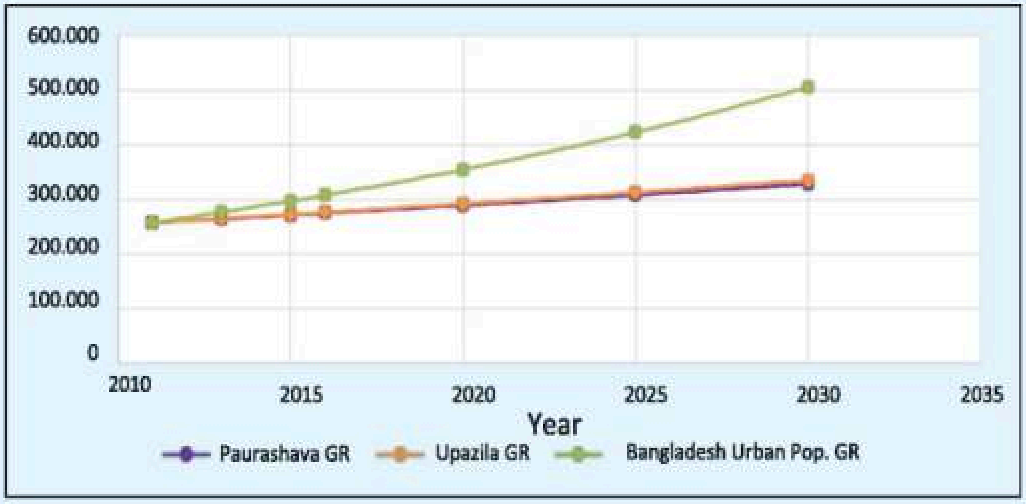
According to the population and housing census 2011 performed by the Bangladesh Bureau of Statistics, the population of Mymensingh paurashava rose from 227,204 persons in 2001 to 258,040 persons in 2011, implying an average population growth rate of 1.28%, which is slightly lower than the Upazila average population growth rate estimated at 1.39%. The population density of the Upazila is 2,037 cap/sq. km.

It should be noted that, according to the questionnaire, the population have been estimated to be 225.811 inhabitants by 2015. These figures are lower than those of the census four years ago. As it is unlikely that the population has decreased, it can be assumed that the administrative boundaries used for both censuses were not the same. The same observation can be made on the density; those given in the questionnaire is, this time, much higher than the one of the Census (18.817 inh/sq meter). Because no records were given to justify the figures of the questionnaire, the consultant proposes, for the next part of the study, to base the projection on the official census of 2011 from the Bangladesh Bureau of Statistics.

In order to get an estimation of the population by 2025, projections presented below were calculated by taking into consideration three different population growth rates :

- A PGW of 1.28%, similar to the one observed from 2001 to 2011
- A PGW of 1.39%, similar to the district PGR observed from 2001 to 2011
- A PGW of 3.6%, corresponding to the national average urban population growth rate forecasted by the UN and WB over the period 2010 - 2015

Figure 5: Mymensingh - Population forecast



The road infrastructure is well developed in Mymensingh. The paurashava is accessible through a dense national (N3 & N4) and regional network. The paurashava is also connected with the national railway and has a developed a bus network. Concerning the state of the roads inside the paurashava, the data provided by each local authority show that 70% of roads are wide and are accessible for trucks or buses. Moreover, 80% of the network is composed of paved roads.

Economy

According to the Bangladesh Bureau of Statistics, agriculture is the main sector of Mymensingh district. About 60% of holdings are farms which produce:

- Crops : Paddy, jute, sugarcane, wheat, oil seed and pulse, betel leaf, karalla, sweet potato, turmeric, ginger, brinjal, cauliflower
- Fruits : Jackfruit, banana, pineapple, papaya, kadbel, guava, boroi, amloki, palm, latko

According to the questionnaire, agriculture remains one of the main activities of the Mymensingh Paurashava, as 37% of population is working in this sector (esp. with Paddy culture). However, the main job provider of Mymensingh paurashava is the garments industry, comprising of 45% of the activities. Indeed, paurashavas like Mymensingh are characterized by the presence of manufacturing and services sectors, which employs a significant part of the population.

Education, Culture, Religion and Gender Considerations

Education often plays an important role in the development of solid waste management systems. As such, it is important to know the literacy and education level of the population.

According to the Census 2011, 51.7% of the population of Mymensingh Upazila aged 7 years and over are literate. There is a difference between the proportion of literate men (53.9%) and literate women (49.6%). Women's literacy rate have had a significant increase from 2001 to 2011.

Concerning religion, Islam is the main religion of the Paurashava (93.8%), followed by Hinduism (6%), and the other religions such as Christians, Buddhist, etc. (0.2%).

4.1.4 Cox's Bazar

Localization and Administrative Situation

Cox's Bazar is a city in the south-eastern part of Bangladesh, in the Chittagong Division. It is the main city of the Cox's Bazar district (2,491 sq. km).

Cox's Bazar paurashava, which stretches out on 7.94 sq km, is sub-divided in 12 wards (Geocode from 01 – Ward No - 01 to 12 – Ward No. 12). The Mayor of the paurashava is Mr. Mahbubur Raitman Chowditury.

The City is situated at the mouth of the Bakhali River, which flows north into the Gulf of Bengal. Hereafter is presented a map of the district.

Climate

The city is situated in th e south-eastern climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 16.1°C to 34.8°C and annual average precipitation of 4,285 mm.

The region is regularly experiencing sea storms, tidal bores, hurricanes and cyclones.

Population

According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, Cox's Bazar paurashava has experienced a significant urbanization from 2001 (51,918) to 2011 (167,477), with an average population growth rate of 12.43%, quite higher than the upazila average population growth rate estimated at 2.76%. The population density of the upazila is 2,011 cap/sq. km.

It should be noted that according to the questionnaire the population has been estimated to until 2015. This figure is much higher than that of the Census four years ago and implies an annual growth rate of 17% (2011-2015). The important increase in the period of 2001-2011 may be reliable and may follow the growing tendency of urbanization observed over this period. However, because no records were given to justify the figures of the questionnaire, the consultant proposes, for the next part of the study, to base the projection on the official Census of 2011 from the Bangladesh Bureau of Statistics.

In order to get an estimation of the population by 2025, the projections presented below were calculated by taking into consideration three different population growth rates :

- A PGW of 12.43 %, similar to the one observed from 2001 to 2011
- A PGW of 2.76 %, similar to the district PGR observed from 2001 to 2011
- A PGW of 3.6%, corresponding to the National Average Urban Population Growth Rate forecasted by the UN and WB over the period 2010 - 2015

Figure 6: Cox's Bazar - Population forecast

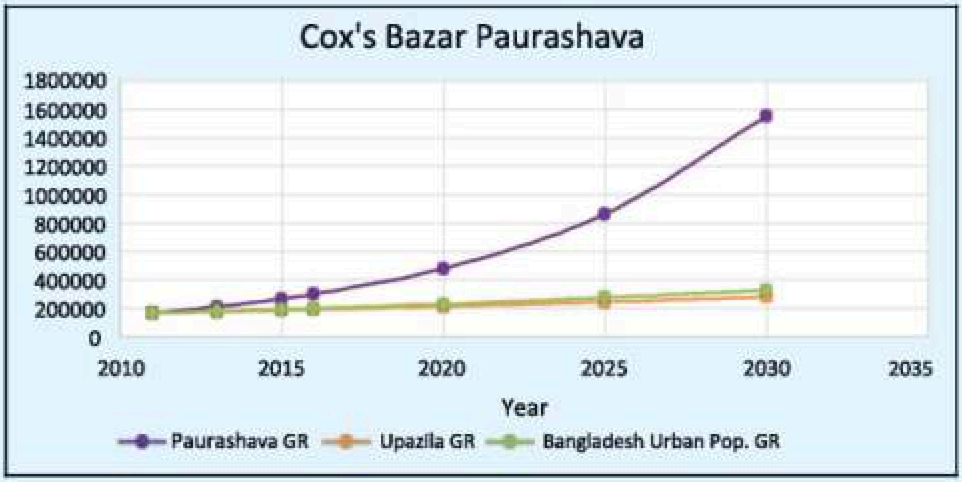


Figure 7 : Situation of Cox's Bazar – Source (LGED, 2010)

Road Infrastructure

Cox's Bazar is connected to the national network through the N1. The paurashava is also crossed by national roads and has a developed bus network.

Concerning the state of the roads inside the Paurashava, the data provided by each local authority show that 50% of roads are wide and accessible for trucks and buses, whereas 30% are considered as narrow, and 20% as non-accessible by vehicle. Moreover, 55% of the network is composed of paved roads. Indeed, according to satellite pictures, it seems that most of the roads of the city are not paved, which may explain difficulties of access to certain areas and in particular for the collection of waste.

Economy

Because of its famous beaches on the bank of the Gulf of Bengal and its natural parks, Cox's Bazar's major source of economy is tourism. Resorts, restaurants and other touristic-related activities are developing fast over the last decades.

Moreover, fishing, salt production and aquaculture (prawns) play an important role in Cox's Bazar's economy, and also constitute an important source of revenue for foreign exchanges.

It is also important to mention the role of agriculture, which remains the main source of income for the population. The production in Cox's Bazar District is mainly focused on:

- Crops : Paddy (Katharivog), wheat, sugarcane, jute, potato, vegetables, onion, garlic and oil seed
- Fruits : Mango, jackfruit, pineapple, banana, papaya, coconut, plum, litchi, guava

Finally, the district offers natural resources, such as natural gas, zircon, rutile, magnetite, monazite, and coralline limestone.

Based on the results of the questionnaire, the paurashava of Cox's Bazar show the following as main sectors; agriculture at 24% (mainly rice) followed by the industry at 22%.

Education, Culture, Religion And Gender Aspects

According to the Census 2011, 49.2% of the population of Cox's Bazar Upazila aged 7 years and over are literate. We can notice a slight difference between literate men (50.4%) and literate women (47.9%). Concerning specifically the population of Cox's Bazar paurashavas, a significant difference between wards can be observed: the literacy rate is about 25% in ward 1, compared to 83.4% in ward 10.

From the education figures on Cox's Bazar Upazila, it can been observed that more than 65% of the 6 – 15 year olds attend school for both male and female with peak values for 6 -10 years (78.35%). However, the attendance drastically decreases for the population aged 20 – 29 years, especially regarding in women (between 0.9% and 6.9% vs 2.3 to 12.3 % for men).

Concerning religion in the Upazila, Islam is the main religion of the paurashava (92%), followed by Hinduism (6.4%), Buddhists (1.3%), and the other religions (0.3%).

4.1.5 Siraganj

Localization and Administrative Situation

Sirajganj is a city in the central part of Bangladesh, in the Rajshahi Division. It is the main city of the Siraganj District (2,402 sq. km). Siraganj paurashava, measures 8.49 sq.km in area, is sub-divided in 15 wards (Geocode from 01 – Ward No - 01 to 15 – Ward No. 15) and is administrated by Mr Abdur Rouf Mukter. The city is located on the banks of the Brahmaputra River.

Hereafter is the map of the District and of paurashava climate.

The city is situated in the south-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 11.9°C to 34.6°C and an annual average precipitation of 1,610 mm.

Population

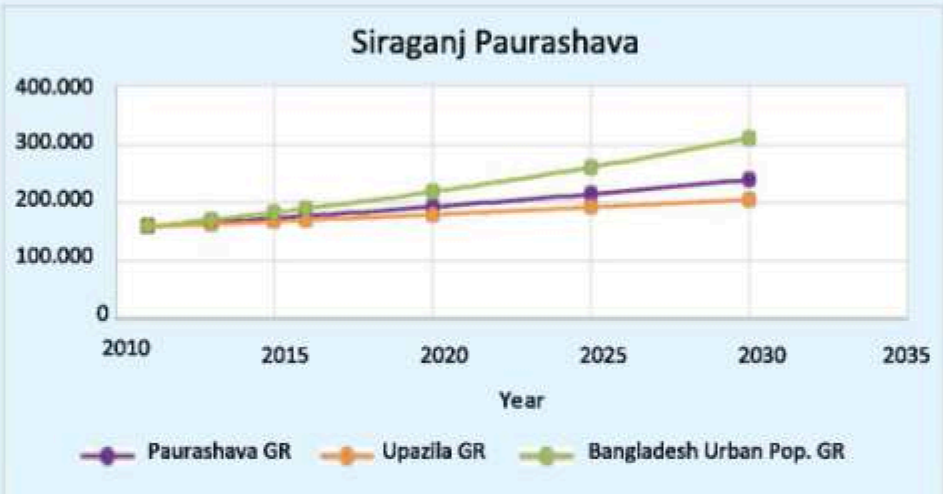
According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Siraganj Paurashava rose from 128,144 people in 2001 to 158,913 people in 2011, implying an average population growth rate of 2.18%, slightly higher than the upazila's average population growth rate estimated at 1.36%. The population density of the upazila is 1734 cap/sq. km.

Figures collected through the questionnaire show a higher population than the one of the Census (297,230 inhabitants) which would imply an annual growth of 17%. As these figures are much higher than the tendency observed over the last few years, it can be assumed that the administrative boundaries used for both censuses were not the same. Because no records were given to justify the figures of the questionnaire, the consultant proposes, for the next part of the study, to base the projection on the official Census of 2011 from the Bangladesh Bureau of Statistics.

In order to get an estimation of the population by 2025, the projections presented below were calculated by taking into consideration three different population growth rates :

- A PGW of 2.18 %, similar to the one observed from 2001 to 2011
- A PGW of 1.36 %, similar to the District PGR observed from 2001 to 2011
- A PGW of 3. 6%, corresponding to the National Average Urban Population Growth Rate forecasted by the UN and WB over the period 2010 - 2015

Figure 8 : Siraganj - Population forecast



Road Infrastructure

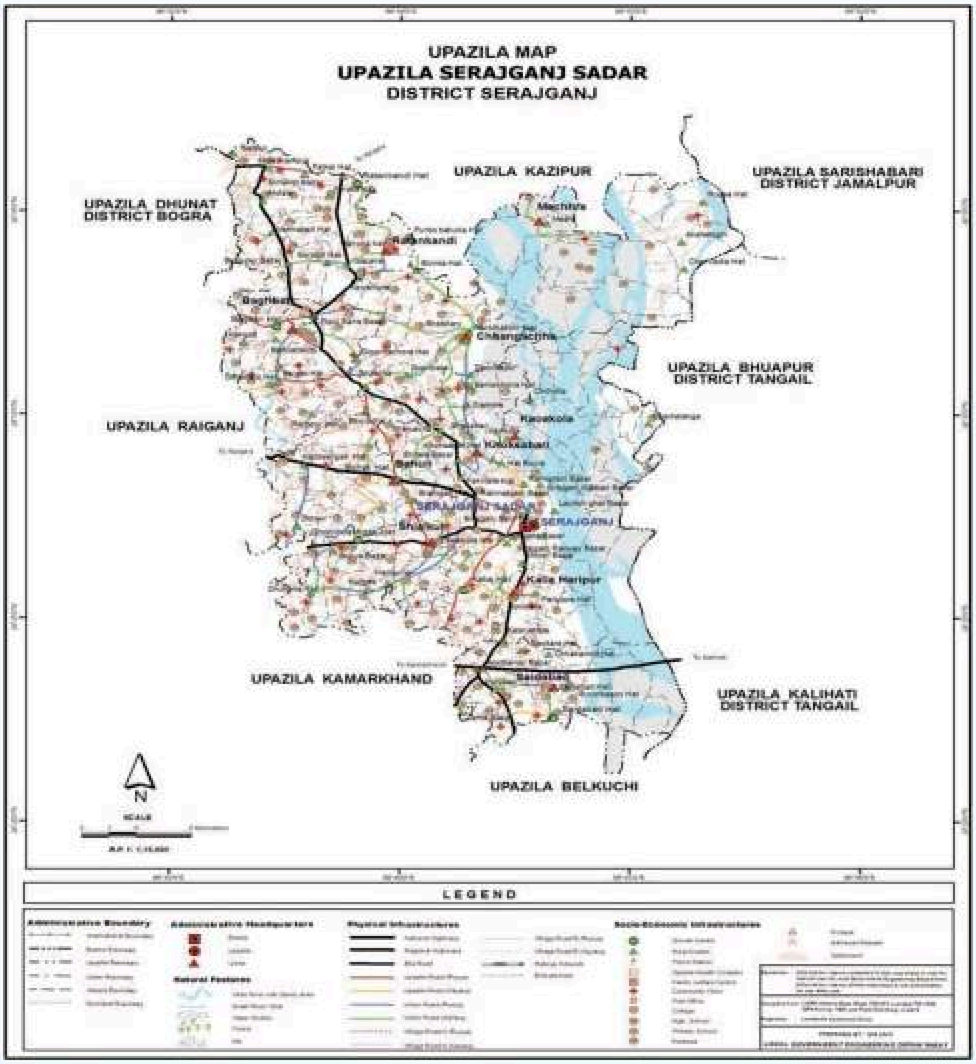
Sirajganj is accessible through several regional roads, but is also situated nearby the National 5 to Bogra and National 4 to Dhaka.

The Paurashava has two railway stations and has a developed bus network.

Concerning the internal road network, according to satellite images, the city is squared by several main paved roads. However, houses seem very concentrated in some places and it seems that the access roads to such areas are unpaved, and, in any case, relatively narrow.

According to the data provided by each local authority, 45% of roads are wide and accessible for trucks or bus, 25% are narrow and 30% non-accessible with vehicle. Some 50% of the network is composed of paved roads.

Figure 9 : Situation of Siraganj – Source (LGED, 2010)



Economy

According to the Bangladesh Bureau of Statistics, agriculture is the main activity sector of Sirajganj District. More than 50 % of holdings are farms that produce mainly :

- Crops : Paddy, jute, wheat, mustard seed, sugarcane, onion, garlic, potato, sweet potato, chilly and ground nut.
- Fruits : Mango, jackfruit, black berry, papaya, guava, coconut, palm, date, olive, bel, tetul and banana

Because of the Brahmaputra River, fishing is also an important source of income for the District through the commercialization of valuable species, such as pangas, airh, kholisha and chingri, ruhi, katla, mrigel, magur, sing, koi, puti, shoil, gozar and boal.

Urban centers are more focused on manufacturing activities. Through its extensive resources of jute, Sirajganj is well-known for being a jute-trading center. In 2011, the Upazila of Sirajganj Sadar included textile mills, rice mills, aluminium factories, jute mills and textile industries, among other industrial factories.

To enhance the industrial sector (and especially the garment and clothes sectors), a Project of Economic Zone (SEZ) is under development in Sirajganj (D.A. Mala, 2016).

Education, Culture, Religion and Gender Considerations

According to the Census 2011, 39.63% of the population of Sirajganj upazila aged 7 years and over are literate: this rate increases up to 58.47% in urban areas like Sirajganj paurashava. We can notice a significant difference between literate men (41.09% in the upazila and 60.54% in urban areas) and literate women (29.63% in the upazila and 45.15% in urban areas).

Concerning religion, Islam is the main religion of the paurashava (94%), followed by Hinduism (5.9%), and the other religion (0.1%).

4.1.6 Dinajpur

Localization and Administrative Situation

Dinajpur is a city in the north-western part of Bangladesh, in the Rangpur Division. It is the main city of the Dinajpur District (Zila).

Dinajpur paurashava, which stretches out on 20.67 sq.km and rises on the bank of Punarbhaba River, is part of Dinajpur city together with 3 adjoining mauzas. The paurashava is sub-divided in 12 wards (Geo-codes 01-Ward No-01 to 12-Ward No-12) and 80 mahallas (Bangladesh Bureau of Statistic, 2014).

Hereafter are maps of the district and paurashava.

Figure 10 : Situation of Dinajpur (LGED, 2010)

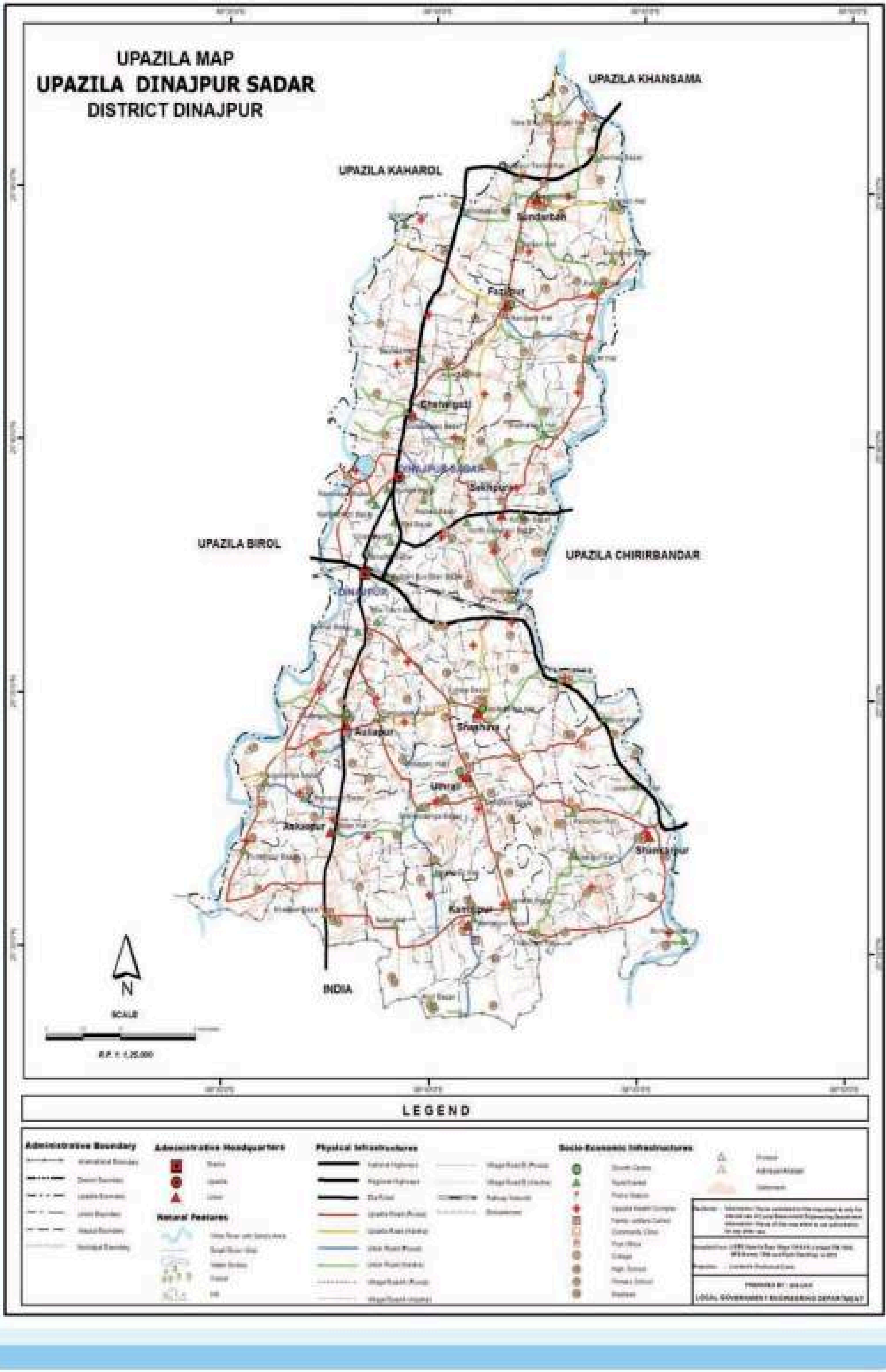
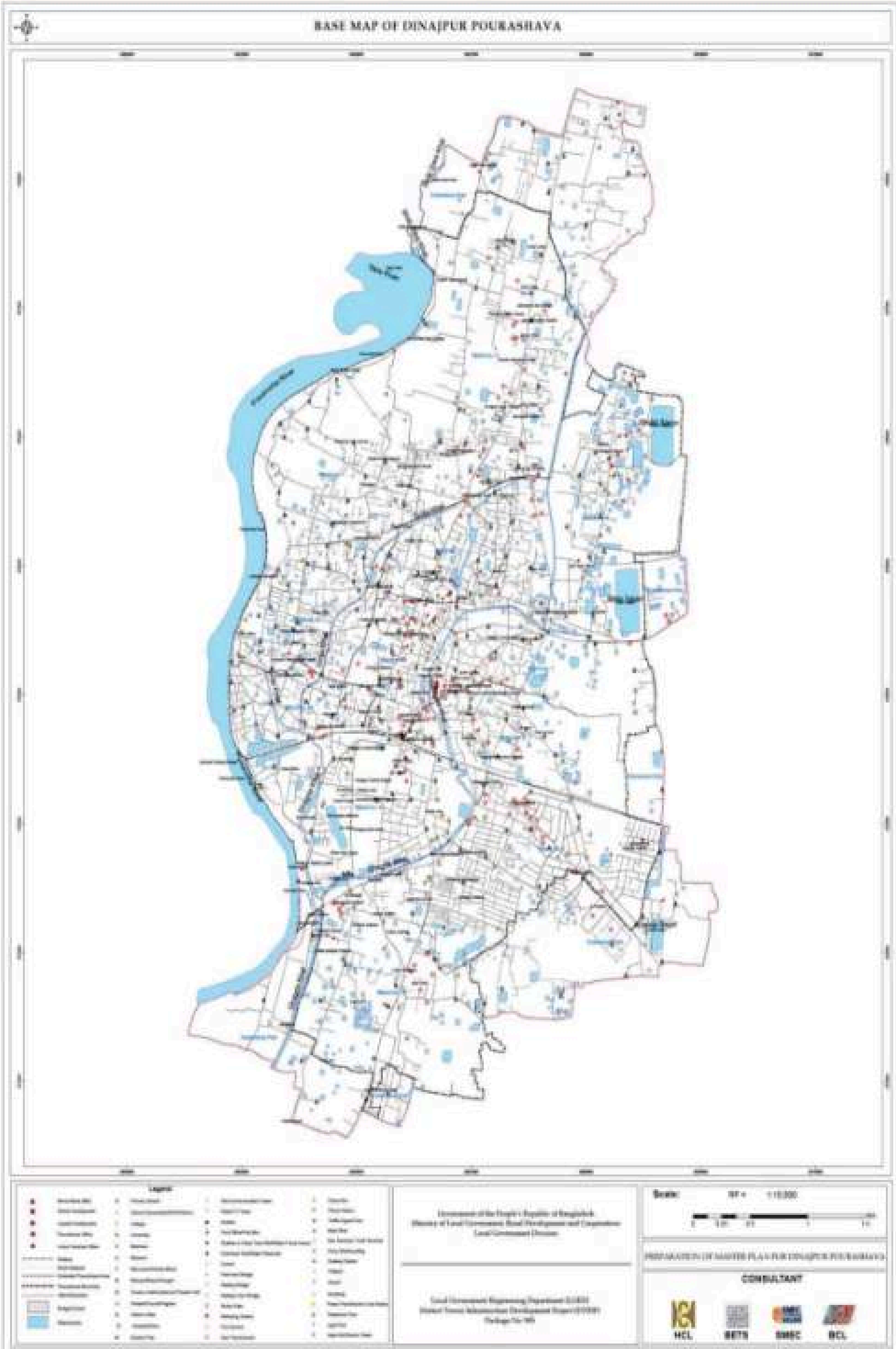


Figure 11 : Map of Dinajpur Paurashava – Source (DTIDP)



Climate

The city is situated in the north-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 10.5 °C to 33.5°C and an annual average precipitation of 2536 mm (Bangladesh Bureau of Statistic, 2014).

Population

According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, Dinajpur pourashava's population rose from 157,914 people in 2001 to 186,727 people in 2011, implying an average population growth rate of 1.69%, slightly higher than the upazila average population growth rate estimated at 1.31%. The population density of the upazila was 1,366 cap/sq. km.

Through the questionnaire sent to the local authorities, updated data from Dinajpur paurashava show a population equal to 210,953 inhabitants by 2015, and a population density equal to 10,675 inh./sq. km. The population growth rate associated to the recent development is therefore equal to 3.10%, close to the prevision of urban population growth rate forecasted by the UN over the period of 2010- 2015.

In order to get an estimation of the population, the projections presented below were calculated by taking into consideration two different population growth rates :

- A PGW of 3.1%, similar to the one observed from 2011 to 2015
- A PGW of 1.31 %, similar to the District PGR observed from 2001 to 2011
- A PGW of 3.6%, corresponding to the National Average Urban Population growth Rate forecasted by the UN and WB over the period 2010 - 2015

By taking into account a similar population growth rate to the one observed over the period 2010 – 2015, the population of Dinajpur will be about 245,702 inhabitants by 2020 and 333,315 inhabitants by 2030.

Road Infrastructure

According to the traffic and transportation survey of Dinajpur Paurashava established in 2011, the road network extends over 288km. The network is mainly composed of tertiary roads (194 km) but includes also 74 km of secondary roads and 20 km of primary roads.

The map below (Figure 13) shows the map of the road network of Dinajpur paurashava (2011).

Concerning the state of the roads inside the paurashava, the data provided by each local authority show that 50% of roads are wide and accessible for trucks and buses. Moreover, about 50% of the network is composed of paved roads.

Economy

According to the Population and Housing Census 2011, agriculture is the main activity sector of Dinajpur district, where farms represent about 60% of the district companies. The production is mainly focused on :

- Crops : Paddy (Katharivog), wheat, sugarcane, jute, potato, vegetables, onion, garlic and oil seed
- Fruits : Litchi, Mango, banana, jackfruit, blackberry, coconut

The district economy also relies on its natural resources (e.g. coal mining and hard rock mining).

In urban areas such Dinajpur, manufacturing (handloom and textile), wholesale and retail trade are also an important source of employment and revenue.

Education, Culture, Religion and Gender Considerations

According to the Census 2011, 64.3% of the population of Dinajpur upazila aged 7 years and over are literate. We can notice a slight difference between literate men (67.4%) and literate women (61 %). From education figures, it can be observed that more than 50% of the 6 – 19 year olds attends school for both male and females with peak values at 6 -14 years (> 80%). However, the attendance drastically decreases for 20 – 29 years, especially in women (between 3% and 20% vs 7.5 to 35% for men).

Concerning religion, Islam is the main religion of the paurashava (86%), followed by Hinduism (12%), Christians (1.7%), and the other religions (0.3%).

4.1.7 Jessore

Localization and Administrative Situation

Jessore is a city in the south-western part of Bangladesh, in the Khulna Division. It is the main city of the Jessore District (2,607 sq. km). Jessore paurashava, which territory occupies 14,71 sq.km, is sub- divided in 9 wards (Geocode from 01 – Ward No - 01 to 09– Ward No 09). The paurashava is administrated by MD Rantu Chakladar.

The city is situated on the banks of the Bhairab River. Hereafter is a map of the district.

Climate

The city is located in the south-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 11°C to 37°C and an annual average precipitation of 1,537 mm.

Population

According to the questionnaire results and the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Jessore Paurashava rose from 176,655 people in 2001 to 201,796 people in 2011, implying an average population growth rate of 1.34%, slightly higher than the upazila average population growth rate estimated at 1.42%. The population density of the upazila is 1707 cap/sq. km. In order to get an estimation of the population by 2025, the projections presented below were calculated by taking into consideration three different population growth rates :

- A PGW of 1.34 %, similar to the one observed from 2001 to 2011
- A PGW of 1.42 %, similar to the District PGR observed from 2001 to 2011
- A PGW of 3.6%, corresponding to the National Average Urban Population growth Rate forecasted by the UN and WB over the period 2010 - 2015

Figure 12 : Mymensingh - Population forecast

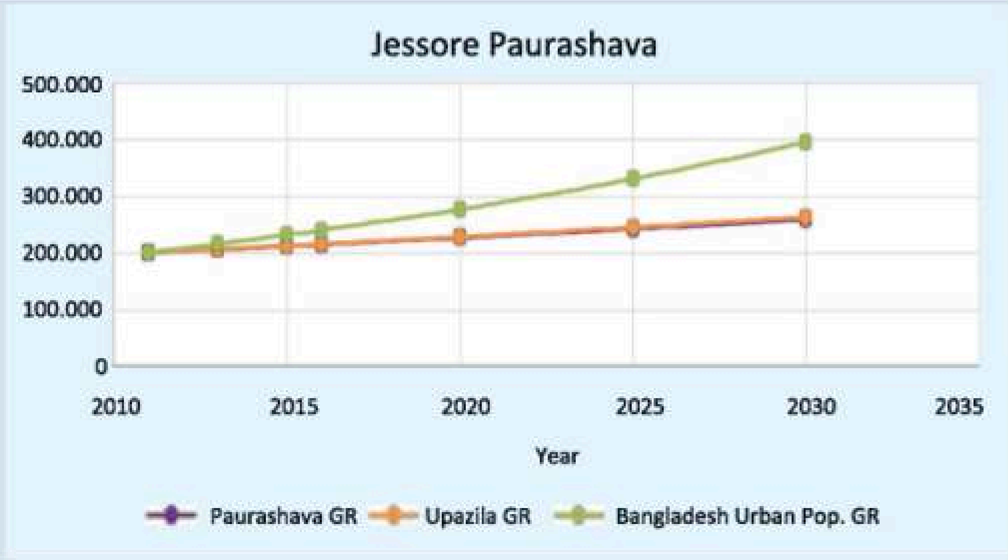
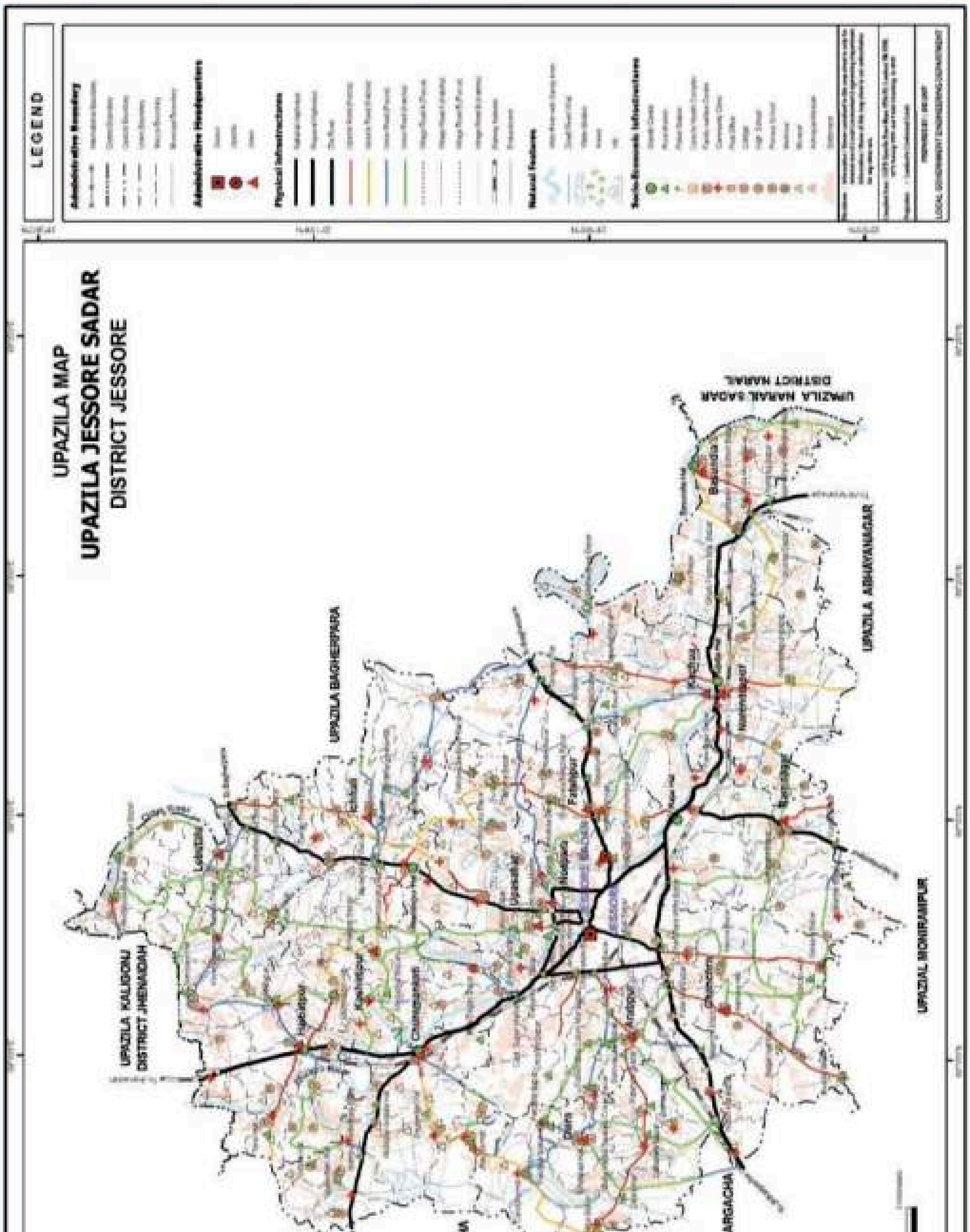


Figure 13 : Situation of Jessore – Source (LGED, 2010)



Road Infrastructure
Jessore is crossed by the National 7 Khulna-Dhaka and other regional roads. The different wards are served by major paved roads.

The paurashava has a railway station and has a developed bus network.

Concerning the state of the roads inside the paurashava, the data provided by each local authority show that 55% of roads are wide and accessible for trucks and buses. Some 50% of the network is composed of paved roads.

Economy
As for the other districts mentioned above, agriculture is the main activity sector of Jessore district. More than 60 % of holdings are farms that produce mainly:

- Crops : Paddy, jute, sugarcane, tuberose, vegetable
- Fruits : Date, jackfruit, papaya, banana, litchi, coconut and betel nut

Even in Jessore, the agriculture sector plays an important role as it represents 40% of the activity (food and fishery).

However, non-agricultural activities play an important role on urban areas, especially in sectors like wholesale, retail trade, hospitality, transport, storage and communication and manufacturing (35% of the activity). Jessore Upazila includes steel industries, jute mills, rice mills and handloom establishment among others activities.

Education, Culture, Religion and Gender Considerations
According to the Census 2011, 58.15% of the population of Jessore upazila aged 7 years and over are literate; this figure rises up to 73.74% for urban area such as Jessore upazila. We can notice a significant difference between literate men (59.7% upazila vs 76.2% urban) and literate women (45.34% upazila vs 57.32% urban).

Concerning religion, Islam is the main religion of the paurashava (89.1%), followed by Hinduism (10.4%) and the other religions (0.5%).

4.1.8 Habiganj
Localization and Administrative Situation
Habiganj is a city in the north-western part of Bangladesh, in the Sylhet Division. It is the main city of the Habiganj District (2,636 sq. km). Habiganj paurashava, which measures 8.97 sq.km, is sub-divided in 9 wards (Geocode from 01 – Ward No - 01 to 09–Ward No 09). Its mayor is Mr. Dilip Dup. The city is situated on the banks of the Khowai River.

Hereafter is a map of the district.

Climate
The City is situated in the south-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 13.6°C to 33.2°C and an annual average precipitation of 3,334 mm.

Population
According to the questionnaire results and the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Habiganj paurashava rose from 55,476 people in 2001 to 69,512 people in 2011, implying an average population

growth rate of 2.28%, higher than the upazila average population growth rate estimated at 1.78%. The population density of the upazila is 1297 cap/sq. km.

In order to get an estimation of the population by 2025, the projections presented below were calculated by taking into consideration three different population growth rates :

- A PGW of 2.28 %, similar to the one observed from 2001 to 2011
- A PGW of 1.78 %, similar to the District PGR observed from 2001 to 2011
- A PGW of 3.6%, corresponding to the National Average Urban Population growth Rate forecasted by the UN and WB over the period 2010 - 2015

Figure 14: Habiganj - Population forecast

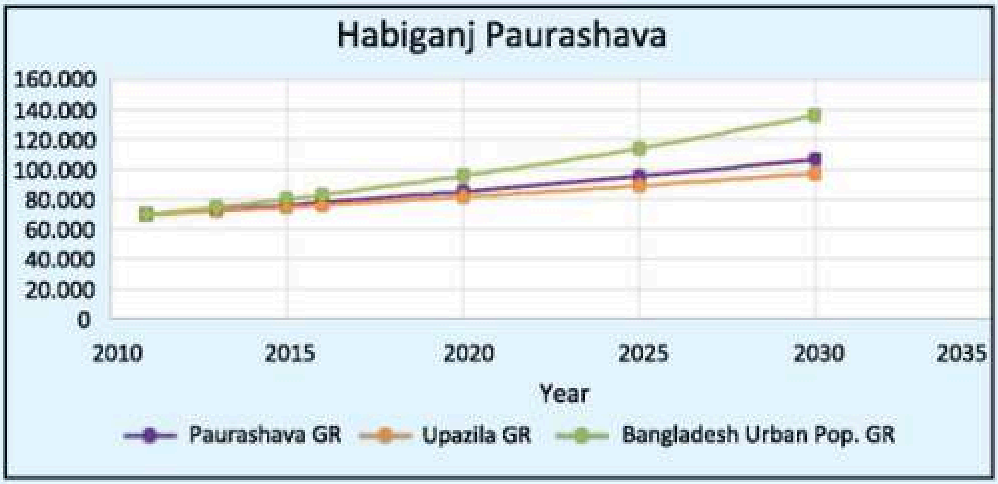
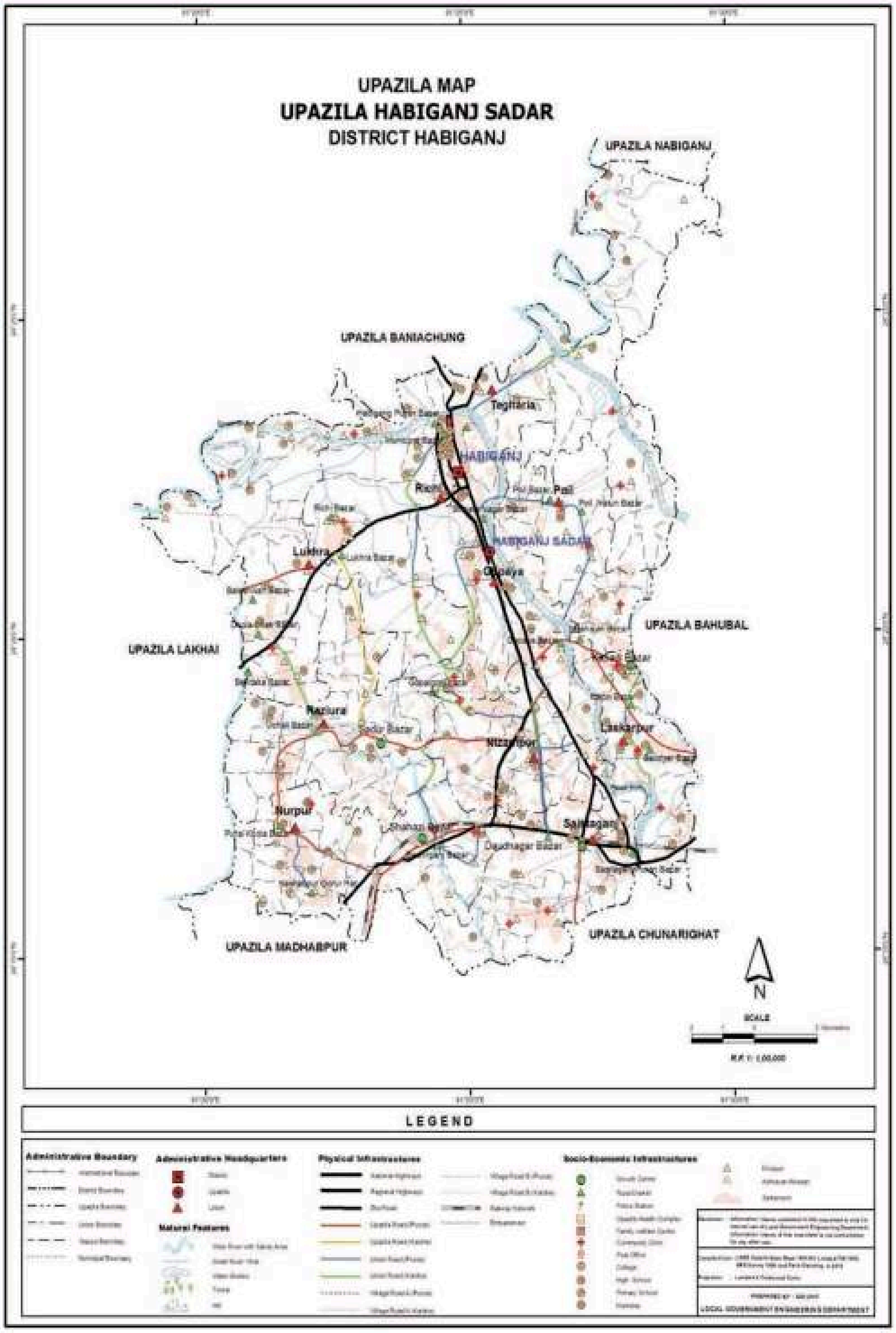
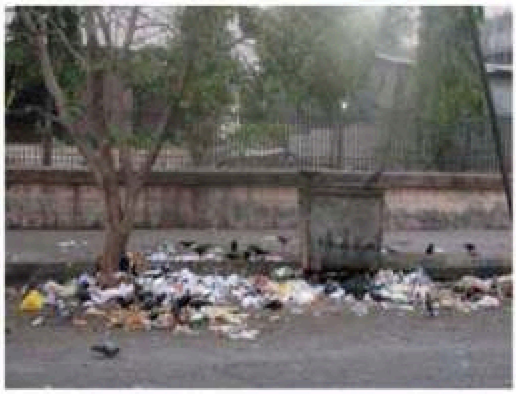


Figure 15 : Situation of Jessore – Source (LGED, 2010)





Road Infrastructure

Habiganj is situated a few kilometers north of the National 2 Dhaka-Sylhet; the paurashava is also crossed by several regional roads. It seems that the different wards are served by wide paved roads.

Concerning the state of the roads inside the paurashava, the data provided by each local authority show that 50% of roads are wide and are accessible for trucks and buses. Some 50% of the network is composed of paved roads.

The Paurashava has no railway station but has a developed bus network.

Economy

As for the other districts mentioned above, agriculture is the main activity sector of Habiganj District. More than 55 % of holdings are farms that produce mainly :

- Crops : Paddy, tea, potato, ground nut and betel leaf
- Fruits : Mango, Jackfruit, banana, coconut, litchi, guava and papaya

Note that the culture of tea is very specific of this district: it includes more than 20% of tea garden of Bangladesh. This plantation represents the most important "cash crops" of Bangladesh, earning a good amount of foreign investment.

In Jessore paurashava, the industrial sector is the main activity (38%), especially regarding textile production. The agriculture sector remains important as well, with 32% of the total activity.

Education, Culture, Religion and Gender Considerations

According to the Census 2011, 50.7% of the population of Habiganj upazila aged 7 years and over are literate. We can notice a slight difference between literate men (52.9%) and literate women (48.5%)). From education figures, it is observed that more than 65% of the 6 – 14 year old group attends school for both male and female with peak values for females at >76%. However, the attendance drastically decreases for the 15 – 29 year old group, especially in female attendance from 20 to 29 (between 1.2% and 9% for women vs 3 to 14% for men).

Concerning religion, Islam is the main religion of the paurashava (89.2%), followed by Hinduism (10.7%) and the other religions (0.1%).

4.2 Regulations

4.2.1 Waste

According to the Bangladesh Environmental Act, "waste" is defined as any liquid, gaseous, solid, radioactive substance which, if set free, dumped or piled up, produces alterations liable to cause harm to the environment.

As for Environmental Conservation Rules, they contain the standards to be followed in Bangladesh for classification of industrial units or projects based on its location and impact on environment, standards for air, water, sound, emissions, odors, sewage discharge, waste from industrial units or projects related to waste, standards on gaseous emissions from industries, standards from sector wise industrial effluent or emissions and fees establishment for environmental certificates and other industry related issues.

There are national and local levels of legal frameworks in Bangladesh in relation to waste management, but only the national policy applies. There is no adequate local level legal framework in the country to address the growing problems of solid waste. The responsibility of removal and disposal of municipal solid waste lies with the city corporations and municipalities. (Jahiruddin, 2015).

The National Environmental Management Action Plan (NEMAP) has recommended actions in the areas of sanitation, solid waste management, water supply and environmental awareness etc.

The National Policy for Water Supply and Sanitation gives special emphasis on participation of the private sector and NGOs in water supply and sanitation in urban areas. However, some solid waste and recycling related strategies are also addressed under this policy; some of these elements are given below :

- Local government bodies (city corporations and municipalities) may transfer, where feasible collection, removal and management of solid waste to the private sector.
- Measures to be taken to recycle the waste as much as possible and promote use of organic waste materials for compost and bio-gas production

4.2.2 Environment

In the framework of the implementation of waste management system, legislation on environmental protection and water protection should also be considered. Indeed, WTE processes may produce by- products (fumes, waste water, ashes, etc.) that could generate an impact on the environment and the population if not addressed properly.

The objectives of Municipal Solid Waste Management (MSWM) are to improve hygiene and sanitation among the population. As such, the system selected should address environmental issues and respect the other legislations in such that the future situation will be less harmful to the environment than the current situation.

The first environmental related legal document to be issued in Bangladesh was the Environmental Conservation Act of 1995, and it recognized the principles of precaution, polluters' pay and people's participation, as well as it added a new dimension to the environmental management by making a shift from pollution control to environment conservation. The amendment in 2002 has given this act the provisions of the law overriding effect over all other laws. According to this document, environment includes water, air, land and physical properties; the interaction between these components and animals and humans are also included in the broader definition of environment.

The most significant advancements after this document were the setting up of quality standards for air, water, noise and soil and the formulation of environmental guidelines to control and mitigate pollution. These standards where defined in the Environment Conservation Rules.

As mentioned before, the Environment Conservation Rules framed in 1997 have detailed out not only standards for environment but also where environmental impact assessment (EIA) would be necessary. This has made EIA mandatory for specific projects and industries although procedural details still have to follow.

Various policies adopted by the government give emphasis on management and conservation of environmental resources. These policies are not enforceable are taken as basis for administration by the concerned agencies. Being more recent documents, these policies reflect on the progressive notions of environment and development.

Policies on environment (1992), water (1999), fishery (1998), energy (1996), industry (1999), and agriculture (1999) require concerned administrative agencies to promote conservation and undertake development program and activities in harmony with nature and eco-system (UNEP).

More recently, a review on environmental policy and legislation updated the legal system regarding water quality with the Bangladesh Water Act of 2013. It makes the provision for integrated development, management, abstraction, distribution, use, protection and conservation of water resources. It defines the national water resources council and its powers and functions, the control on water resources development and managemtent, the control on water use, protection and conservation of water resources and the offences, punishments and trials. Besides, the Environment Conservation Rules states the quality standards for discharge into the environment :

Table 3 : Water Standard Discharge - Env. Conservation rules 1997

Parameter	Unit	Standard Limit
BOD	miligram/1	40
Nitrate	"	250
Phosphate	"	35
Suspended Solids (SS)	"	100
Temperature	Degree Centigrade	30
Coliform	number per 100 ml	100

These parameters are important because it sets limits that some WTE processes that produce waste water will have to respect.

Regarding air quality, UNEP did a research in 2015 that states that national air quality policy does not exist in a standalone document and that these issues are addressed in the ECA 1995 and ECR 1997. The national ambient air quality standards should meet WHO Interim Targets except NO_2 and SO_2. National ambient air quality standards (NAAQS) have been enshrined in the Environment Conservation Rules 1997 (ECR). The Government was considering the revision of the existing NAAQS to meet WHO air quality guiding values.

When designing the future installation, all these regulations must be taken into consideration and potential discharges should be monitored regarding these standards.

4.2.3 Energy

The main legal framework regarding energy is stated in the National Energy Policy from 1996 (updated in 2005), issued by the Ministry of Power, Energy and Mineral resources of Bangladesh.

It commits to ensure environmentally sound sustainable energy development programs causing minimum damage to environment. The policy admits that unplanned and uncontrolled use of biomass fuels (contributed 65.5% of primary energy in 1990) are causing environmental degradation and committed to develop a regional energy market for rational exchange of commercial energy to ensure energy security. Providing a new source of energy to household through WTE processes may be another way to solve this issue and reduce the negative impact on environment.

This policy sets the overall framework for the improved performance of the energy sector. The objectives are to provide energy for sustainable economic growth, ensure optimum development of all the indigenous energy sources (oil and gas, coal, hydropower), ensure sustainable operation of the energy utilities, ensure rational use of total energy sources, ensure environmentally sound energy development programs, encourage public and private sector participation in the development and management of the energy sector, bring entire country under electrification by the year 2020, ensure reliable supply of energy to the people at reasonable and affordable price, and develop a regional energy market for rational exchange of commercial energy to ensure energy security.

The report provides a series of recommended energy policies on the following areas: non-renewable energy, petroleum, marginal gas field development, renewable and rural energy, power, rural electrification, and demand estimation and planning. The stated policies are:

- Private Sector Power Generation Policy, 1996
- Policy Guidelines for Small Power Plants in the Private Sector, 1998
- Guidelines for Remote Area Power Supply Systems, 2007
- Policy Guidelines for Enhancement of Private Participation in the Power Sector, 2008
- Renewable energy Policy of Bangladesh, 2009

In 2012, it was stated that there were capacity concerns for energy in the country since the effective peak generation of about 4,000 MW of electricity against a peak demand of 5,500 MW meant large- scale load shedding which seriously impacts industrial, commercial and social life.

The country also has known potential for the production of energy through several renewable sources: Solar energy has a potential of 4-6.5 kwh/m^2, wind energy in coastal areas, biomass, biogas, hydropower and others to be explored.

Another important policy that has to be taken into consideration is the renewable energy policy of Bangladesh developed in 2008. This policy stresses the potential of production of biogas from waste and mentions the fact that waste-to-biogas processes are already implemented in Bangladesh in many households and villages for power generation or for cooking purposes. Moreover, one of the objectives pointed out in this policy is to increase the development that promotes electricity generation through new renewable sources as well as development of solutions for enhancing biogas production. The policy mentions the incentives that may be used for expending the RE market (CDM, carbon funds, taxes exemption [income tax], micro-credit support, investment facilitation, incentive tariff, etc.).

4.3 Features on the waste sector

4.3.1 Waste Production

4.3.1.1 Objectives

The development of waste-to-energy systems requires understanding the potential from waste generation in each paurashava and its evolution over time. As a consequence, this section aims at defining the average waste production ratio, forecasting its evolution and then projecting the daily waste amount.

During the first workshop, it has been indicated that several industries have already developed their own system for waste management and their valorization. As such, the production of waste by such entities is not taken into consideration. Concerning agriculture and valorization, without proper records, it is difficult to evaluate the amount of waste that could be treated by the WTE process. However, as agriculture waste is concerned, the consultant has considered this criterion as a qualitative criterion, meaning that it will be taken into consideration if such waste would be available.

4.3.1.2 Methodology

The aim of this section is to evaluate the production of waste over the next years according following the population growth, and in order to capture tendencies on the expected amount that should be treated, and thus, the energy it will be possible to be recovered.

Therefore, the current waste production is estimated and the waste production growth determined. The waste production is calculated based on data from waste concern surveys, from the period 2013-2014. Over this period, the survey has gathered information on waste production (2013) in different cities of Bangladesh. According to the populationfigures transmitted in the document, it appeared that the data are not only focused on the paurashava but also include neighboring areas. In order to improve the accuracy of our study, a ratio will be considered.

This information is provided for both dry and wet periods; as such, the methodology presented below will be applied for both seasons. The data of waste concern differentiate between the waste generation rate for wet and dry season and these different rates have been integrated to calculate the average annual waste production. Other parameters that can influence the annual waste volumes like the tourism in Cox Bazar or the population growth rate must be further investigated in a subsequent characterization study in order to produce accurate detailed studies for the design of future waste treatment facilities.
Example of Habiganj Paurashava :

- waste concern survey : waste production between 18 and 33 t/d and waste production rate between 0.25 and 0.43 kg/cap/d
- mayor office : waste production of 30 t/d and waste production rate of 0.3 kg/cap/d
- questionnaire results : waste production of 75 t/d (and calculated WPR of 1.3 kg/cap/d)

Because the information transmitted by the paurashavas' offices were not justified by records of field survey results, and in order to use homogeneous data ration matrix has been used.

4.3.1 Results
The Table 4 below presents the results obtained through the methodology.

Table 4: Waste production projection per paurashava by 2025 – domestic waste

Parameters	Unit	Dinajpur	Cox's Bazar	Mymensingh	Habiganj	Sirajganj	Jessore
Dry Season							
Waste Growth Rate 2013	kg/cap/day	0.37	0.33	0.29	0.25	0.20	0.19
Waste Generation 2013	ton/day	73	70	78	8	33	40
Waste Growth Rate 2025	kg/cap/day	0.44	0.39	0.35	0.30	0.23	0.23
Waste Generation 2025	ton/day	125	340	108	29	50	56
Wet Season							
Waste Growth Rate 2013	kg/cap/day	0.51	0.46	0.41	0.36	0.28	0.27
Waste Generation 2013	ton/day	102	98	109	26	46	56
Waste Growth Rate 2025	kg/cap/day	0.61	0.55	0.49	0.42	0.33	0.32
Waste Generation 2025	ton/day	175	476	151	40	71	79
Annual average (Wet season from March to October and Dry season from October to March)							
Waste Generation 2013	ton/year	31,818	30,685	34,042	8,095	14,318	17,651
Waste Generation 2025	ton/year	54,576	1,48,826	47,177	12,622	22,051	24,632

4.3.2 Waste Composition

4.3.2.1 Objectives

This section aims at determining the different waste streams in the selected paurashavas, as well as defining, when possible, their chemical-physical parameters, such as the moisture content, the chemical composition, the caloric value, the C/N ratio, etc.

4.3.2.2 Methodology

The determination of waste streams is based on several sources of information.

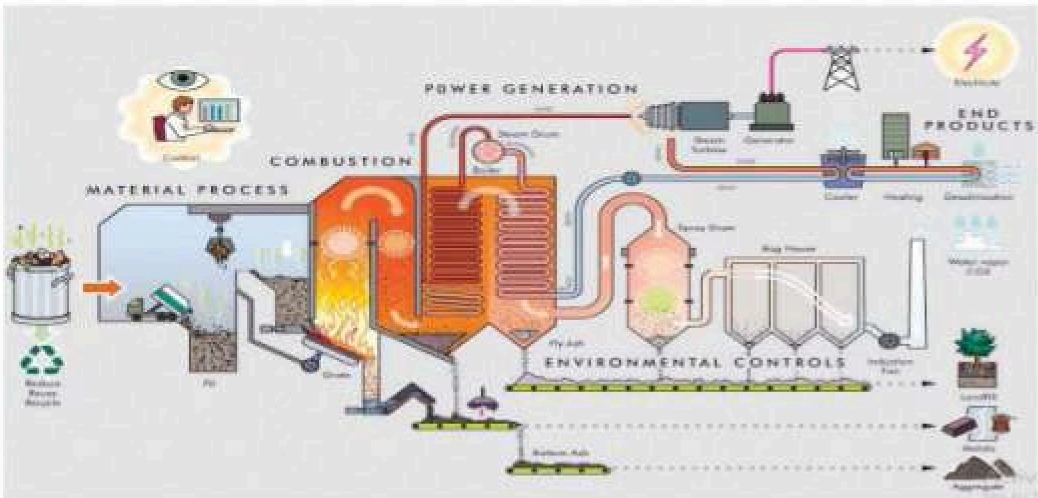
Waste composition and related tonnage

Waste composition

When available, waste composition is determined from field surveys results made by the local authorities and/or private operators (collection, landfill, etc.) and/or research articles (university).

In view of the data collected so far, this procedure is applied to Jessore (Characteristics of Household Solid Waste and its Management Options in the Urban Areas, Jessore, Bangladesh, 2014).

If the waste composition of the paurashava is not available, the consultant will proceed by extrapolation. It is assumed that the composition of urban solid



waste of each paurashava will be similar to those of the city corporation of the division to which they both belong (e.g. Cox's Bazar and Chittagong).

In view of the data available from international studies (I. Enayetullah et. al, 2005), this procedure will be applied to Mymensingh, Cox's Bazar, Sirajganj and Habiganj and Dinajpur.

The dry mass is computed through typical moisture contents given by the literature. Two sources were used:

- Priority is given to field data and analysis recovered by the University of Jessore: compostable, paper, plastic and umw (textile, wood and rubble)
- For the remaining components (glass and metal), the typical data given by Tchobanoglous and all is used

Table 5 : Typical moisture content Source (Characteristics of Household Solid Waste and its Management Options in the Urban Areas, Jessore, Bangladesh, 2014)[1] and (Tchobanoglous et. al, 1993)[2]

Component	Moisture content
Units	%
Compostable1	72%
Paper 1	8%
Plastic 1	7%
Metal 2	3%
Glass 2	2%
UMW (Textile, Wood etc.)	30%

Density

The density is a key parameter for processes that require temporary storage (useful when unstable supply of waste due to mismanagement) or permanent storage, such as landfill. Indeed, this parameter will give information on the volume of waste that has to be considered, and thus the capacity of the storage area.

Table 6: Typical density of waste

Component	Typical Density kg/m^3
Compostable	240
Paper	85
Plastic	65
Metal	320
Wood	240
Textile	65
Glass	195
Rubble	480

Chemical composition :

The chemical composition of waste is very important because it will be used to determine the Low Calorific Value (LCV) of waste, and therefore, will give information whether or not waste can be used in thermal processes (see Section 4.4.2).

Because the composition of waste is different in each paurashava, the resulting LHV will vary. Therefore, it is necessary to get the elementary chemical composition in C, H, O, N, S, water and ashes of the wet matter per type of waste stream (organic, plastic, paper, etc.), in order to calculate the typical amount of each element (C, H, etc.) for each paurashava.

It is important to note that this information may be difficult to obtain because it requires a thorough analysis on the waste composition. A literature review on university research paper will need to be implemented in that case.

However, if the data are not available, the consultant will look for general data on waste chemical composition in Bangladesh. As a consequence, it will not be possible to get a detailed result per paurashava but it will give a general tendency of what could be expected.

Total Solid (TS)

Total solids refer to the residue that remains when a water or sludge sample is filtered and dried at 105°C. It is measured in mg/L (mass per volume) or as a percentage of wet weight. Moisture content plus TS (both expressed as percentage of wet weight) equal 100 per cent (anaerobic digestion of biowaste in developing countries, 2014).

Total solid is a parameter used in bio-chemical process to calculate the production of biogas. It is evaluated based on literature review.

4.3.2.3 Results
Waste Composition

Case study 1 : Jessore

According to the questionnaire, the local authorities of Jessore do not have information on the composition of waste stream (not field characterization performed yet). Nevertheless, the Department of Environmental Science and Technology of the Jessore University has published in 2014 an article on the characteristics of household solid waste in the urban areas of Jessore (characteristics of household solid waste and its management options in the urban areas, Jessore, Bangladesh, 2014). The research included a field survey on some representative wards of Jessore paurashava, where the composition of waste was reported into different categories. The further analysis on waste composition in Jessore is therefore based on this document.

The survey also includes information on proportion of biodegradable waste (93.5%), combustible waste (92.4%) and waste valorized through other processes such as recycling or reuse (7.6%).

The results of the analysis on waste composition are given in the below :

Table 7: Average percentage composition of waste in Jessore Paurashava Source (Characteristics of Household Solid Waste and its Management Options in the Urban Areas, Jessore, Bangladesh, 2014)

Type of waste	Ratio
Vegetables	86.95%
Paper	1.67%
Plastic	1.19%
Metal	0.71%
Grass and wood	4.31%
Clothes	0.64%
Glass	1.47%
Other	3.07%

Case study 2 : Mymensingh, Cox's Bazar, Sirajganj and Habiganj

Investigations launched by waste concern in 2005 have resulted in the development of statistics on waste stream composition in the main city corporations.

Results are presented in the Table 8 below :

Table 8: Waste composition of city corporations – Source (I. Enayetullah et. al, 2005)

	Dhaka	Chittagon	Rajshahi	Sylhet
Food & vegetable waste	70.12%	69.5%	62.4%	75.8%
Paper	4.29%	5.7%	6.3%	5.2%
Plastics	4.10%	4.3%	8.0%	5.3%
Metals	0.13%	0.1%	0.0%	0.2%
Wood/ grass/ leaves	0.16%	4.8%	11.0%	3.9%
Rags, textile, jute	4.57%	4.7%	3.4%	1.6%
Glass	0.12%	0.2%	1.3 %	0.9%
Organic non compostable	11.44%	7.2%	6.9%	4.0%
Others	5.07%	3.4%	0.6%	3.1%

As mentioned in the Section Methodology above, it is assumed that the waste composition of Mymensingh, Habiganj, Sirajganj and Cox's Bazar will be respectively similar to the waste composition of Dhaka, Sylhet, Rajshahi and Chittagong.

Case Study 3 : Dinajpur

In Bangladesh each municipality is classified into 3 different categories (A, B & C) in function of the annual revenue collected over the last 3 years. Within these rankings, Dinajpur is considered as A- type.

In 2014, waste stream composition has been evaluated for each type of paurashava. The results are presented below for A-type paurashava.

Table 9: Waste stream composition for A-type paurashava.

Paurashava A 2014	Househol
Food Waste	79.1%
Papers	3.7%
Plastic	4.2%
Metals	0.3%
Wood	5.4%
Electric and Electronic	0.5%
Fabrics	1.5%
Other	5.3%

Waste Projection

According to the projection on waste production and the results of this survey, the tonnage per type of waste is given in the below:

Table 10 : Projection of waste generation

Parameters	Unit	Dinajpur	Cox's Bazar	Mymensingh	Habiganj	Sirajganj	Jessore
Tonnage 2013							
Dry Season							
Vegetables	ton/day	57.5	48.7	54.5	14.0	20.4	35
Paper	ton/day	2.7	4.0	3.3	1.0	2.1	0.7
Plastic	ton/day	3.0	3.0	3.2	1.0		0.5
Metal	ton/day	0.2	0.1	0.1	0.0	0.0	0.3
Grass and wood	ton/day	3.9	3.4	0.1	0.7	3.6	1.7
Clothes	ton/day	1.1	3.3	3.6	0.3	1.1	0.3
Glass	ton/day	0.0	0.2	0.1	0.2	0.4	0.6
Other	ton/day	4.3	7.4	12.8	1.3	2.5	1.2
Wet Season							
Vegetables	ton/day	80.5	68.1	76.3	19.6	28.6	49
Paper	ton/day	3.7	5.6	4.7	1.4	2.9	51
Plastic	ton/day	4.3	4.2	4.5	1.4	3.7	0
Metal	ton/day	0.3	0.1	0.1	0.1	0.0	68
Grass and wood	ton/day	5.5	4.7	0.2	1.0	5.0	78
Clothes	ton/day	1.5	4.6	5.0	0.4	1.6	0
Glass	ton/day	0.0	0.2	0.1	0.2	0.6	0
Other	ton/day	6.0	10.4	18.0	1.8	3.4	0

Tonnage 2025							
Dry Season							
Vegetables	ton/day	98.6	236.1	75.6	81.6	67.3	93.7
Paper	ton/day	4.6	19.5	4.6	5.6	6.8	1.8
Plastic	ton/day	5.2	14.7	4.4	5.8	8.6	1.3
Metal	ton/day	0.4	0.5	0.1	0.3	0.0	0.8
Grass and wood	ton/day	6.7	16.5	0.2	4.2	11.9	4.6
Clothes	ton/day	1.8	16.1	4.9	1.8	3.7	0.7
Glass	ton/day	0.0	0.8	0.1	1.0	1.4	1.6
Other	ton/day	7.3	35.9	17.8	7.6	8.1	3.3
Wet Season							
Vegetables	ton/day	138.1	330.5	333.7	360.6	297.1	413.8
Paper	ton/day	6.4	27.3	20.4	24.8	30.1	7.9
Plastic	ton/day	7.3	20.5	19.5	25.4	38.0	5.7
Metal	ton/day	0.6	0.7	0.6	1.1	0.0	3.4
Grass and wood	ton/day	9.4	23.0	0.8	18.4	52.4	20.5
Clothes	ton/day	2.6	22.5	21.7	7.8	16.2	3.0
Glass	ton/day	0.0	1.1	0.6	4.2	6.4	7.0
Other	ton/day	10.2	50.3	78.6	33.5	35.7	14.6

Once again, it is important to mention that these figures represent the global trend in terms of capacity. However, it does not reflect the quantity available for the future treatment facility because the waste collection has to be considered. It is important to stress that this data is critical in any waste management study because it will be used to calculate the true usable potential. However, such information could not be found through the data collection and analysis (literature and questionnaire) because of the absence of an efficient waste management system.

According to the different trends on waste management observed by local authorities and research studies, it seems that this collection rate may be really low. As a consequence, the real quantity that will be used in the process will also be very low.

This observation confirms that waste management must be implemented step by step: without an efficient waste collection, it will be difficult to implement successfully the further steps that require much more technical management and that are more expensive.

Chemical-physical Properties

Moisture content

The estimated moisture content of waste is presented below.

Table 11 : Moisture content and density

Parameter	Dinajpur	Cox's Bazar	Mymensingh	Habiganj	Sirajganj	Jessore
Moisture	63.7%	58.9%	57.6%	60.8%	57.2%	67.1%

According to the study conducted by the University of Jessore on the energy potential of waste (charateristic and energy potential of household waste in the urban areas, Jessore, Bangladesh, 2014), the average moisture content of Jessore waste has been estimated at 68.05%; a result close to the one calculated above.

It can be observed that the moisture content is quite high, especially for Dinajpur and Jessore, which will have a significant influence on the later technology selection process.

Density

The estimated density of waste is presented below :

Parameter	Dinajpure	Cox's Bazar	Mymensingh	Habiganj	Sirajganj	Jessore
Density	193	178	176	183	168	219

Chemical composition

Because no information is available on the elementary composition of waste streams in Bangladesh, the consultant could not determine the composition of waste for each paurashava.

Nevertheless, the Bangladesh Council of Scientific and Industrial Research have carried out studies on the general composition for residential solid waste. The result of the study is given below :

Table 12: Composition of solid waste in residential areas – Source (BCSIR, 1998)

Constituents (%) by	Residential
Carbon (C)	26.06
Hydrogen (H)	3.53
Nitrogen (N)	1.62
Sulfur (S)	0.01
Ash	18
Oxygen (O)	0.78

Total Solid (TS)

No information was found on the total solid content. Hereafter are presented two tables with typical figures on the TS proportion of biodegradable waste and biogas yield from anaerobic digestion :

- Typical TS proportion in biodegradable waste

Table 13 : Typical concentration of TS in biodegradable matter

Substrate	TS (% of raw waste)	VS (%of TS)	Literature Source
Spent fruits	25-45	90-95	Deublein and steinhauser (2011)
Vegetable wastes	5-20	76-90	Deublein and steinhauser (2011)
Market wastes	8-20	75-90	Deublein and steinhauser (2011)
Leftovers (canteen)	9-37	75-98	Deublein and steinhauser (2011)
Overstored food	14-18	81-97	Deublein and steinhauser (2011)
Fruit wastes	15-20	75-95	Gunaseelan (2004)
Biowaste	25-40	50-70	Eder and schulz (2007)
Kitchen waste	9-37	50-70	Eder and schulz (2007)
Market waste	28-45	50-80	Eder and schulz (2007)

- The biogas yield records from anaerobic digestion of organic solids (Khalid et. al, 2011)

Table 14 : Estimated Biogas yield from anaerobic digestion

Substrate	Methane Yield (L/kg VS)
Palm oil mill waste	610
Municipal solid waste	360-530
Fruit and vegetable wastes	420
Food waste	369
Rice straw	350
Household waste	350
Swine manure	337
Maize silage and straw	312
Food waste leachate	294
Lignin-rich organic waste	200

We can observe that MSW has a good potential of methane production

4.3.3 Waste Management System

4.3.3.1 Objectives

Solid waste management is a set of actions comprising storage, collection, transfer, processing, and disposal. In order to guarantee an effective, reliable and complete management, each action should be implemented properly and with respect to the different steps. Indeed, the treatment of waste cannot be efficient without a reliable collection and storage at the beginning of the chain. Moreover, the whole system cannot be well operated without an effective management of data and an understanding of the waste features.

Therefore, this section aims at determining the state of waste management system of each paurashava, regarding, when available, the following elements :

- Description of the current WMS (collection, operation, management, financing, etc.)
- Daily collection rate, waste concentration
- Current waste treatment installations/landfill + estimation of treatment capacity
- Structure of the local waste management public administration
- Taxes/financial systems for WM
- Data on a possible site for new facilities implementation : hydrology, geology, accessibility, existing brownfield, social aspect

4.3.3.3 Results

Mymensingh

Due to the increasing amount of waste, the implementation of an effective waste management is one of the priorities of Mymensingh local authorities. According to a recent study conducted by the University of Mymensingh (Household satisfaction on solid waste collection services conducted by NGOs in Mymensingh Municipality, Bangladesh, 2015), the main challenge identified in the Paurashava is the primary storage and collection, whereby households do not deliver all wastes to the designated points from where they can be collected.

In order to fix this issue, a project has been recently launched by the German Technical Cooperation (GTZ) and the local governance to improve this key element through the involvement of local NGOs (MATI, SBSUS, TUS, etc.) for door to door collection.

A recent survey realized by the University of Mymensingh on the areas concerned by this initiative shows that daily waste collection was 43.34%, whereas 32.5% of waste was collected after 1-2 days and 24.16% of waste was collected even after few days later of waste production. Moreover, depending on the areas, the collection is undertaken in the morning (14.2%), at noon (62.5%), in the evening (11.7%) whereas 11.6% of waste was collected without a clear timeframe. The study stresses the fact that the most suitable time for waste collection according to householders is noon. Moreover, it has also been highlighted that the population has a good understanding of the impacts of waste mismanagement on health and environment and as such, most of them are willing to pay service charge for waste collection (87.5%).

Table 15 : Respondents willingness to pay service charge & the amount of service charge they wanted to pay NGOs Data in Mymensingh Municipality, 2015)

Category		Percent
Willing to pay	Yes	87.5%
	No	12.5%
Amount of money	10 – 20 Tk	14.2 %
	21 – 30 Tk	41.7 %
	31 – 40 Tk	32.5 %
	41 – 50 Tk	11.7 %

According to the same study, some NGOs are willing to develop their services (esp. recycling) and to increase their working force. Moreover, GIZ is supporting NGOs in the development of awareness campaigns for household and capacity building and training for staff.

For the other areas, which are not concerned by the GIZ program, results of the questionnaire show that the wastes are collected by the workers of the paurashava (conservancy office) through trolley and vans based on door to door collection.

Concerning disposal/treatment, and apart from waste disposed into ponds, backsides of houses or into the nearby dustbins, waste is disposed in several dumpsites. The main official site is a 7.3 acres area located north of Shombhugonj Bridge on which waste is dumped without any environmental protection since 12 years ago.

It should be noted that no information related to financing and administrative management of this sector has been transmitted so far.

Cox's Bazar

According to some references (International Conference on Circular Economy-Waste Management and Recycling in Cox's Bazar Municipality, 2010), it is stated that this paurashava does have a proper and functional waste management system, only an uncontrolled collection system for few parts on the municipality.

Wastes are not considered as resource here, as there are no technology and no climate change awareness amongst the local people. Most of the cities canals are choked by the dumping of untreated waste, which is contaminating the environment. Environmentalist state that at least 10 to 12 tons of raw wastes a day are dumped in the canals daily1

In March 2016, (bdn) published that "Only seven of the 300 hotels and motels located in the town's specified zone have environmental clearance and sewerage treatment plants (STP), according to the Department of Environment. The rest have been dumping their waste into the sea or into the Bakkhali River, thus damaging aerial roots of mangrove plants causing substantial danger to their growth. The authorities have served show case notices to 20 of these hotels for not having any environmental clearance or STPs on March 8, said Sarder Shariful Islam, Assistant Director of Environment Department's Cox's Bazar office."

The Minister of Cox's Bazaar however informed that there is a landfill named "Shona Market", with 2.5 acres, that is receiving waste for about 10 years. According to the municipality, 300 dumping labors are working on this landfill.

No information on financing or administrative management for the existing waste management system was transmitted so far. Therefore, it is difficult to evaluate the current existing systems on waste management and assess their effectiveness.

Sirajganj

A publication in 2015 states that Sirajganj does not have a proper waste treatment plant and therefore the wastes from factories in the district are disposing their wastes into the rivers and canals and other water resources in unplanned ways, affecting public life as well as underground water.

Although this information is useful, it should be stressed that no information related to financing and administrative management of this sector has been transmitted so far.

According to the only information received from the paurashava council, there are two sites used for dumping waste in Sirajganj:

- First, 6.2 acres site situated at Bonbaria, and used for 4 years
- Second, 2 acres site located at Shailkot

1 Archive.dhakatribune.com: Cox's Bazar lacks proper waste management.

Dinajpur

At Dinajpur, the Waste Management and Operation System is the responsibility of the public sector; and the official person in charge in this dedicated Service is Mr. Golam Nobi.

Concerning the procedure of waste management, wastes are collected by the workers of the paurashava by means of trucks and vans in the different collection points and then dumped in the city. Nevertheless, it is important to mention that the Municipality is looking for new sites for implementing new waste treatment facilities. Presently, a 6.5 acres area situated in Moila Godda has been identified to provide sufficient storage capacity for at least 8 years.

It should be stressed that no information related to financing and administrative management of this sector has been transmitted so far.

According to the questionnaire, the Waste Division of Jessore is working on possible actions that must improve the current waste management system.

Jessore

According to the characterization study launched in Jessore in 2014 (Characteristics of Household Solid Waste and its Management Options in the Urban Areas, Jessore, Bangladesh, 2014), the existing waste management system is improperly managed in urbans areas of Jessore because of three main reasons :

- Management issues of the local authorities
- Absence of waste segregation of household waste
- Large amount of waste stored in improper sites (open field, drain, roadside, etc.)

Officially, household wastes are mainly stored in collective dumping buckets (open containers, closed container) or directly stored on the roadsides in poly-bags. Waste is then collected by the workers of the Paurashava through trucks and vans in the different collection points. The collect is performed every day or twice per week depending to the ward.

However, it seems that a large amount of waste are not collected by the public services due to improper waste storage by household, which are dumping waste in yard, roadside or ponds.

The main dumping site of Jessore is situated on the territory of Hamidpur, a low population density area. The site is an open field without any protection for preventing soil, water or air pollution. However, the municipality has identified a site where a new treatment facility may be implemented. The 4.5 acres site is located in Jhumjhumpur and should have a minimal lifespan of 10 years.

It should be noted that no information related to financing and administrative management of this sector has been transmitted so far.

Habiganj

According to the Mayor Office (Habiganj Paurashava - Mayor Office), waste management in Habiganj is environmentally ineffective and represents a hazard for both public and operators. The current system is operated by the conservancy section whose work is difficult by :

Structural Issues :

Insufficient number of dustbins and irregular cleanness of dustbins

- Transfer stations inadequate
- Insufficient and unmaintained vehicle fleet
- Lack of manpower
- Absence of managed and controlled dumping sites
- Lack of drainer labor and drainage facility
- Narrow roads and lane in town

Non-structural Issues :

- Lack of cooperation and social awareness from the population
- Lake of systematic approach for waste management in the different wards
- Unplanned urbanization in Habiganj Town

According to general information from the local surveys carried out by the Mayor Office, only 20% are disposed on waste bins supplied by the municipality. The remaining wastes are :

- thrown into nearby ponds : 26%
- thrown into nearby drains : 30%
- thrown in their respective compound : 25%
- thrown into roadsides : 15%
- thrown here and there : 4%

The collection is carried out by the paurashava's workers through 40 dustbins storage points. Information in the questionnaire mentioned also the practice of door to door collection. The municipality fleet is composed of :

- 5 garbage trucks, out of which only 1 is active
- 3 trolleys, out of which 2 are active
- 6 rickshaw vans for waste disposal purpose

Although the municipality is fully aware of the negative impacts on the environment and attempts to remedy the situation, direct dumping is used to reduce costs generated by waste management. Indeed, solid Waste dumpsite are unregulated and unsanitary, creating impacts on water (pollution), health (attraction of disease carrying insects and rodents), air, soil, etc.

Several improvements proposals have been studied by the municipality over the last years to improve waste management. The project proposes to delegate the MSW management into two separate systems:

- In residential areas : implementation of a Community-based Management System with the creation of a Community Based Organization (CBO)
- In non-residential areas : implementation of a non-governmental based management system

The Municipality recommends selecting the members in various layers of the population in order to have a good understanding of the different issues encountered. This element is particularly important because the CBOs will be responsible for fixing the charges for every household. Moreover, it has been proposed to carry out the collection door to door with rickshaw vans; the Municipality will support the initiatives by providing sufficient dustbins & vehicles.

Recently, discussions for the selection of an official dumping site have been undertaken by the planning unit. The selection process will have to take into consideration several aspects for the site selection, such as location outside town at a reasonable distance to prevent excessive fuel costs, good accessibility including minimal width for truck movement, etc. Presently, three official landfill sites have been identified :

- A 5.5 acres dumpsite near Shilpo nagar (lifespan 10 years)
- A 4.5 acres dumpsite near Koladoba Bridge (lifespan 10 years)
- A 2 acres dumpsite at Goshaipur (lifespan 5 years)

4.3.4 Other Information

Hereafter is presented some transversal information that may improve the understanding of waste management in the selected cities and informs about uses and social behaviors concerning waste.

According to WI-LO, waste is defined as useless, unwanted and discarded material; as such, people want to quickly get rid of their waste in the most convenient place for them, without taking into account the environmental and social impacts these illegal dumping have. This is reinforced by the fact that, most of the time, they do not have access to places dedicated for storage of waste, or storage areas are already saturated due to mismanagement of the collection system.

A paradigm shift should be initiated in order to change the perception of waste as a resource and not as a useless material. And according to literature review, some paurashavas have already started this evolution.

Indeed, it can be observed an increasing awareness that waste is a source of environmental pollution and health hazard; therefore, the population is sometimes ready to pay for proper collection and disposal (example of Mymensingh).

Moreover, in some paurahsavas (Mymensingh, Habiganj, etc.), the local authorities, supported by local NGOs, want to implement awareness campaigns through educational program at school level but also by implying the religious representatives to transmit advices and recommendations regarding waste management in households during church services.

Local initiatives for Waste-to-Resource (compost, recycling) have been implemented or are under development (Khulna, etc.).

Besides, the question of informal sector will have to be addressed when improving the system. Indeed, many households are dependent on revenue from waste sorting and collection. No information have been supplied or found on this question. Further investigations will be requested to evaluate the way to include them into the system.

4.4 Features on The Energy Sector

4.4.1 Situational Analysis

4.4.1.1 Objective

The objective of this section is to give an overview of the energy sector in each paurashava, and especially regarding the current infrastructure, the uses and the needs.

4.4.1.2 Methodology

Information is collected through the questionnaire or though literature review (scientific research, IFI website, stakeholders like RPCL or NWPGCL, etc.).

4.4.1.3 Results

Mymensingh

According to the local authority of Mymensingh paurashava, local households, industries, services and farms have connection to the main electric grid and gas supply through cylinder gas network.

Electricity of Mymensingh paurashava and district comes from the Shambhuganj Power Station, a 210 MW Combined Cycle Power Station managed by the Rural Power Company Ltd and composed of four gas turbines and one steam turbine (Rural Power Company LTD). A project of extension is planned by the RPC to upgrade the power station by 2021 into a 360 MW combined power cycle PP working with gas and LNG.

Cox's Bazar

According to the Census 2011, 86% of Cox's Bazar paurashava households are connected to the electricity grid. However, this figure hides important disparities between the wards (from 30.8% to 95.9%). The connection is on average much higher in the paurashava than in Cox's Bazar district, where the electricity connection rate is about 54%. Due to its significant development over the last decade, energy demand in Cox's Bazar city and district is growing fast, forcing the authorities to find solutions for energy supply. Two projects are discussed/under development for the development of Power Plants in Cox's Bazar (A.R. Rasel, 2013) :

- First, 1,200 MW coal-fired power plant loaned by the Japan International Cooperation Agency at Matarbari (Production start expected between 2015 and 2017)
- Second, 5,320 MW electricity power plant at Moheskhali

A pilot project of wind farm (60MW) will be developed in Kurushkul using Danish investment funds (Daily Sun, 2016).

The local authority of Cox's Bazar informs that the main usages are gas and electricity for domestic industry, services and agriculture purposes.

Sirajganj

According to the Population and Housing Census of 2011, 47.09% of Sirajganj Zila's households are connected to the electricity grid. Moreover, gas is supplied through a cylinder gas network.

Sirajganj is supplied by a combined cycled power plant of capacity 225 MW located in Soydabad Sirajganj. The Plant, financed by ADB and GOD, is operated by North Western Power Generation Company Ltd (NWPGCL), and the electricity is purchased by the Bangladesh Power Development Board through a power purchase agreement.

According to IFC, the construction of a Greenfield 414 MW dual-fuel Combined Cycle Power Plant will be developed in Sirajganj through an EPC contract; the Project is expected to start by 2016 and be completed by 2018. The power plant will include one Gas Turbine (GT) unit, one set of heat recovery steam generator and one steam turbine generating unit with associated auxiliary equipment. The operation and maintenance of the project will be undertaken by the project company with the support of a long term service agreement for the GT with the manufacturer. It is important to mention that the site, where the new plant will be constructed, is located on the same complex of the 225 MW plant. Moreover, it seeams that another third project may also be developed by NWPGCL in 2016 on this same site.

Dinajpur

According to the Census 2011, 89.8% of Dinajpur paurashavas' households are connected to the electricity grid. The range differs slightly between the wards from 82.9% to 96.5%. The connection is on the average much higher in the Paurashava than in Dinajpur District, where the electricity connection rate is about 64.5%.

All 10 unions of the upazila were covered by the rural electrification program. However, a total of 64.5% general households reported to have electricity connection in the entire upazila in 2011 against the 41.5% in 2001.

As a consequence of the presence of coal in Dinajpur territory, electricity of Dinajpur Paurashava and District comes from the Barapukuria Power Station, a 125 MW coal-fired power station operated by the Bangladesh Power Development Board.

Jessore

According to the Population and Housing Census of 2011, 61.09% of Jessore's Zila are connected to the electricity grid, compared to 36.01% in 2001 which shows a sharp increase of 25.08 percentage points during this decade. A rapid progress is also observed in the urban and rural areas which reflect 14.95% and 25.97% increase correspondently.

The local authority of Jessore informed that the main usages are gas and electricity for domestic industry, services and agriculture purposes.

Habiganj

According to the Census 2011, 69% of Habiganj Sadar Upazila total number of households is connected to the electricity grid.

The Habiganj Sadar Upazila access to electricity includes all the 10 unions from the upazila on the Rural Electrification Program. Since 2001, when the number of households with electricity was of about 11.8% there was a significant increase in electricity access.

4.4.2 Needs and Forecasted Products

Energy produced by WtE processes can be divided into four types: power, heat, hot water and gas. And most of the time, processes can produce a combination of these four types of energy sources (heat and power, gas and electricity, etc.).

This section will present in details the awaited output in function of the technology considered. Two elements have to be taken into consideration when discussing about energy production :

- The compatibility with needs
- The local integration

Needs

The objective of the Project is to improve the life conditions of the population by proposing solutions to improve waste management and treatment, but also by making the population a direct or indirect beneficiary of the energy outputs of the forecasted WTE Process.

It is therefore at utmost important to deeply understand the energy needs, first for the households and in a second end, to the other sectors (industry, agriculture, transport, etc.)

The below shows the results of the questionnaire regarding the energy needs of the different sectors :

Table 16 : Questionnaire Results : Energy Needs

Energy source	Mymensingh	Cox's Bazar	Dinajpur	Sirajganj	Jessore	Habiganj
Domestic	Gas/LNG	Gas/LNG	No information provided	Gas /LNG	Gas/LNG	Gas/LNG
Industry	Gas/LNG	Gas/LNG		Gas /LNG	Gas/LNG	Gas/LNG
Agriculture	Electricity	Electricity		Electricity	Electricity	Electricity
Services	Electricity	Electricity		Electricity	Electricity	Gas/LNG
Transport	Gas/LNG	Gas/LNG		Gas/LNG		Gas/LNG

We can observe that the main energy is for domestic purposes are gas/LNG. Indeed, gas is used frequently in Bangladesh for cooking through stoves feed with natural gas.

Moreover, other important sectors are in demand regarding this energy source, such as transport and industry. As such, the production of gas may be considered as a priority in the selection of WTE Processes.

Local Integration and Market Compliance

When referring to energy production, it is important to mention needs but also to discuss about the requirements for the local integration. All the elements discussed below must be put in perspective.

In the case of gas, three aspects have to be taken into consideration :

The yield

The volume of gas produced should be sufficient for the facility to be cost-effective and provide energy to the targeted consumers.

The quality

It is important to understand that further treatments may be necessary to fulfil the minimum requirements of the potential application. Indeed, the gas produced may contain some impurities that need to be removed before being combusted or use in an engine for example. The gas producer has the responsibility to produce a raw material that guarantees the safety of the users.

The way to transport from the source to the final consumer Two types of transport may be developed depending on the scale of application :

- Small scale application : direct supply to the consumer
- Medium/Large scale application: bottling

In the case of electricity, two aspects have to be examined :

Production

It is important to compare the amount of power than can be produced to the energy needs of the paurashava. Moreover, it is also interesting to verify if a power plant installation is already implemented in the paurashava. These both elements will give precious information to evaluate the relevance of this energy production with regard to the proportion that this production will represent.

Producer to consumer

Power can be directly used into the facility for covering its energy requirements, meaning that the recovery of cost from the selling will be very low/not possible.

Power can also be injected on the grid. It should be pointed out that this operation is always very costly unless combined with upgrading of the local network. Moreover, it is generally difficult to find an injection point and will require further investigation in order to determine a cost-effective solution of connection.

Hot water is used for heating purposes.

It can be useful for industries that may include hot water in their process (heat exchange, etc.); in this case, a special attention must be put on the location of the WTE plant, which must be situated near the place the hot water is requested.

Finally, steam production is mainly used for industrial purposes. Like the case of hot water, the WTE facility has to be situated near the place the energy will be used.

4.4.3 Technical Considerations

4.4.3.1 Objective

The quality of the raw material is a critical factor to assess whether or not a thermal/non thermal process could be implemented. The objective of this section is to determine two key parameters that will give precious information on the feasibility of implementation of certain solutions.

Lower Heating Value (LHV)

The first parameter to be checked is the Lower Heating Value of Waste (LHV). The LHV corresponds to the total energy released as heat when a substance undergoes a complete combustion with oxygen under standard conditions. This LHV is extremely dependent of the type of waste, the water content and the ash content.

Approximate calorific values of waste are given below :

Table17: Typical Calorific Value (ISWA, 2013)

Fraction	Calorific Value
Metal	0
Glass	0
Organic material	4
Paper	16
Textiles	19
Plastic	35
Others	11

In Bangladesh, organic material is the main component of MSW. Moreover, wastes with higher calorific value like paper and plastic are often removed by scavengers (informal recyclers) for recycling. As a consequence, the overall calorific value of waste may be low. The determination of the Lower Calorific Value is thus the first element that should be determined.

C/N Ratio

Carbon to nitrogen ratio is the ratio of the mass of carbon to the mass of nitrogen in a substance. This ratio is very important for bio-processes like composting or anaerobic digestion, where microorganisms are involved in the decomposition of the organic matter. Carbon is used by bacteria as a source of energy whereas nitrogen is used for building cell structure.

When the nitrogen content is too low, the decomposition slows down until the nitrogen is consumed completely. Conversely, in excess of nitrogen, bacteria may produce ammonia. The determination of this ratio is therefore at utmost importance.

4.4.3.2 Methodology

Lower Calorific Value and Fuel Triangle

The LCV can be determined through empiric formula. Some of them are presented above.

Boie	Hu = 34 C + 101.6 H + 6.3 N + 19.1 S –9.8 O-2.5 W (MJ/kg)
Michel	Ho = 34 C +124.3 H + 6.3 N + 19 .1 S – 9.8 O (MJ/kg)
Verband	Hu = 34 C + 121.8 x (H - O/8) + 10.5 S – 2.52 W MJ/kg)

This method requires a detailed understanding of the waste composition and reliable information on the elementary composition of the waste stream, both of which are usually determined through field surveys.

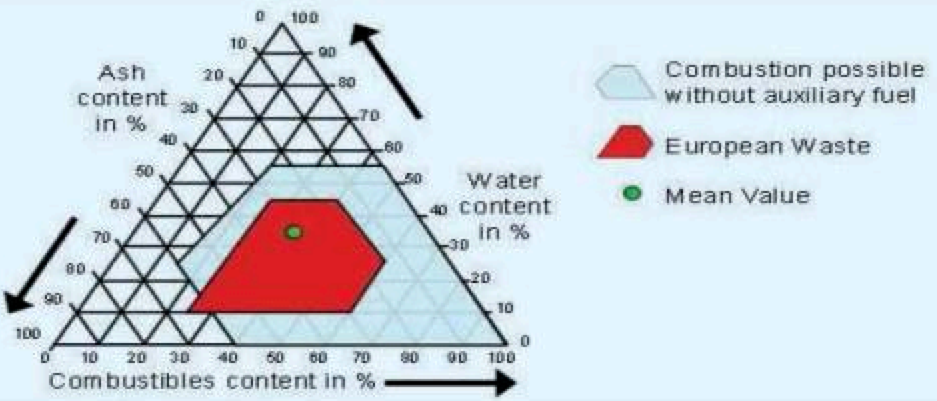
If such data become available, the consultant will use the previous formula to determine an average trend for the LHV.

Considering the current management system in each of the selected cities, it is most likely that these data will not be available in the selected paurashava. As a consequence, literature reviews should be performed in order to determine such values.

Besides, another method can be used to evaluate whether or not the combustion is feasible. For that purpose, the fuel triangle will be used.

This triangle is based on the composition of the fuel (in our case, the waste), and specifically the content in combustible, ash and water. Depending of the values, the combustion will be possible without additional fuel to maintain the combustion.

Figure 16: Fuel triangle



Based on the waste composition, the consultant will determine in which areas are situated the paurashavas' waste.

C/N Ratio

The C/N ratio is a criterion determined in each characterization study, realized through field investigations. Note that the C/N is then measured through a CHN analyzer or a flow isotope ratio mass spectrometer.

The present study does not include this type of analysis. As such, literature review and use of local authority's studies will be used to determine this ratio.

4.4.3.3 Results
Lower Heating Value
The result of the questionnaire and the literature review show that the chemical composition of waste is not available in the selected Paurashava. Therefore, it is not possible to define their respective LHV of waste.

However, the Bangladesh Council of Scientific and Industrial Research evaluated the calorific value of residential waste at 6.048 MJ/Kg.

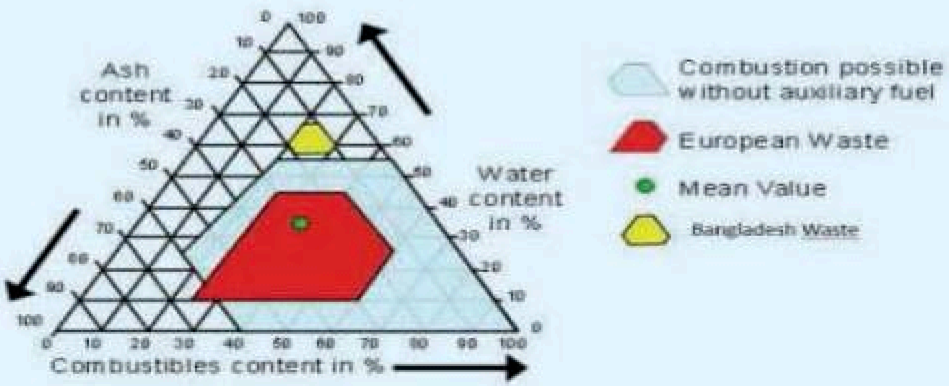
The method of fuel triangle, as preliminary evaluation, can also be implemented. According to the results of the chemical composition of waste in residential areas and the moisture content, the following parameters will be considered :

Figure 16: Fuel triangle

Parameters	Interval considered
Ashes	10% – 20%
Combustible	20% – 30%
Moisture	57% – 67%

The result on the fuel triangle is given in the Figure 19 below.

Figure 17: Fuel triangle method applied to Bangladesh Waste



According to the above data, it can be observed that combustion with waste as raw material cannot be maintained without addition of auxiliary fuel.

C/N Ratio
According to the questionnaire and the literature review, no information is available about the C/N ratio of waste in each of the paurashavas.

5. Action 4 : Generic Discussion on Energy Options

5.1 Objective

In the developing economy of Bangladesh, the energy consumption, mainly under the form of electricity, has experienced a rapid and significant increase over the last decades. Energy generation is mostly based on conventional energy sources such as natural gas (75%), fuel/petroleum (18%) and coal (2%) (Bangladesh Power Development Board, 2011). Although the country still disposes of natural reserves mainly in terms of natural gas, the dependence to importation is high and the energy sector is subject to market volatility. Moreover, due to the use of conventional energy sources, the energy sector is a matter of concerns because of its generous contribution to greenhouse effect and global warming.

Through these observations, Bangladesh authorities want to diversify the energy mix of the country with the implementation of alternative solutions based on unconventional energy sources.

In parallel of that, the increasing urbanization coupled with the change in consumption patterns lead to the production of thousands of tonnes of waste every month throughout the country. Sometimes dumped into a landfill but mainly illegally dumped into streets and riversides, waste is becoming a major concern for Bangladesh authorities and represents a social, environmental and technical challenge.

In the light of these considerations, the development of Waste-to-Energy technologies in urban areas of Bangladesh is seen as a possible solution for both stakes of energy supply and waste management.

Indeed, Waste-to-Energy is based on the concept of generating energy in the form of heat, gas or electricity from waste (MSW, industrial waste, etc.). WTE offers recovery of energy by conversion of materials through various processes including thermal and non-thermal technologies. The energy produced is clean and considered as renewable, with reduced carbon emissions and minimal environmental impact compared to any other form of energy.

As a consequence, the objective of the current chapter is to give an overview of possible WtE technology's options for Bangladesh.

5.2 Methodology

This chapter is structured according to the following items:

- Description of the basic principle of each process;
- Opportunity of energy recovery;
- Technical considerations;

- Advantages and disadvantages.

5.3 Results

5.3.1 WTE Options

As previously mentioned, Waste-to-Energy conversion refers to the production of electricity, heat and/or gas from Waste.

Waste can refer to municipal waste, industrial waste, etc. Depending on the conversion process and technologies, the fraction of waste that should be considered may be different (all waste vs specific fraction like biodegradable, paper, etc.)

The end-use consumption is one of the most important parameters that will influence the choice of the energy recovery system. Depending on the local conditions, electricity, gas, heat or a combination of them can be relevant. According to common knowledge, two options of Waste-to- Energy conversion are currently applied :

- Thermal conversion (incineration, gasification, pyrolysis, plasma arc gasification, etc.)
- Non-thermal conversion (anaerobic digestion, landfill gas recovery)

Both processes and their applied technologies are presented below.

5.3.2 Thermal Conversion

Thermal processes can be defined as the conversion of waste into gaseous, liquid and solid production, with or without energy valorization (Tchobanoglous and et al. 1993). Indeed, the organic compounds of waste are destroyed under the influence of heat, leading to the reduction of waste volume and the production of end-products (ashes, flue gas, etc.) on which additional processes can be applied to recover energy.

Three thermal methods are currently used (Bosmans, 2013)

5.3.2.1 Principle

Incineration

MSW Incineration has been very popular over the last decades in high income countries especially because of its advantages in terms of reduction of waste volume and the possibility to recover energy. According to scientific literature, the grate incinerator forms the vast majority of installation worldwide because of its robustness, its reliability and its simplicity when well-managed. The development of rotary kiln and fluidized bed is limited

- Incineration; an exothermic process in which the load (waste) is directly heated by the entire combustion of waste. Electricity and heat are potential conversion products of such method;

- Gasification; an endothermic process in which energy should be supplied to the process to perform the thermo-chemical reaction. The conversion product from gasification is low- value gas;

- Pyrolysis; another endothermic process that leads to the production of medium-value gas, liquid fuel and solid fuel.

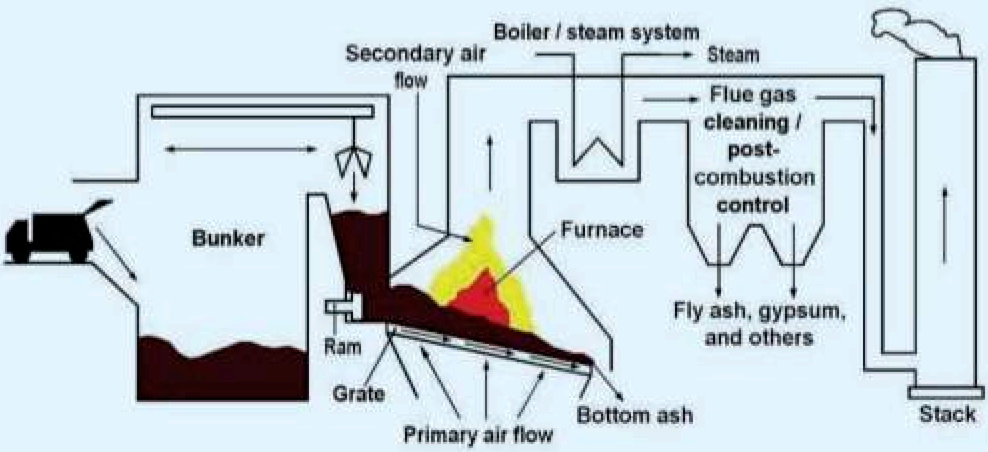
so far; these technologies are not totally mature and require strict conditions to be efficient and cost-effective (ISWA, 2013).

As a consequence, there is a great temptation in middle and low income countries to implement incineration plants as a fast remedy to the waste issues. However, operating conditions are totally different and should thus be carefully analyzed.

Description of the process

Incineration is the most common method throughout the world for Waste-to-Energy generation. This exothermic process consists in the thermal breakdown of waste, which occurs in excess of air and leads to the production of a flue gas (CO_2, O_2, N_2, water vapor) and heat (ISWA, 2013). Its working principle is based on the combination of pyrolysis, gasification and combustion steps.

Figure 18: Waste Incineration plant scheme (Leskens, 2013)



Gasification

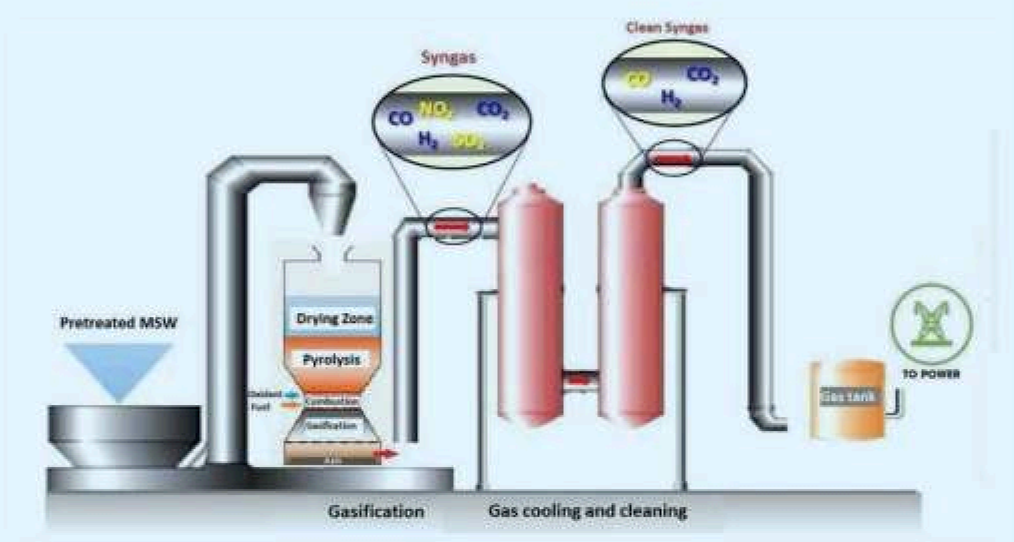
Preliminary considerations over the last few years, gasification, also called, indirect combustion', is considered to an alternative to the supremacy of incineration.

Description of the process

Contrary to Incineration process, gasification consists in the thermal breakdown of waste under oxygen starved conditions, leading to the production of a fuel-rich product called syngas (ISWA, 2013), liquid (oils and tars) and solids (char = fixed carbon and ashes). Chemical reactions involved in the gasification process depend on temperature, pressure ad concentration of O_2 in the reactor. Most of the reactions are exothermic (heat producing). However, some heat may be required to initialize and sustain the gasification process. Basically, part of the fuel is combusted to provide the heat needed to gasify the rest (autothermic gasification), as in the case of air gasification, or heat energy is provided by an external supply (allo-thermal gasification), as in the case of plasma torch utilization (U. Arena, 2012).

The gasification process takes place in two steps (Arena, 2012). Below 600°C, the pyrolysis stage leads to the decomposition of waste into volatile components in the absence of oxygen. During the second stage of gasification, carbon-based materials are either reacted with steam, air or pure oxygen between 760°C and 1650°C under high pressure. The O_2 inflow is managed in such a way as to avoid combustion.

Figure 19: The process of gasification.



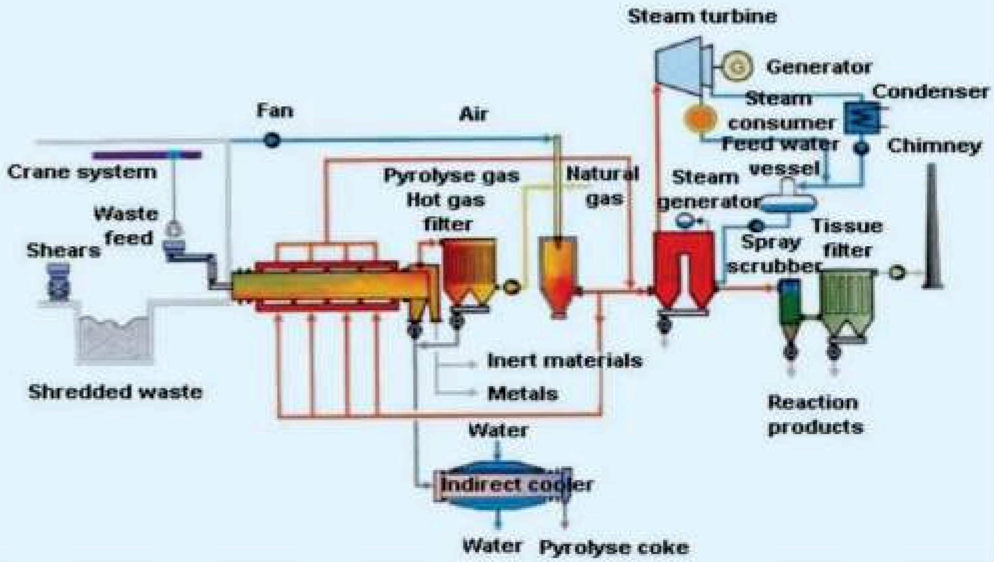
Pyrolysis

Description of the process

Pyrolysis is a process in which organic matter is broken down at high temperatures (400°C - 900°C), in the absence or near absence of oxygen, into products that may be gaseous, liquid, or solid in form, or as a collection of all three forms. The quantity and composition of the products of pyrolysis are functions of the composition of the raw material ("input", "charge"), and of the temperature and pressure applied in the process. The higher the temperature, the greater is the yield of gas, whereas that of the liquids and char is correspondingly less.

Pyrolysis differs from incineration in that it is an endothermic reaction and takes place in oxygen- free or low-oxygen atmosphere. Because the pyrolysis reactions are endothermic, a considerable amount of energy input is required to attain the high temperatures required to volatilize the organic compounds.

Figure 20: Pyrolysis Process with wood chips as raw material – Source (European Commission, 2006)



5.3.2.2 Focus on The Technologies Available

Different types of technologies have been elaborated for pyrolysis, gasification and incineration. The section below describes briefly some technologies commonly used on the market.

It is important to mention that most of the standard technologies used for incineration (grates, fluidized bed, rotary kiln) may be adapted to be operated under pyrolysis and gasification (European Commission, 2006), such as operation at lower temperature or with reduced/absence of oxygen levels. Moreover, pyrolysis and gasification system are often combined or coupled with downstream combustion in order to recover energy from the produced syngas.

The following section will focus on these three technologies :

Grate Reactor

The grate reactor is the most commonly implemented process worldwide for incineration. However, this technology may be operated under pyrolysis and gasification conditions.

Figure 21 : Pyrolysis on a grate with directly connected high-temperature incineration – (Source-INDAVER 2018)

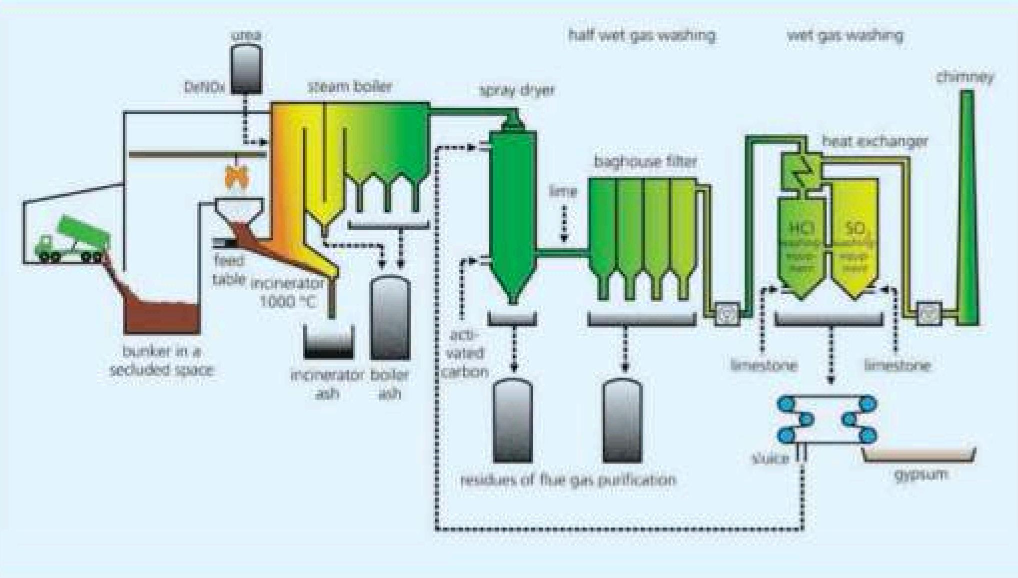
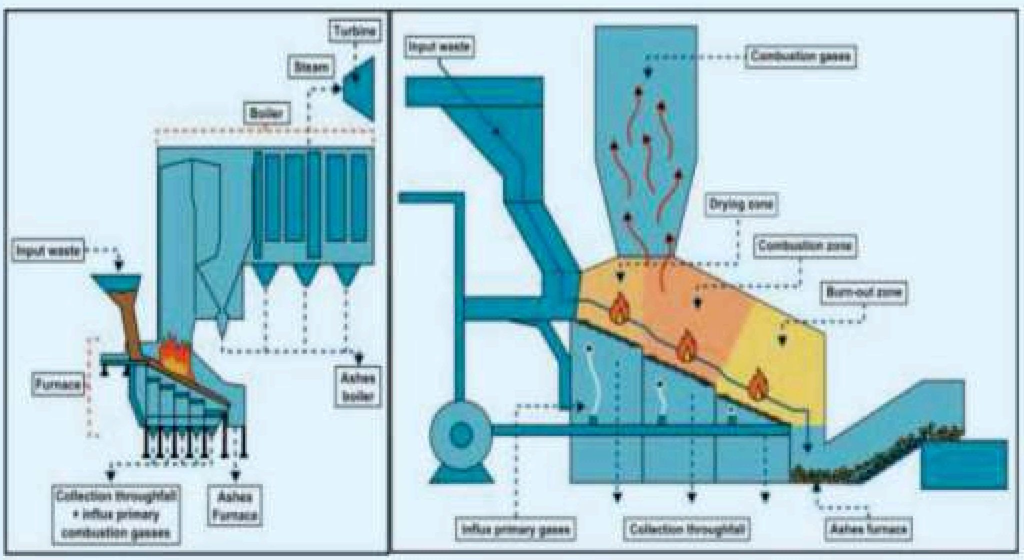


Figure 22 : Process Diagram and detail Diagram of incineration with a Grate Incinerator



In this process, waste are dumped on a grate (moving or fixed) and pushed onto the burner tray. The moving grate enables the optimization of the movement of the waste through the chamber, allowing a more efficient and complete incineration/pyrolysis.

Rotary Kiln

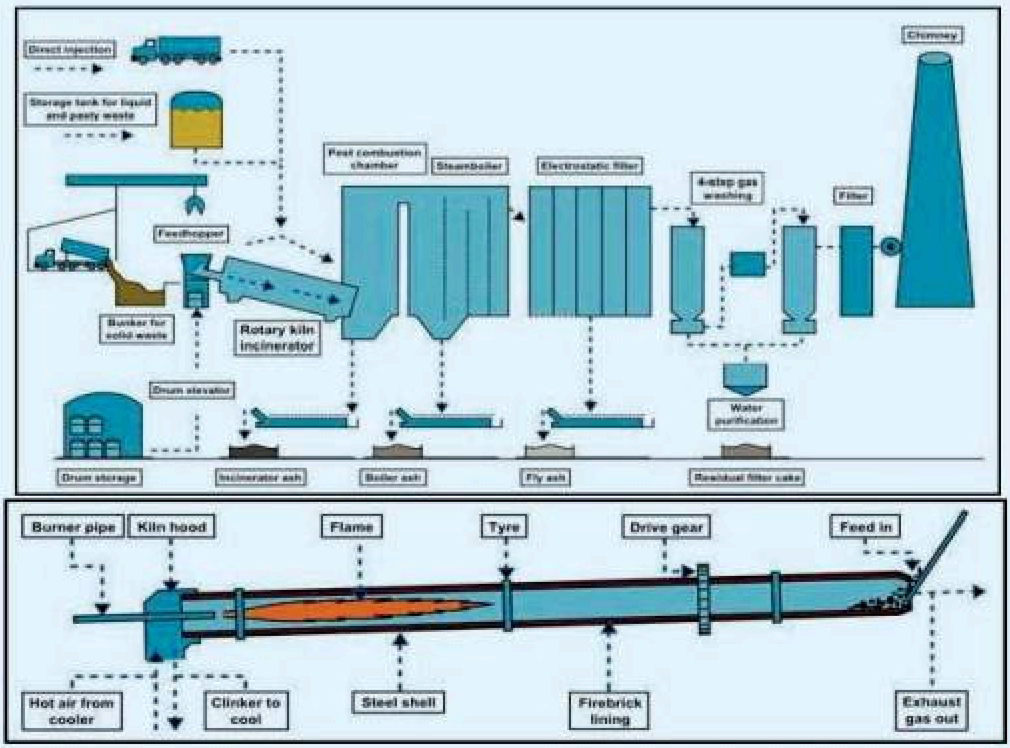
The rotary kiln reactor is composed of a rotating chamber that foster waste moving and mixing with the primary air in case of incineration. Waste material is introduced from one side of the chamber and is transported gradually to the end of the furnace due to of the slight inclination of the drum. The rotating movement of the vessel ensures the continuous mixing of the load which results in a complete combustion of waste.

The direction of flue gases into the chamber implies two different types of rotary kiln :

- Counter-current rotary kiln: flue gases flows in the opposite direction of the waste and thus in the opposite direction of the inclination.
- Co-current rotary kiln: flue gases flows in the same direction of the waste and thus in the same direction of the inclination. This system has usually lower performance than the counter-current rotary kiln (presence of unburned carbon in the ashes)

The Diagram Process of the facility is given in Figure 25 below.

Figure 23 : Process Diagram and Detailed Diagram of Incineration with a kiln Incinerator (counter current rotary kiln)



It is important to mention that due to economic reasons, such technology requires waste with high calorific value. Although SWM applications are possible, the process is mainly developed for the treatment of hazardous waste, PCB waste, medical waste, chemical waste, sludge, industrial waste, oil waste.

Fluidized Bed Reactor

Fluidized-bed reactors require pre-processed waste that is injected in an air/steam stream with a floating sand bed. Under appropriate conditions, a solid/fluid mixture will thus be formed that will behave as a fluid (Fluidization Process). Due to fluidization of the mixture, heat transfer occurs between air, sand and waste; leading to the gasification/combustion of the organic fraction of waste.

Figure 24 : Process Diagram and Detailed Diagram of incineration with fluidized-bed incinerator

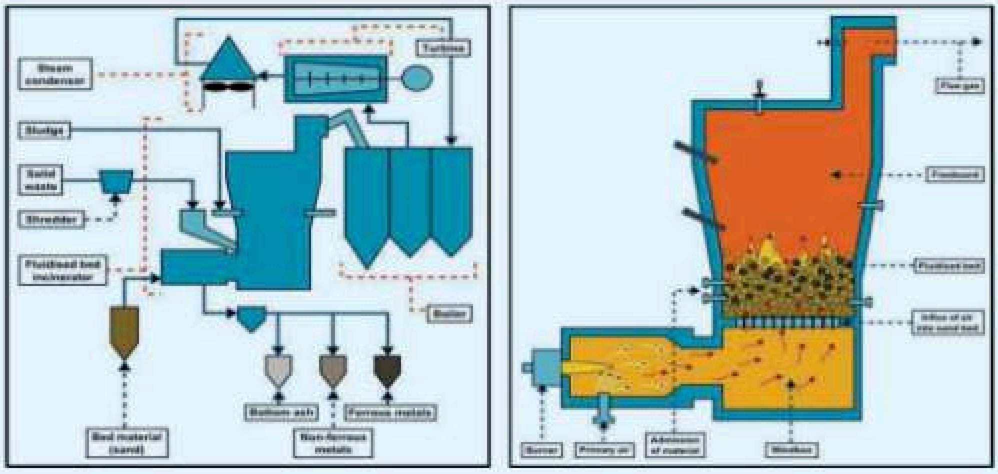
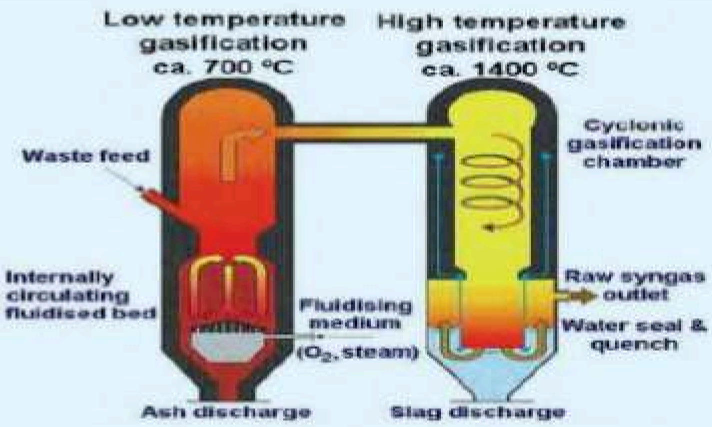


Figure 25 : Fluidized bed gasifier with high temperature slagging furnace



Note that due to this efficient heat transfer, fluidized-bed reactors may work at lower temperature combustion than grate incinerators. However, this process requires the pre-treatment of waste before combustion in order to reduce and standardize their size.

5.3.2.2 Energy Recovery

Depending on the process developed, different sources of energy can be recovered (electricity, heat, steam, etc), as well, sometimes, as valuable material.

Incineration

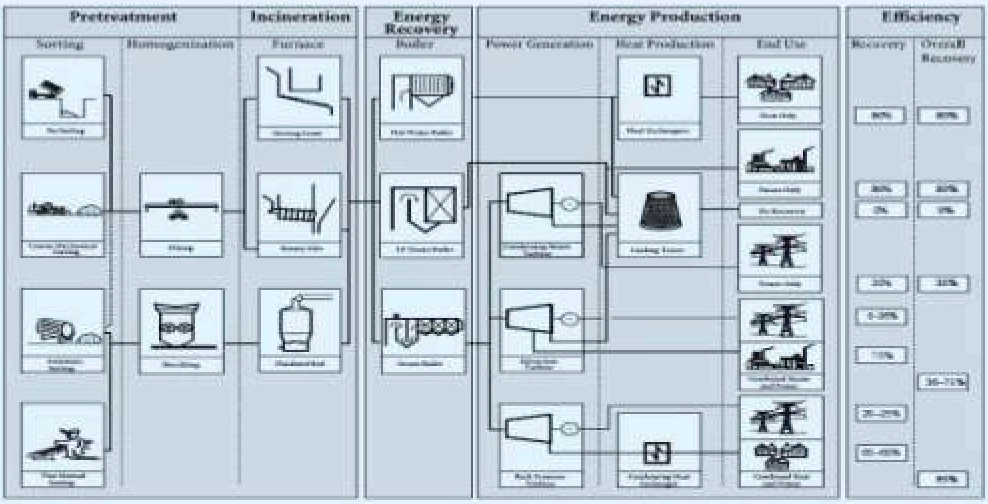
Depending on the expectations in terms of end-products, incineration can provide electricity, heat or a combination of both. Energy recovery is performed through the use of a hot water / steam boiler.

Steam can be directly used for industrial purposes. Moreover, steam turbines may be used to produce electricity and heat exchanger to produce heat.

According to ISWA Guidelines for Waste-to-Energy in Low and Middle Income countries (ISWA, 2013), the energy recovered in MSW incineration plants is about 20 to 25% for power producing plants and about 80 to 90% for combined heat and power plants.

Figure 28 below provides an overview of possible Incineration Technologies and available energy valorization modes.

Figure 26 : Overview of incineration technologies (WB, 1999)



Note that it is also possible to implement cooling systems instead or in addition to heat recovery systems. A heat exchanger and an A-frame cooler are included in the process.

Gasification

Gasification process is used to produce syngas.

Syngas is mainly composed of carbon monoxide, hydrogen, nitrogen and methane, which proportion depends on the reagent (O_2, air, steam, etc.). With different temperatures, a variation in the composition of the gas can be determined :

- <1.000°C: Next to CO_2 and H_2O, the gas consists mainly of CO, H_2, CH_4, other hydrocarbons and tar
- >1.200°C (or with the use of a catalyst): Bio-syngas consisting solely out of CO_2, H_2O, H_2 and CO

Because of its composition, syngas has a calorific value whose potential is related to the reactant used:

- 4-7 MJ/Nm^3 when gasification with air
- 10-15 MJ/Nm^3 when gasification with pure oxygen

Syngas can be incinerated for energy recovery (heat, electricity, and steam) or converted into a wide range of products, including (GSTC):

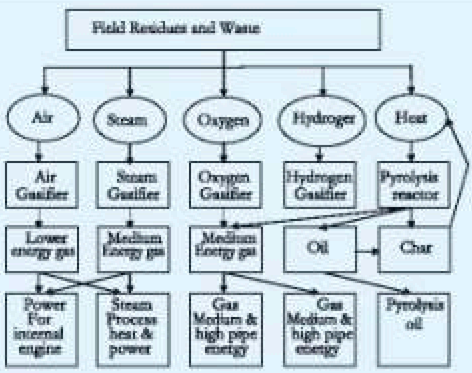
- Industrial gases (pure CO or H_2)
- Liquids (alcohols, transportation fuels)
- Substitute Natural Gas (SNG)
- Ammonia and urea

Figure 29 below summarizes the different options and results.

Nevertheless, it should be noted that according to the report of the European Commission on the Best Available Technique for Waste Incineration, "both pyrolysis and gasification differ from incineration in that they may be used for recovering the chemical value from the waste (rather than its energetic value)". However, it is stressed that combined processes (pyrolysis, gasification and combustion) are mainly used when the raw material is waste and as such, energy recovery may be maximized rather than maximizing chemical production.

Note that depending on the intended use, the contaminants (dust and soot/tarry residues) that compose the syngas need to be removed. Indeed, various other hydrocarbon gases may be present into the syngas but in lower proportions. Therefore, a cleanup step can be necessary to remove all trace of impurities.

Figure 27: Products of gasification – Source (S. Sadaka)



Pyrolysis

During the process, the hydrocarbon content of the waste reacts and generates pyrolysis products, such as pyrolysis gas, pyrolysis coke and tar. Their proportion is influenced by temperature and pressure.

As such, two types of pyrolysis may be defined (Prof. B.B Uzun, et al.) :

- Slow Pyrolysis : operated at low temperature during a long period of time in order to maximize char formation (35% bio-char, 30% bio-oil and 35% gaseous products)
- Fast Pyrolysis : operated at a temperature range of 650°C to 1000°C, depending whether bio-oil or bio-fuel are desired

Syngas production is principally composed with CO and H_2 (+/- 85%), but may also contain CO_2 and water. It is important to note that because the process is performed at low temperature, the production of pollutants such as NOx is quite reduced compared to incineration and the syngas may be directly use for electricity production or heat recovery in boiler applications and/or gas turbine and gas engine. Indeed, the gas has a calorific value between 5 and 15MJ/m³ (waste as raw material) and 15 and 30 MJ/m³ (Refuse Derived Fuel as raw material), depending on the raw material being processed.

Pyrolysis also leads to the production of oil mixtures, that may be directly combusted in boilers, gas turbines and diesels for heat and power application (LHV ~ 17.5 MJ/kg) (Prof. B.B Uzun, et al.).

Bio-char, produced at low temperature, can also be used in combustion process for heat recovery. Note that this product may also be valorized as activated carbon or for soil amendment.

Concerning chemical feedstock recovery, this way of valorization is technically achievable at this time; but seems most of the time economically unsustainable.

5.3.2.1 Technical Data and Condition of Operation

Common technical data of thermal processes are given in Table 18 below.

Table 18 : Technical features of Thermal Processes (Coolsweep) (ISWA, 2013) (WB, 1999) (U. Arena, 2012) (Bosmans, 2013)

Waste features					
Technique	Incineration			Gasification	Pyrolysis
	Moving grate	Rotary kiln incinerator	Fluidized Bed Incinerator		
Type	Municipal Solid Waste Non-hazardous industrial waste Special design : non-hazardous medical waste, sludge, biomass	Industrial Waste Hazardous waste (chemical, pesticide, medical waste, etc.) Sludge waste, cattle waste Possible: SW with high	Municipal Solid Waste Waste with high fluid content (sludge) Fluid in combination with solid waste	Organic waste Vegetable, wood, oil, sludge, MSW, etc.) Plastic waste Hazardous Waste, dried water sewage sludge	High calorific waste (plastic, tires, oil) Vegetable waste, pre- treated MSW, wood Sludge Contaminated
Quality	Annual Average Calorific value:7MJ/kg <CV <15 Average Lower Calorific Value > 6 MJ/kg throughout all	Calorific value : 16 –35 MJ/kg depending on the type of waste	Annual Average Calorific value : 4MJ/kg < CV < 35 MJ/kg	Annual Average Calorific value : 7 MJ/kg < CV < 18 MJ/kg Low concentration of CI, F and S in the raw material	Min 4MJ/kg (additional gas is usually supplied to keep the reaction going)
	Moisture <			< 50%	<
Quantity	Annual amount : 65 kt/year –1Mio t/y (min 50kt/y) Weekly variations limited to 20%			in development	In development
Pre-process	No pre-processing : non-homogeneous waste accepted	No pretreatment : non homogeneous waste permitted (but blending may be performed)	Dewatering of sludge Removal of ferrous metal / material capable of lowering the melting T°C of and Particle size reduction (≤30cm)	Dewatering of sludge (drying) Removal of some unsuitable material (glass, metal, inert, etc.)	Removal of some unsuitable material (glass,metal, inert, etc.) Mechanical preparation (size reduction)

Combustion conditions					
Technique	Incineration				
T°C of furnace (Min-Max) Pressure (bar)	Moving grate 800 °C – 1450°C	Rotary kiln incinerator 1000°C – 1200 °C 1	Fluidised Bed Incinerator 800 °C – 900 °C	Gasification 500°C - 1600 °C 1 - 45	Pyrolysis 250°C - 700°C 1
Atmosphere	Air			Gasification reactant : O2, air, steam	Inert / Nitrogen
Stochiometric ratio	> 1			< 1	0
Feeding	Required continuous and stable feeding			Constant feedstock flow required (impact on gas yield	Required constant supply of waste with high calorific value
Min. condit. in the after-burning chamber	850 °C during at least 2 second with min. 6% of O_2	850 °C during at least 2 second	850 °C during at least 2 second		
End-products					
Technique	**Incineration**			**Gasification**	**Pyrolysis**
Solid phase	Bottom ashes (metal, inerts, unburned material, etc.) -> ~10% of the volume of the waste input -> ~20-30% of the weight of the wasteinput Fly ashes -> ~1-3% of the weight of the waste input -> Toxic compounds (heavy metals, HCl, dioxin, furans, etc.) Slag			Solid residue of non-combustible material (ash) with low carbon level	Coke + solid residues
Liquid Phase	Water from wet treatment of fumes			Waste water from washing of syngas and cooling of the	Oil mixture and water
Gaseous phase	Flue gas (CO_2, H_2O, O_2, N_2) with possible trace of dioxin and heavy metal => extensive flue gas treatment required			Syngas (H2, Co, CO_2, CH_4, H_2O and N_2) with calorific	Syngas (H_2, CO, hydrocarbons, H_2O, NO_2) and flue gas if treatment of syngas
Additional products with a recycling potential			Material removed during the pre-process of raw material (ferrous metal,	Material removed during the pre- process of raw material (metal, glass, etc.)	Material removed during the pre-process of raw material (metal, glass, etc.)
Technique	Incineratio				
	Moving grate	Rotary kiln incinerator	Fluidized Bed Incinerator	Gasification	Pyrolysis Syngas (and heat from flue gas if combustion of syngas)
Energy recovery	Heat from the flue gas recovered through a steam/hot water boiler			Syngas (and heat from flue gas if combustion of syngas)	
Energy products	Electricity production (steam turbine) => 400-700 kW / ton of waste (data from WTE Facilities Europe) Steam and hot water Electricity for pumps, fans, mechanical pretreatment, air pre-heating, etc.			Syngas (4 -15 MJ/Nm³) If combustion of the syngas : Electricity production through gas turbine (syngas) and steam turbine (heat recovery from the flue gas of the combustion) Steam and hot water In theory : chemical compounds	Syngas (5 -30 MJ/Nm³) If combustion of the syngas : Electricity production through gas turbine (syngas) and steam turbine (heat recovery from the flue gas of the combustion) Steam and hot water Pyrolysis oil and Bio-char In theory : chemical compounds
Energy needs	0.062 MWh to 0.257 MWh per tonne of waste feedstock for electricity and 0.021 MWhto 0.935 MWh per tonne of waste incinerated (data from WTE Facilities Europe)			Energy required at the start of partial oxidation and for maintaining the temperature into the reactor	Energy required at the start of partial oxidation and for maintaining the temperature into the reactor

5.3.2.3 Advantages and Disadvantages of Thermal Conversion

Advantages of thermal processes

Table 19 : Advantages of Incineration and its related techniques

	General advantages	Specific advantages regarding the different techniques
Common advantages	▪ Reduction of waste volume and thus the demand of landfilling ▪ Environmental benefits compared to a traditional landfill (greenhouse gases production due to organic material decomposition)	
Incineration	▪ Diversification of the energy mix (electricity, heat) / substitute to fossil fuel ▪ Possible valorization of ashes in construction work	**Grate incinerators** ▪ Mature, simple and robust technology ▪ Very efficient process ▪ No pre -processing of waste (regarding size requirements) ▪ Wide variety of waste material can be used
		▪ Fluidized -bed incinerators ▪ Lower combustion temperature thangrate incinerators
		Rotary kiln ▪ No pre -processing of waste (regarding size requirements) ▪ Treatment of a large variety of waste including liquids ▪ Robust process with resistance to high temperature ▪ Flexibility (handle in batch or continuous mode)
Gasification	▪ Syngas can be used in a gas engine for energy recovery Smaller flue gas volume (and therefore treatment requirements) compared to flue gas volume in incineration (factor 10 when using pure O_2) ▪ Smaller waste water flows from synthesis gas cleaning ▪ Implantation near urban areas possible due to reduced air pollution (less transportation) => reduce public health risks. ▪ Modular plants that can operate at smaller scale	
Pyrolysis	▪ Pyrolysis process happens at relatively low temperature compared to other thermal processes ▪ Possibility of recovering energy, chemical material (but not really applicable with waste) and valorizing the biochar ▪ Possibility of increased electrical generation using gas engine or gas turbine instead of steam boilers ▪ Reduced flue gas volume after combustion, which may reduce the capitalsts ▪ No dioxin in the off-gas and the solid residue ▪ Implantation near urban areas possible due to reduced air pollution (less transportation) = > reduce public health risks ▪ Modular plants that can operate at smaller scale	

Disadvantages of the thermal processes

Table 20 : Disadvantages of Incineration and its related techniques

	General disadvantages	Specific disadvantages regarding the different techniques
Common disadvantages	▪ Unless recycling and composting are operated at source, thermal processes will undermine theirdevelopment.Moreover, thermal processes compete with recycling (and composting) as certain amount of calorific material are requested (plastic, paper, etc.). Finally, energy savings from waste prevention and recycling are likely to be greater than the energy produced. ▪ Minimum requirement in terms of Lower Calorific Value ; else, auxiliary fuel will be requested to maintain the process ▪ Disposal of ashes or solid residue is required, as well as water treatment processes for waste water from clean gas systems ▪ High investment and O&M costs ▪ Constant supply requested, which can be a significant challenges when the WMS is not already efficient and implemented ▪ If mismanagement, risks of fast degeneration of the equipment with probable significant impacts on environment , health and economy ▪ Processes that require highly qualified personnel, daily operation, and complex equipment ▪ Equipment (reactors) must be imported	
Incineration	▪ Minimum requirement in termsofwastesupply (between 40,000 to 100,000 t/year) ▪ Minimum requirement in terms of Lower Calorific Value (> 7 MJ/kg) ▪ No suitable for waste with ahigh moisture content ▪ No production of syngas or valuable oil or valuable char; steam turbine is the only way to recover energy ▪ Complex and expensive flue gas treatment ▪ NYMBY syndrome ▪ Significant surface area	Grate incinerators ▪ When instability, fast development of practical problems such as temperature peak, incomplete combustion with production of NOx Fluidized-bed incinerators ▪ Need of pre -processing the waste to remove unsuitable material and ensure size homogeneity **Rotary kiln** ▪ Very high investment costs and thus requires waste with sufficient Calorific Value ▪ Electrical efficiency lower than for the other technologies ▪ Continuous wear and abrasion caused by the movement of the materials leads to considerable wear to the lining.
Gasification	Pre-processing of waste required ▪ Require O_2, air or steam supply implying additional costs and additional equipement ▪ When gases, char or oils are burnt, production of emission that must be cleaned ▪ In practice, the reuse of syngas is only considered with the treatment of high calorific waste like plastic ▪ Deposit of tar may cause operational challenges associated with inefficiencies and plant failures	
Pyrolysis	Pre-processing of waste required ▪ Require additional fuel, jeopardizing the financial sustainability of the facility (part of the produced fuel may be used, meaning no costs recovery) ▪ Deposit of tarmay cause operational challenges associated with inefficiencies and plant failures ▪ According to literature review, pyrolysis is a complex process with high operational and investment costs ▪ Uncertainty about the real practical and financial performance of these plants : technology non mature ▪ Limited example of application throughout the world for waste treatment	

5.3.3 Bio-chemical Conversion

Bio-chemical conversion can be defined as the extraction of energy from a raw material (waste) by bio-chemical decomposition performed by microorganisms (Waste to Energy Council, 2013). The result of the decomposition of waste is the production of an energy-rich fuel.

Processes associated with bio-chemical conversion are:

- Anaerobic digestion; biological decomposition of organic waste carried out in absence of oxygen. The products of anaerobic digestion are :

i) an energy-rich biogas that can be used as bio-fuel or to generate power and heat

ii) a liquid fraction called digest, that can be valorized in agriculture or in composting

- Biogas recovery from Landfill; the natural decomposition of waste in a landfill produces bio methane, that can be valorized as fuel or for power and heat generation
- Bio-ethanol production ; process based on hydrolysis, fermentation and distillation of a specific fraction of organic waste, and which leads to the production of bio-ethanol and/or hydrogen
- Dark fermentation or Photo-fermentation; technique that can convert organic substrates (in general waste water) into hydrogen with the absence or presence of light
- Microbial fuel cell; device that convert the chemical energy content of organic matter (in general waste water) through catalytic reactions to electricity

Anaerobic digestion and biogas recovery from landfill are the most developed and applied techniques throughout the world. Moreover, the others are more suitable for waste water treatment than domestic waste. Therefore, the Consultant will focus this section on these two processes.

5.3.3.1 Principle

Anaerobic Digestion

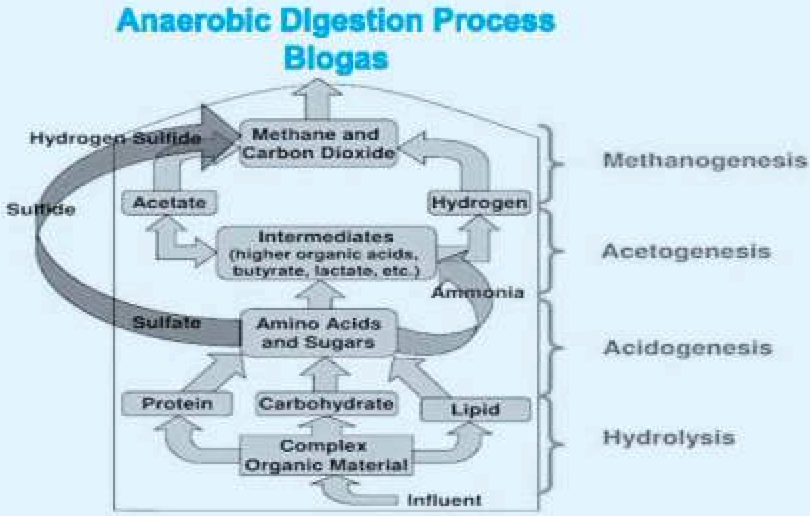
Anaerobic digestion is a biological process where a bacterial decomposition of organics material takes place in absence of oxygen, leading to the production of biofuel (CH_4) used for power generation, thermal application (dryers, boilers, thermic fluid heaters, furnace, transport, etc.) or both.

Biomass like food residue (organic fraction of waste), cereal husks or palm oil effluent is adapted to such process.

The process involves 4 different phases that happen simultaneously :

- Hydrolysis ; bacteria break down the organic matter into liquefied monomers and polymers (= small particles)
- Acidogenesis ; bacteria convert these small particles into sugar and organic acid
- Acetogenesis ; acetic bacteria transform organic acid into hydrogen, carbon dioxide and acetic acid
- Methanogenesis ; acetic acid and hydrogen are converted into methane gas and carbon dioxide by methanogenic bacteria

Figure 28 : presents the principle of anaerobic digestion (Source : Scientific and technical principles of digestion technology, 2010)



Description of the facility

The anaerobic digestion system must be composed of:

- Input Platform (weighing bridge, temporary storage area)
- Sorting and preparation facility (removal of unsuitable waste, shredding and mixture of waste, intermediate storage)
- Bioreactor
- Gas recovery system (drainage network, gas processing equipment, purification system, power generation facility, etc.)
- Treatment of residues (Dewatering of the digested waste, aerobic composting, compost storage unit)

Energy Recovery From Landfill
Description of the principle

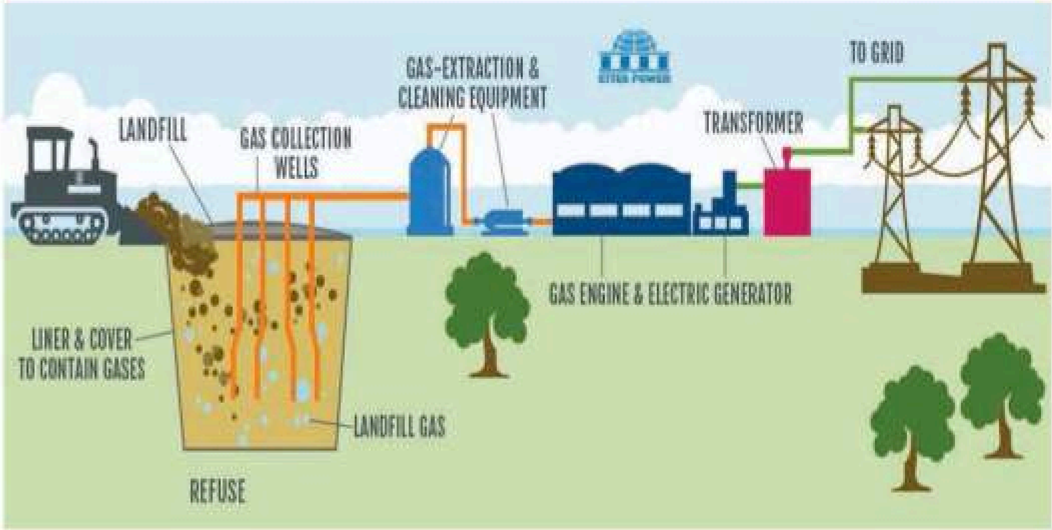
Sanitary landfill is a step by step construction activity. Every day, waste is deposited in cells and once filled, these cells are hermetically isolated (soil, air) using geotextile, creating an anaerobic atmosphere in which the organic waste decomposes into a gaseous phase (biogas rich in methane) and a liquid phase (leachate rich in nutrient). Note that the working principle is often similar to that of anaerobic digestion.

These two phases have to be removed from the cell through drains:

- gaseous fraction because high risk of explosion or ignition
- liquid fraction, because of the risk of pollution

Indeed, because the methane is a dangerous greenhouse gas, the gaseous phase cannot be directly released into the atmosphere. Often, it is burned through flares. However, the recovery of this gas is more and more developed throughout the world because it can be used for power generation or as biofuel for transportation or kitchen purposes.

Figure 29 : Engineered landfill with gas recovery



Concerning the liquid phase, leachate is partially used to moisture the cells contains, which increase the gas yield; the other part should be treated before being released into the environment. The more wet the climate, the more the volume of leachate.

Description of the facility

A sanitary landfill with energy recovery system is composed of:

- Input Platform (weighing bridge)
- Bioreactors (cells for waste storage)
- Gas recovery system (drainage network, extraction wells, landfill gas processing, purification system, power generation facility, etc.)
- Leachate management system (drainage system, storage tanks, recirculation network, waste water treatment plant)

It has to be noticed that this type of landfill requires even more space than a basic landfill facility because of the additional gas treatment facility and/or power generation facility.

5.3.3.2 Focus on Technologies Available

Anaerobic Digestion

The selection of an anaerobic digestion technology strongly depends of various operating parameters:

- Wet or dry solid content ;wet meaning operating with Total solid content less than 16%
- Batch or continuous feeding mode;
- Mesophilic or thermophilic temperature; mesophilic meaning T°C between 30-40°C and thermophilic meaning T°C between 50 - 60°C
- One stage or multi-stage process; with multi-stage meaning separation of acidogenesis and methanogens phases

Another criterion that must be taken into consideration is the flexibility provided by such process. Indeed, anaerobic digestion may be implemented on a wide range of scale; the technologies available can be implemented at small scale (household, ward), as well as at large scale (Paurashava).

There are several technologies that can be applied at small, medium or high scale. In developing countries, small scale solutions are often implemented :

- Balloon-type reactors (continuous / wet / mesophilic / one stage)
- Fixed-dome reactors (continuous / wet / mesophilic / one stage)
- Floating drum reactors (continuous / wet / mesophilic / one stage)
- Garage-type reactor (batch / dry / mesophilic / one stage)
- Etc.

But new alternatives are developed:

- Plugflow anaerobic digester (continuous / dry / thermophilic / one stage)

5.3.3.3 Energy Recovery

Anaerobic Digestion

End products of anaerobic digestion process are biogas and digest.

The gas mixture obtained is mainly composed of methane (+/-60%) and CO_2 (+/-40%) with traces of nitrogen, hydrogen, oxygen and sometimes hydrogen sulfide (<2%).

Biogas can be used as energy-rich fuel for domestic purposes (kitchen) or for transport. If combusted, electricity, steam and/or hot water may also be produced.

Moreover, it is important to mention for the Bangladesh context that some technologies have been developed to purify and liquefy biogas into a methane-rich mixture.

Figure 30: Liquefied Biogas facility - Source (GTS)

Finally, it should be mentioned that anaerobic digestion produces a semi-solid residue called Digest, which may be used as fertilizer on farmland if allowed by the legislation regarding soil and water protection.

Energy Recovery From Landfill

As mentioned before, this process produces gas with high methane-content.

The most common use of biogas is in a gas engine running an electric generator producing power. According to H.C Willumsen, the normal plant sizes with gas engines produce between 350 and 1200 kW power per engine (Energy recovery from landfill gas in denmark and worlwide)

In larger plants, gas turbines or steam turbines may be used to produce power, heat and also cooling (Combined Heat and Power Plant).

In order to use methane as fuel, it may be required to increase the calorific value of the fuel by removing impurities and increasing the proportion of methane. In this case, it will be necessary to upgrade gas quality through:

- Chemical Absorption
- Pressure Swing Adsorption
- Membrane Separation

However, gas purification plant are a significant investment, and a detailed study must be performed to analysis the technical and economic parameters that must be fixed for the installation to be sustainable.

5.3.3.4 Technical Data and Conditions of Operation

The Table 21 below gives information on technical data and conditions of operation.

Table 21: Technical characteristics of bio-chemical conversion processes

Waste		
Technique	Anaerobic Digestion	Biogas recovery from landfill
Feedstock	Organic/biodegradable fraction of domestic waste (kitchen waste) Agriculture residues Industrial biodegradable residues	Domestic waste
Quality	Low/Absence of Heavy metal or other toxic compounds for bacteria Organic material carbon-rich	No specific requirements but the presence of certain pollutants (heavy metal, etc.) may slower the process because of their
Quantity	Small scale plant : design adapted for small quantity Large scale plant combined with composting : 25 – 50 kt/y	no minimal value
Pre-process	Separation (mechanical or manual) Shredding and mixing	No need of pre-processing
Operational parameters in the digester		
Technique	Anaerobic Digestion	Biogas recovery from landfill
Temperature	Anaerobic digestion does not work properly at low temperature	Low temperature (<15°C) can lower the process of gas production
	Process sensitive to high temperature variation (night and day, seasonal variation, etc.)	
	Mesophilic system : temperature in the digester must be maintain between 30°C and 40°C	
	Thermophilic system : temperature in the digester must be maintain between 50°C and 60°C	
Moisture	High moisture content enhances methane yield	High moisture content enhances methane yield
C/N ratio	C/N ratio range : 16:1 to 25:1	
pH	pH range : 6.5 – 7.5 pH adjustment may be required (lime, sodium carbonate, sodium	
Organic loading rate	ORL : 4 - 8 kg VS/m^3 for stirred reactors ORL < 2 kg VS/m^3 for non-stirred reactors	

Hydraulic retention time	Mesophilic condition : 10 - 40 days Thermophilic condition : lower HRT than that of mesophilic conditions	
Inoculation and startup	Need to inoculate bacteria at the first use	Recirculation of leachate enhances methane yield
	Managing and control to avoid overloading	
Surface requested	Small scale applications possible	Important

Technique	Anaerobic Digestion	Biogas recovery from landfill
Solid phase		Solid elements from the decomposition + other waste that has not
Liquid phase	Nutrient-rich digest	Leachate + runoff water
Gaseous phase	Energy-rich biogas	Methane-rich gas
Material removed during the pre-additional products with process of raw material (plastic, metal, a recycling potentialglass, etc.)		None if no sorting plant
Energy aspects		
Technique	AnaerobicDigestion	Biogas recovery from landfill
Energy recovery	Energy-rich biogas	Methane-rich gas
Energy products	Biogas as fuel for kitchen, transport, etc. Electricity, steam and hot water if combustion	Biogas as fuel for kitchen, transport, etc. Electricity, steam and hot water if combustion
Energy needs	Energy may be required for large scale facility	Energy needed for electrical

5.3.3.5 Financial Aspects

Anaerobic Digestion

According to World Bank studies on solid waste management costs (Hoornweg and Thomas ; WB SWM Group, 2010), the estimated costs of anaerobic digestion in Lower Middle Income Countries like Bangladesh is about 20 to 80 USD/t. This estimation includes sale of energy from methane and excludes costs of residue sale and disposal.

Cost of composting plant, excluding the revenues of sale of final compost, is about 10 to 40 Usd/t.

Gas Recovery From Landfill

A sanitary landfill requires a significant initial investment for the equipment, and especially:

- The water treatment system that must respect the standards concerning water release into the environment. This observation is particularly important in dry areas, where the volume of leachate tends to be more important than in dry area, but also in area with special concerns regardingwater management (drinking water, surface and groundwater, coastal areas, etc.)

- The energy recovery system, that may include expensive equipment s uch as purification units

Moreover, the system requires a regular maintenance and qualified technicians to operate and manage the site properly.

Nevertheless, it is commonly admit that this method is the less expensive one in developing country, mainly because it allows to solve in a short term the problem of managing all waste (no sorting required) while producing a high quality gas with multiple possibilities of valorization (power, fuel for transportation and household).

According to the World Bank, the costs of sanitary landfill is estimated at 15 and 40 USD/t. However, other costs and revenues must be taken into considerations, as well as the influence of many factors on the economic aspect. Note that costs of open dumping is evaluated at 3 – 10 USD/t.

5.3.3.6 Advantages & Disadvantages of Non-thermal Conversion

Advantages of the bio-chemical conversion.

Table 22: Advantages of biochemical conversion processes

	General advantages
Common advantages	▪ Reduce pollution from waste and pollution from fossil fuel (reduction of fuel consumption) ▪ Possibility to recover an energy-rich fuel and a nutrient-rich liquid fraction, that are controllable and storable ▪ Production of biofuel (renewable energy) that reduce the fossil fuel dependency
Anaerobic digestion	▪ Cradle to cradle : reliable treatment and valorization of waste without creation of new waste ▪ Possibility to produce compost with the digested waste and diversified the financial income ▪ Small scale facility and possibility to install part of the equipment/structure underground ▪ Reduces solid waste volume and avoid disposal costs
	▪ When no sorting at source, anaerobic digestion will implement a system where non suitable matter (such as plastic, metal, etc.) must be removed from the raw material but will be valorized through recycling and/reuse methods ▪ At small scale, the system requires small technical expertise

Landfill gas recovery	▪ Easiest method when no proper waste management system already implemented and when no sorting at source ▪ Possibility to upgrade unsanitary land fill into sanitary landfill with gas recovery ▪ After shutdown, and if well managed, possibility to redevelop the site

Disadvantages of the biochemical conversion

Table 23: Disadvantages of biochemical conversion

General	
Anaerobic bacteria digestion	▪ Process m ore sensitive, slower and less energy -intense compared to composting ▪ Need to ensure that the residue is not contaminated with hazardous ▪ Require a constant supply of feedstock ▪ Technical skills for operating and maintenance ▪ Waste must be pre- treated (sorting and mechanical preparation) ▪ Process only focused on biodegradable waste ; the other waste must be at least landfilled, or, in a more positive perspective, recycled or reused
Landfill gas recovery	▪ Filled up quickly if waste are not reduced, recycled or reused ▪ Requiring of an important surface area ▪ Cannot be implanted in urban area ▪ Risk of water pollution if the system is not sealed properly/liner is damaged/the waste water system is not operated in such a way as to respect the standards ▪ High costs for high tech landfill ▪ After shutdown, operation, maintenance and monitoring must continue for at least 50 years

6. Action 5: Evaluation of Solutions for Each of The Municipalities

6.1 Objective

This Section aims at determining a ranking of the processes of WtE conversion in each Municipality regarding to the specific requirements of each Process.

The analysis will be performed on the 5 processes that have been studied :
Thermal conversion processes :

- Incineration
- Gasification
- Pyrolysis

Bio-chemical conversion processes :

- Anaerobic Digestion
- Energy recovery from landfill

6.2 Methodology

The Consultant has proceeded in three steps.

6.2.1 Step 1 : Detailed Analysis

According to the technical information collected on each process, the Consultant proposes the following category to perform the analysis :

Table 25 : Categories proposed by the Consultant

N°	Category
C1	Compatibility of waste regarding the requirements
C 2	Compatibility with the current waste management system
C3	Complexity of the process and evaluation regarding the local skills
C4	Compatibility of the possibilities of energy recovery with needs, current uses and existing facilities
C5	Inves tment costs
C6	Environmental, social and economic considerations

6.3 Analysis Per Category

C1 : Compatibility Of Waste Regarding The Requirements

	Incineration	Anaerobic digestion	Gasificatio
Type of waste	All fractions of domestic waste	Biodegradable fractions of domestic waste	▪ Organic waste (biogradable, plastics, paper, textiles, etc.)
Pre-processing	▪ In theo In theory, waste should not be pre-treated but pre-processing may be required if the raw material does not fit to the requirement. ▪ The moisture content ofthewhole Paurashavas are far above the upper limit fixed (50%); the wastes are too wet for being incinerated. ▪ If the incineration is selected anyway, waste has to be dried and/or mixed with drier material.	▪ Waste must be sorted in order to collect the biodegradable fraction at source (small scale facility) or in a sorting unit. ▪ No separation at source is implemented in the Paurashavas and no initiative of this type is currently scheduled by the Municipalities. ▪ For alargescale plant(LSP), shredding & mixingisrequiredto enhance the efficiency of the process. ▪ For a small scale bio-digester (SSP), shredding and mixing is not necessary.	▪ Mixed MSW mustbe sortedin order to exclude inorganicsubstanceslike metal, glass and rocks in a sorting unit. ▪ Mixed MSW must be dried in order to increase its calorific value. ▪ Homogenization and shredding
Climate / Seasonality	▪ The moisture content will probably be higher during the wet season and the waste will be too wet to be incinerated properly. ▪ Especially in the Paurashavas of Cox"s Bazar, Mymensingh and Habiganj.	No significant impact.	▪ Variation in moisture content will cause that different drying practices need to be applied dependent on the humidity of the waste.

	Incineratio	Anaerobic digesti on	Gasificatio
Moisture content	A significant variation (some 40%) is observed in the waste generation from wet season to dry season. ▪ The facility must be designed in such a way as to be able to absorb this surplus of feedstock. The moisture content of waste must be below 50% for the combustion to be operational in satisf actory conditions. ▪ In each Paurashava, the moisture content is above 57%, and as indicated above, the situation may be even worse during the wet season.	▪ A significant variation (some 40%) is observed in the waste generation from wet season to dry season. ▪ The facility must be designed in such a way as to be able to absorb this surplus of feedstock. ▪ Moisture content coherent with requirement of a bio - digester. ▪ The moisture content will have an impact on the type of biodigestor (dry/wet).	▪ A significant variation (some 40%) is observed in the waste generation from wet season to dry season. ▪ The facility must be designed in such a way as to be able to absorb this surplus of feedstock. ▪ The moisture content of waste must be below 50% for the combustion to be operational in satisfactory conditions. ▪ In each Paurashava, the moisture content is above 57%, and as indicated above, the situation may be even worse during the wet season.
C:N ratio	Criterium no relevant for incineration.	▪ C:N ratio must be between 16:1 to 25:1 ▪ No data available for the Paurashavas due to lack of informati on concerning the characterization. ▪ National data show an average composition of 16:1. ▪ Biodigestion is already implemented in ▪ Bangladesh , which proves that waste likely fits to this requirement.	Criterion no relevant for gasification
pH	Criterion no relevant for incineration	▪ pH must be comprised between 6.5 and 7.5 ▪ No data available; a detailed characte rization must be performed to assess (among others) this parameter ▪ pH adjustment required if the pH does not enter this range	Criterion no relevant for gasification

	Incineratio	Anaerobic digestion	Gasificatio
LHV	▪ Annual Average Calorific value must be between 7MJ/kg and 15 MJ/kg, and should never fail under 6 MJ/kg ▪ No data available ; a detailed characterization must be performed to assess (among others) this parameter ▪ National data show an average value of 6 MJ/kg; additionalfuelrequested for maintaining the combustion	Criterion no relevant for anaerobic digestion	▪ Annual Average Calorific value : 7 MJ/kg < CV < 18 MJ/kg ▪ No data available ; a detailed characterization must be performed to assess (among others) this parameter ▪ National data show an average value of 6 MJ/kg ; additional fuel requested for maintaining the combustion
Size vsminimal production	Large scale application only : minimum requirement concerning the tonnage at this entrance in order to guarantee the-cost effectiveness of the installation According to the estimation of waste production (present and forecasted), only Cox's Bazar may respect this lower limit (50kt/y) but only in many years and with the consideration that the forecasting population growing rate will be very high over the next decade (12%). Note that an annual growing rate of 2.8% implies an annual production much lower than the lower limit requested for incineration	Wide range of application; from household level to large scale plants for Cities	▪ Large scale applicati on only : minimum requirement concerning the tonnage at this entrance in order to guarantee the cost cost-effectiveness of the installation

C2: Compatibility With The Current Waste Management System

	Incineratio	Anaerobic digestion	Gasificatio
Impact of collection efficiency And frequency of waste supply	▪ Incineration plants are operated without interruption (despite of maintenance time), and therefore require a constant supply of feedstock to operate in good conditions. ▪ The collection is not efficient in all Paurashavas; and without significant improvement, the collection rate will remain low, jeopardizing the possibility of reaching the minimum supply requ ested. ▪ The frequency of the collection seems quite chaotic and uno rganized in the 6 Municipalities; without significant improvement, constant supply cannot be guaranteed. ▪ a storage platform may be implemented to ensure a constant supply.	▪ SSP: daily supply guaranteed regarding the composition of food waste (unless case of mismanagement). ▪ LSP : constant supply requested ▪ The management system has to evolve in order to ensure the separate collection of biodegradable waste; then, the collection should be on a regular basis. a storage platform may be implemented to ensure a constant supply.	▪ Incineration plants are operated without interruption (despite of maintenance time), and th erefore require a constant supply of feedstock to operate in good conditions. ▪ The collectin is not efficient in all ▪ Paurashavas; and without significant improvement, the collection rate will remain low, jeopardizing the possibility of reaching the minimum supply requested. ▪ The frequency of the collection seems quite chaotic and unorganized in the 6 ▪ Municipalities; without significant improvement, constant supply cannot be guaranteed. a storage platform may be implemented to ensure a constant supply.
Competition with other initiatives	▪ Scavengers may be involved in the recovery of wa ste (dumped in streets) with high calorific value, such as plastic, carton, paper, etc. ▪ The calorific value of waste, already assumed as insufficient, may be even lower. ▪ New management rules to forbid the street recovery by the scavengers will conduct to a significant loss of revenue;	▪ According to the completed questionnaires, composting has not yet been implemented in the selected Paurashavas. ▪ No competition with other initiatives identified so far in the 6 Paurashavas.	▪ Scavengers may be involved in the recovery of waste (dumped in streets) with high calorific value, such as plastic, carton, paper, etc. ▪ The calorific value of waste, already assumed as insufficient, may be even lower. ▪ New management rules to forbid the street recovery by the scavengers will conduct to a significant loss of revenue;

C3: Complexity of The Process and Evaluation Regarding The Local Skills

	Incineratio	Anaerobic digestion	Gasificatio
Complexity of the process	▪ Incineration plants are large scale complex facility with tecinical equipment (incl. process,measuring instruments, monitoringinstrumentsetc.)	▪ SSP : simple process with few technical equipment ▪ LSP: complex facility with technical equipment (incl. process, measuring instruments, monitoring instruments, etc.)	▪ Gasification plants are large scale complex facility with technical equipment (incl. process, measuring instruments, monitoring instruments, etc.)
O&M frequency	▪ Daily technical maintenance and daily/periodic expertise required	▪ Daily technical maintenance and periodic expertise required	▪ Daily technical maintenance and daily/periodic expertise required
Local skills	▪ Engineers and experts will be requested for several aspects of the operation and maintenance daily ▪ Daily tasks may be performed by technician with adequate training ▪ Dinajpur has already an electrical engineer, a mechanical engineer and a civil engineer that may be trained to perform some tasks; additional personnel may however be required ▪ The other Paurashavas mentions skilled but without precision ; it will be assumed that their resources are similar to those of Dinajpur	SSP : managed at household level or ward level by the population, under the control of a technician (control and monitoring) ▪ With proper formation, local personnel (and population) may perform the tasks ▪ LSP: engineers and experts will be requested for certain aspects of the operation and maintenance; daily tasks may be performed by technician with adequate training ▪ Dinajpur has already an electrical engineer, a mechanical engineer and a civil engineer that may be trained to perform some tasks; additional personnel may however be required ▪ The other Paurashavas mentions skilled but without precision ; it will be assumed that their resources are similar to those of Dinajpur	▪ Engineers and experts will be requested for several aspects of the operation and maintenance daily ▪ Daily tasks may be performed by technician with adequate training ▪ Dinajpur has already an electrical engineer, a mechanical engineer and a civil engineer that may be trained to perform some tasks; additional personnel may however be required ▪ The other Paurashavas mentions skilled but without precision ; it will be assumed that their resources are similar to those of Dinajpur

C4 :Compatibility of The Options of Energy Recovery with Needs, Current Uses & Existing Facilities

	Incineratio	Anaerobic digestion	Gasificatio
Type of valorization Compatibility with needs	▪ Incineration produces heat ▪ Through heat exchange with a boiler, energy can be recovered as electricity and/or steam and/or hot water ▪ Apart from Dinajpur, where information was not provided, gas/LND would be preferred for domestic purposes, but also for transport and industry ▪ Incineration does not comply with the domestic needs	▪ Anaerobic digestion produces biogas ▪ Biogas can be used as raw material, but can converted to produce electricity and/or steam ▪ Apart from Dinajpur, where information was not provided, gas/LND would be preferred for domestic purposes, but also for transport and industry ▪ Anaerobic digestion complies with the domestic needs	▪ Gasification produces syngas cleaned and purified syngas can be used for the production of chemicals or as a fuel for electricity production. ▪ Apart from Dinajpur, where information was not provided, gas/LND would be preferred for domestic purposes, but also for transport and industry
Competition with other similar facility/ local market company Local integration	▪ Presence of (or future) Power Plant in the district of Dinajpur (210MW), Cox"s Bazar (6,520MW), Sirajganj (225+414) and Dinajpur (125MW) Connection to the grid : ▪ An injection point will has to be defined in each Paurashava Production ▪ The electricity producedthrough the incinerationplant will benegligible compared to the general consumption of each Paurashava and the current producers (1-2mWcompared to the power installed) Heat and hot water ▪ A specific network will have to be designed to supply the consumer	▪ Each Paurashava is already supplied by ▪ NG (cylinder gas network) SSP ▪ Direct connection from source to consumer LSP Biogas: A Bottling plant will have to be constructed ▪ Electricity : injection point + relevance regarding the current needs and production Heat and hot water ▪ A specific network will have to be designed to supply the consumer	▪ Presence of (or future) Power Plant in the district of Dinajpur (210MW), Cox's Bazar (6,520MW), Sirajganj (225+414) and Dinajpur (125MW) Connection to the grid : ▪ An injection point will has to be defined in each Paurashava Production ▪ The electricity produced through the in cineration plant will be negligible compared to the general consumption of each Paurashava and the current producers

C5: Investment Costs

	Incineratio	Anaerobic digestion	Gasifi
Investment costs	Incineration has the highest unit price per ton of waste	SSP : Medium Investment costs LSP : High Investment costs	Gasification has the lowest unit price per ton of waste

C6: ENVIRONMENTAL, SOCIAL AND ECONOMIC CONSIDERATIONS

	Incineratio	Anaerobic	Gasification
Impact on water	Water is vaporized : no significant impact on water	If no valorization of the digest, water treatment requested In case of mismanagement, possible	Water is vaporized : no significant impact on water
Impact on air	Production of NOx possible : fume treatment is required	Odor if mismanaged	Production of NOx and SOx possible : exhaust treatment is required
Impact on soil	Significansurfacearea required Negative Impact on soil qualityif	Small (SSP) or medium (LSP) surface area required Negative Impact on soil quality if mismanagement	Negative Impact on soil quality if mismanagement
Involvement of the population	No specific involvement apart from awareness for the proper storage of waste	Separation of waste at source	No specific involvement apart from awareness for the proper storage of waste
Job creation / reconversion	Technicians and experts will be required	SSP : job creation limited LSP : technicians and experts will be required	Technicians and experts will be required
Economic costs/revenues of By products	▪ Ashes must be disposed ▪ Fumes must be treated according to the Air Quality Standards	▪ Possibility to combine anaerobic digestion and compost that can be sold on the local market ▪ The digest may be valorized directly as fertilizer (quality standards must allow the spreading of biological fertilizer) ▪ Water may have to be treatment according to the Water Quality Standards for Discharge ▪ Biogas quality must be guarantee and cleaning unit may be requested ▪ A unit may be added to convert the biogas into LNG	▪ Ashes, Tar and other residues must be disposed ▪ Fumes must be treated according to the Air Quality Standards

7. Action 6 : Development of Possible WtE Projects

The objective of this Section is to propose for each Municipality an integrated system that can enhance the waste management and give solutions / guidance for its proper implementation.

During the second Workshop performed in Dhaka (November 2016), the results of the Interim Report have been presented, leading to a discussion with the different stakeholders on the objectives of the final report. It has been decided that this deliverable should present guidelines to support Municipalities in the development of a Pilot "Environmental Park" that integrate Waste treatment and valorization methods, but that will also promote sustainable development by proposing the use of alternative sources of energy and by ensuring Environmental and Human protection.

For that purpose, the background data will be first reminded. Then, the Consultant will present concepts and basic designs of an "Environmental Park", including a cost benefit analysis of the installation. Information will be given on the O & M requirements and management aspects. Environmental and social impacts will also be addressed, as well as the regulation aspects that will frame the development of such facility. Finally, recommendations in terms of capacity building of local authorities and awareness rising of the population will be presented.

7.1 General Concept

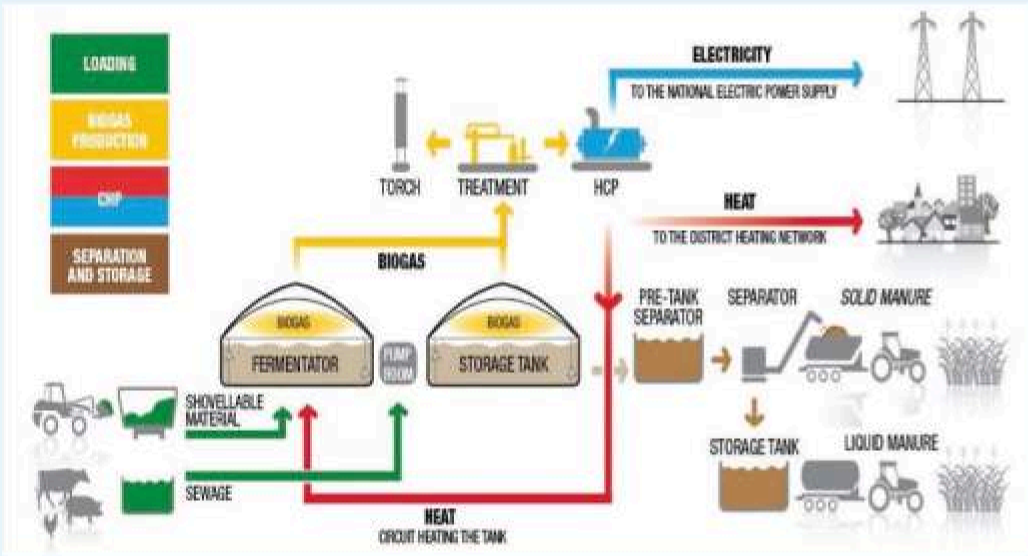
7.1.1 Modular Design 1 : Anaerobic Digestion + Recylcing + Composting.

The concept of the proposed biogas plant will not only cover the treatment of the organic municipal solid waste, but will also present additional modules that can be added to the site to treat the other waste. Indeed, the proposed technique aims at the transfer of waste streams into valuable and marketable output products, such as organic fertilizer and energy (heat, gas and/or electricity).

In general, a biogas plant is composed of following sub-elements:

- Reception hall and pretreatment;
- Anaerobic digestion of the organic fraction
- Biogas production and treatment;
- Combined heat and power units (CHP).
- Treatment of digestate and mixing with green waste;
- Aerobic composting plant with hygienization and curing;
- After-treatment and refining of the compost to fertilizer fractions;
- Utilities: biofilter – water treatment – energy & control.

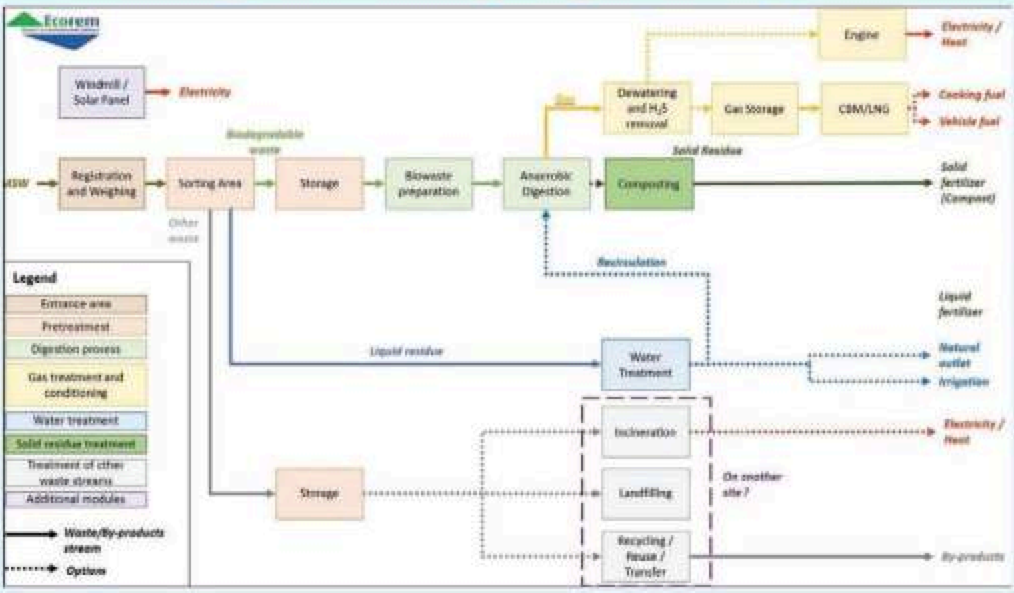
Figure 31 : Anaerobic process and valorization options



The sections hereafter will present in detail the different parts of the plant, according to the Flow Scheme shown in Figure 31.

Details of specific equipment will further be given in each Section presented below.

Figure 32 : Process flow chart – Possible options for the development of an integrated waste management system with WtE process



7.1.1.1 Collection

Waste collection is a key element for the management of an integrated and efficient system; it aims at:

- Maintaining cleanliness and hygiene in the different wards
- Guaranteeing the regular supply of the Waste Treatment Facilities in order to ensure the performance and cost-effectiveness of the installations

It represents an important challenge for Bangladesh, for both the Population and the Local Authorities. Although no official records are available, observations on the field show that the collection rate is quite low (average 55%), leading to environmental and social issues.

Waste collection at source is the best system for optimizing recycling and reuse but its management by local authorities /a single entity is much more complex and requires a strong and perfectly managed logistic. In a certain way, however, a sort of separation at the source already takes place since informal collectors ensure the collection of certain valuable materials such as plastic, paper, metal, etc., for wholesalers (or sometimes directly to industries).

Considering the current difficulties for waste management faced by each Municipality, it is proposed to focus on the development of a performant centralized system for which the different elements of the collection (itinerary, collection period, equipment, integration of scavengers, etc.) must be, rethought' and integrated into the present system. In this option, sorting will be performed directly in the Waste Treatment Site in a Sorting hall (see Section below).

This centralized approach should not however prevent pilot and progressive initiatives for separate collection of some waste fractions (glass?) in wards in which the population shows an important involvement.

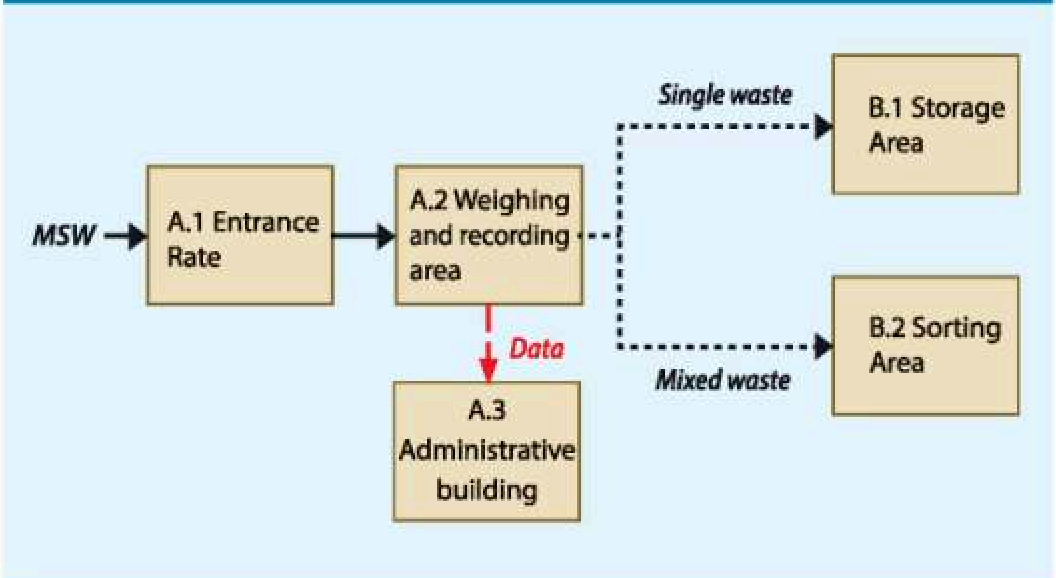
This system will take into consideration also the informal waste pickers and middle men already involved in waste collection by integrating them into the new system. Because it seems that informal sector is more profitable than the official one, it will be necessary to resize the whole system to support formal work. This will allow a better control of the system and costs by local authorities.

7.1.1.2 Entrance Area

The input area is considered as a transition zone which should provide several functions :

- Control of waste streams entering the plant
- Recording of waste
- Management of the site

Figure 33: Flow chart - Entrance area



A.1 Access Gate

This function can be ensured by an automatic barrier or by the presence of a guard. The objective is to protect the infrastructure by limiting the access to the personnel of the plant and the collection trucks.

Note that appropriate closure (fence) of the site will also be needed.

A. 2 Registration and Weighing Zones

The importance of data collection and management has been highlighted along the different phases of the Study. They make it possible enhancing the management of the facilities, forecasting their extension, defining new means of valorization, etc.

As such, the entrance area should include a recording zone, where trucks/rickshaws will be weighed. Preference must be given to a double bridge; the first allowing the weighing of the incoming trucks (loaded) and the second the weighing of the outgoing trucks (unloaded). The difference between both measures will give the exact weigh of waste in the truck. This system must be linked to a data base managed from the administration.

This system will make the incoming and outgoing traffic on the installation more fluid: it is highly likely that the collection will take place over a reduced time slot and that consequently the arrival of trucks on site will not take place on the whole day but on shorter time periods. It is therefore necessary to provide a system which avoids waiting for trucks entering the site.

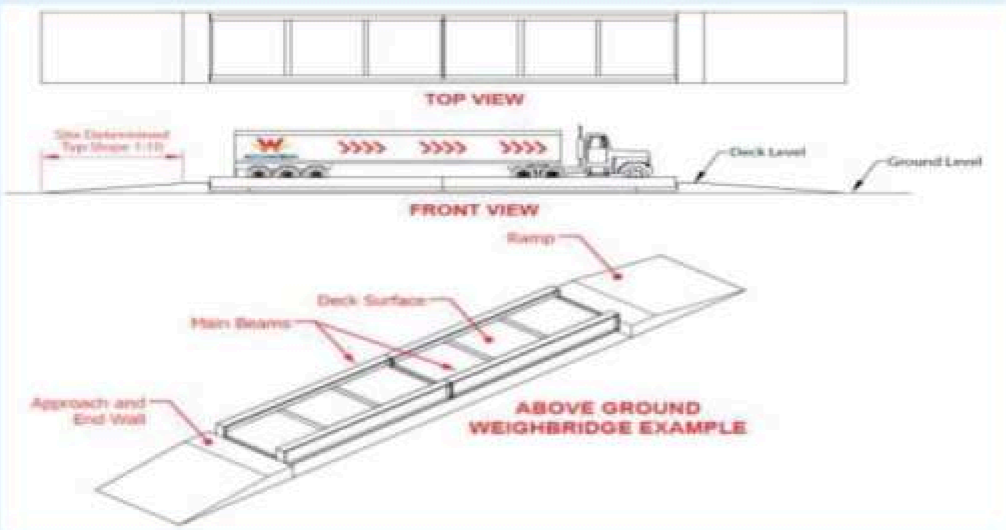
Visual inspections must be performed (and results recorded) on the incoming truck loads in order to collect information such as the type and origin of the waste, etc. .

A preliminary sorting will be done at this step:

Figure 34 : Weighbridge – Source (Accuweigh)

- The incoming load is composed of one single waste fraction such as plastic, inert, glass, etc. : the load will be directly directed to the dedicated storage area.
- The incoming load is composed of mixed waste : the load will be directed to the acceptance area' preceding the sorting area

Figure 35 : Technical view of Weighbridge



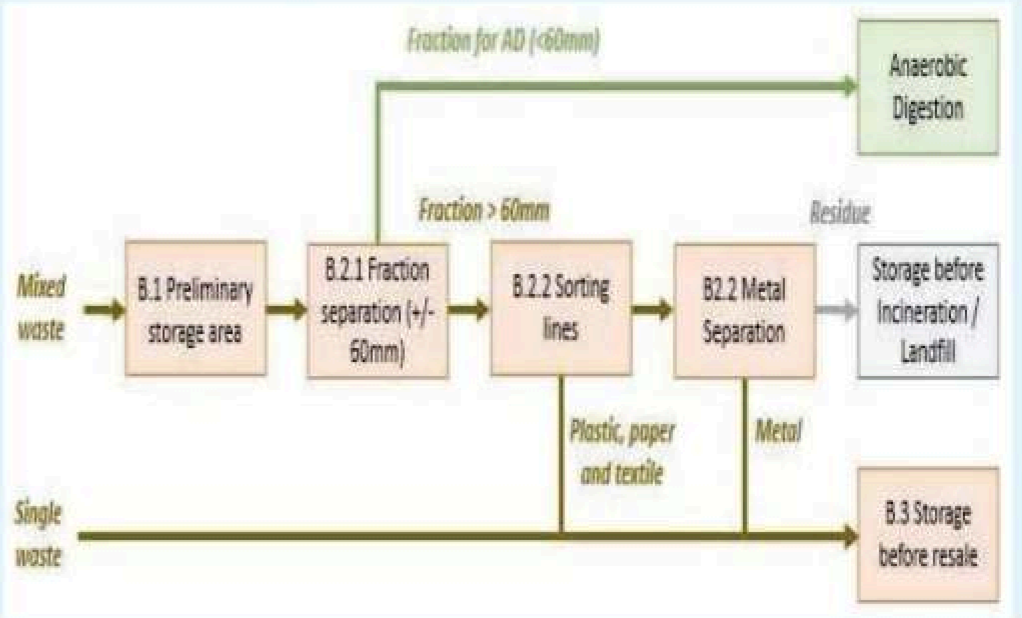
A.3 Administrative Zone

The administrative zone will be the focal point for ensuring the site management. It should include at least an office for the administrative personnel, parking space, but also cloakrooms with showers for field workers and a prayer room.

7.1.1.3 Pretreatment

Pretreatment is a critical step in the development of Waste-to-Energy technologies, and especially in the case of anaerobic digestion for which feedstock should be only composed of organic waste. Because this site is a pilot Project for promoting Waste-to-Energy and Waste-to-Resource, the site will propose options to recover valuable material such as plastic and paper but also processes to retrieve the organic matter necessary for

Figure 36 : Flow Chart - Pretreatment



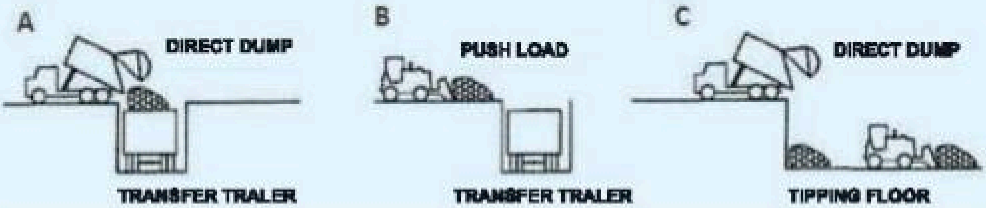
B.1 Preliminary Storage Of Mixed Waste

Most of the time, waste entering the site will be mixed. In order to recover valuable material, a sorting phase will be necessary. Prior to this operation, incoming trucks/rickshaws will have to unload the waste into a preliminary storage area that will be used as a buffer area for feeding the sorting line. The unloading area may be situated outside the covered warehouse that includes the dumping area and the storage area. However, in order to prevent rainwater infiltration in the waste, this unloaded area should be covered and a rainwater harvesting system will have to be designed.

In the design, it is important to remember that this unloading ramp must be wide enough to allow several trucks to unload at the same time.

Several options of dumping area can be developed, as shown below :

Figure 37 : Options for preliminary storage of mixed waste



A : Direct transfer in a trailer /
B : Tipping floor and transfer via Bulldozer in the trailer /
C : Direct dumping on a reception pit and transfer via a Bulldozer in the conveyor belt

However, it is most likely that mixed waste entering the Treatment Site will be very wet and will already contain leachate. In order to make the sorting step easy, it is necessary to evacuate as much water as possible when the waste will be unloaded from the trucks. As the consequence, preference will be given to option C.

In the dumping zone and in the preliminary storage zone, a leachate collection system will be designed on the tipping floor to evacuate as much water as possible. We consider that about 20% of the waste mass is composed of water that can be directly evacuated through a collection system.

Two systems may be implemented.

System 1 : Bunker with slope
In this system, running water from waste will be collected at the low point of the bunker by a pipe.

Figure 38 : Principle of leachate evacuation - Slope

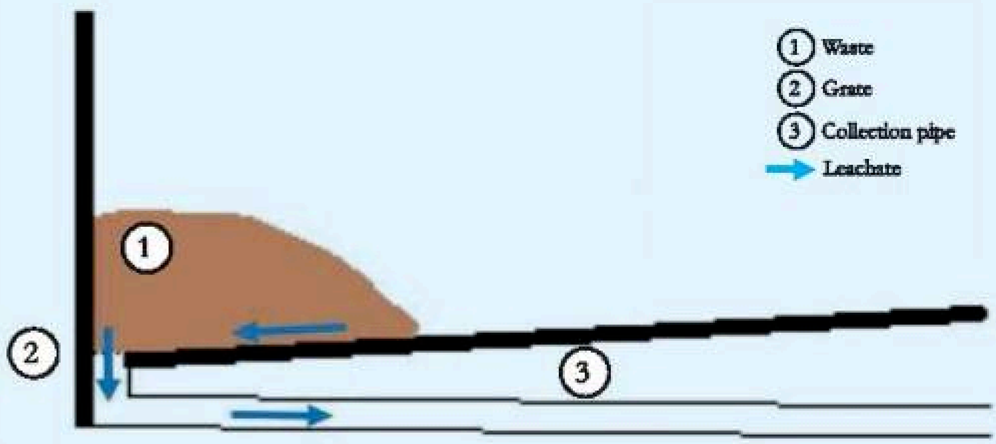


Table 27 : Advantages and drawbacks of perforated Floor Systems

Advantage	Drawback
▪ Multiplication of evacuation points ▪ Evacuation possible even if clogging of few grates	▪ Regular maintenance through pressurized water systems ▪ Possible stagnation of water between two grates

Because of the humidity of waste, especially during wet season, the second system seems more adapted to the local situation and will evacuate a larger water flow. Note that for the following design, we will consider that 20% of the waste mass will be composed by water.

The waste will then be moved to a temporary storage area via a loader. The use of this specific equipment is interesting in such a context because it can be used in different places of the Waste Treatment Site, which enable to increase its efficiency and to make it cost-effective.

Figure 39 : Wheel Loader with Waste Handling Package

Source (Case Construction) A specific attention will be made on the height of the building; indeed, the size should be sufficient for the Loader to perform its tasks safely. As a consequence, a minimum of 4.5m will be necessary.

Note that this temporary storage zone should be situated in a (naturally or forced) ventilated warehouse for the comfort and safety of the workers. Moreover, fog systems may be added in the storage area to limit dust.

Note that an operator will be requested. However, because this operation will not stand the whole day, this operator may be affected to other tasks onsite.

B.2 Sorting Hall

The workshop n°2 has highlighted the wish of the stakeholders to develop recycling and circular economy in Bangladesh. As such, this demonstration plant aims at showing the possibility in terms of waste recycling. This is important because these materials have a market value and can be used as a means of recovering the costs of O&M.

Moreover, the anaerobic digestion process requires a biodegradable feedstock; it is thus important to remove as much as possible unwanted material prior to enter the bioreactor, such as plastics, metal, etc.

As shown on the Figure 38, the sorting process will generate three outputs:

- The feedstock for the bioreactor (Biodegradable waste + other material)
- The by-products with a potential of valorization (plastic, metal, etc.)
- The remaining fraction for incineration or landfilling

Note that it will be considered that the operation will be conducted 6 days over 7 whereas the production of waste is 7 days a week. This means that the quantity of waste generated in 7 days will be treated in 6 days.

B.2.1 Recovery of Organic Matter

The first step will consist in recovering the organic fraction contained in the mixed waste entering the process. Because the size of organic fraction is mainly below 60mm/40mm, a screening will be done to recover the material below this fraction for feeding the anaerobic digestion.

The waste will be loaded in a fraction separator. Preference will be given to a mobile drum sieve with removable grids of different screening fraction (e.g 40mm/60mm). The operating capacity of such equipment is between 30 and 80 m^3/h.

Figure 46 : Mobile drum sieve – Source (EMS Equipment)

Preference is, another time, given to mobile equipment: this modularity is important because it will be possible to use the machine in different places and for other usages such as sieving the compost. Moreover, this equipment has the capacity to pierce the bags and thus to increase the potential for recovery of organic matter.

Through this first separation, some 50% and 70% of the organic fraction will therefore be recovered, as such as about 10% of the other fractions.

B.2.2 Sorting lines
According to field data, there is a local market for recyclable material.

Table 25 : Local market prices for recyclable material - Source (Waste Concern 2013)

Recyclable material	Mymensingh	Sirajganj	Cox's Bazar	Habiganj	Dinajpur	Jessore
	Tk/kg	Tk/kg	Tk/kg	Tk/kg	Tk/kg	Tk/kg
Plastic	21-24.00	19-	22-25.00	22-23.00	18-	24-26.00
Paper	17-20.00	17-	14-16.00	15-17.00	14-	18-20.00
Glass	20-21.00	18-	18-19.00	19-20.00	18-	20-22.00
Metal	35-40.00	32-	34-38.00	33-37.00	31-	34-39.00
Other (item) *	15-17.00	11-	15-16.00	12-15.00	11-	14-18.00

** Textile may be included in "Other" ; however, because textile is often collected in City with textile industries, the inferior value will be decreased to 10 TK.*

According to good practices and field feedback, the most suitable material to be recovered from this type of collect (mixed waste instead of sorting at the source) are plastic, paper and metal. Regarding the Bangladesh context, textile may also be recovered for alternative uses (combustible, etc.).

Glass recovery is very difficult without an effective separation at source. The valorization of glass requires a perfect separation between colored glasses and white glasses; however, glass utensils will be broken before arriving on the sorting chain. Therefore, it will not be possible to recover a good quantity of perfectly separated glass. Moreover, the handling of broken glass is highly risky for manual workers; it is therefore not advisable to carry out their recovery on the sorting tape.

According to practical experience, the following recovery rate will be considered for the preliminary design :

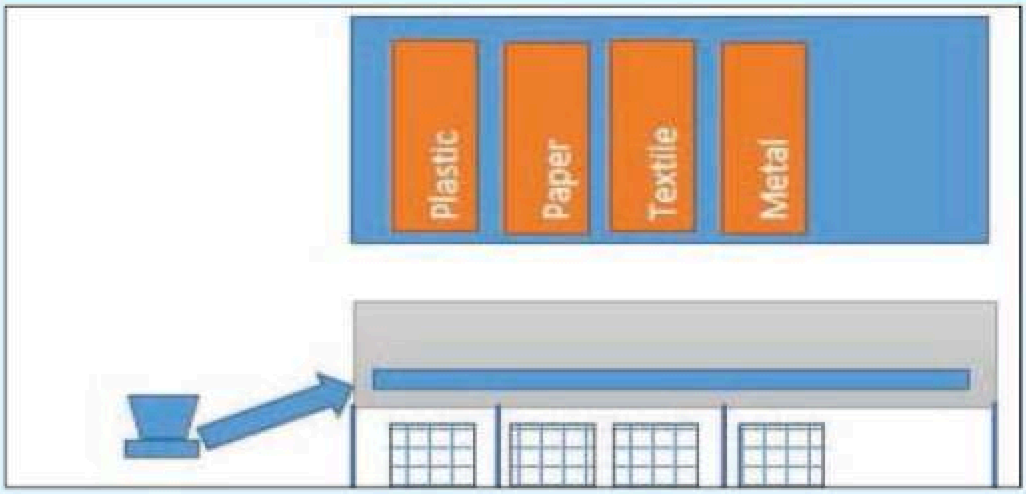
Table 26: Typical recovery rate of recyclable material

Technical parameters	Unit	Value
Recovery rate for plastic	%	50%
Recovery rate for paper	%	40%
Recov ery rate for textile	%	75%
Recovery rate for metal	%	80%

Note that a detailed analysis of the waste stream and the assessment of the valorization needs to be performed in perfect collaboration with the local authorities and the other sectors (industry, services, agriculture, etc.) in order to determine which waste has to be considered as valuable.

After passing the drum sieve, the fraction of waste (>60mm) will be transported through conveyor belts and sorted manually or automatically. Considering the social and economic aspects (employment) on one hand and the investment, operation and maintenance aspects (complexity of equipment, automation requirements, etc.) on the other hand, preference may be given to manual sorting.

Figure 41 : Sketch of the sorting line principle



In order to increase the efficiency of the sorting, some measures can be proposed:

- Two workers per type of waste
- Maximal height of waste of 20 cm

Hereafter are presented some characteristics of such conveyor.

Table 30 : Example of design parameters

Technical parameters	Unit	Value
Speed max	m/s	0.25
Speed min	m/s	0.1
Width of the conveyor belt	m	0.8 -
Max Height of waste	m	0.2

The type of conveyor will result in a compromise between optimal height of waste and maximal width in order to increase the efficiency of the sorting and the comfort of the workers.

The sorting hall can be a permanent building (in this option, the building must be closed and passive vented to control dust and odor) or composed of prefabricated modules in which the sorting lines are integrated and mounted on top of removable containers which allows the temporary storage of recyclable materials before their transfer.

Note that for maintenance reason, a minimum of two lines may be planned. Waste are then stored in specific containers before transfer to the storage area.

Figure 42 : Manual sorting (FCC Environment CE)
Automatic aeraulic separator

(Vauché) Depending on the reqirements, the sorting hall may also contain :

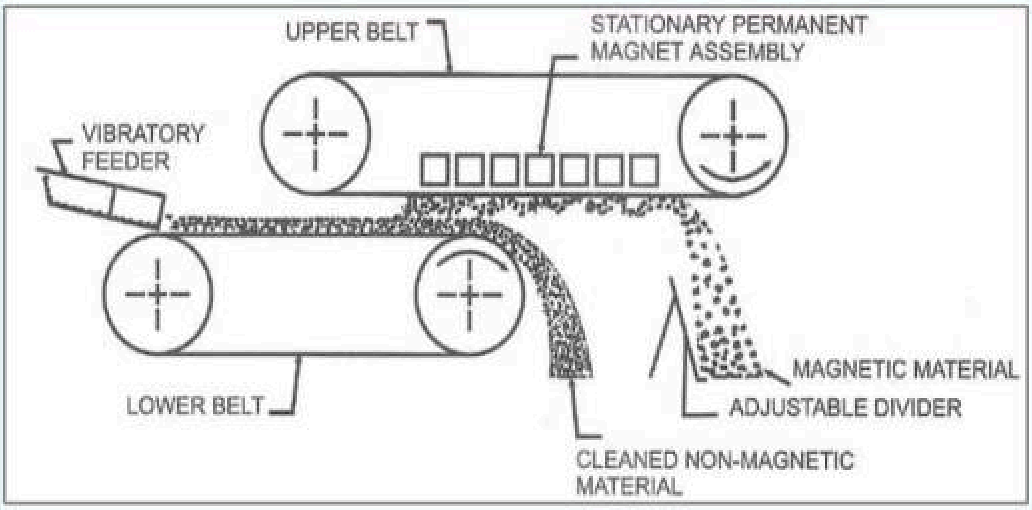
- Lines for preliminary preparation of recyclable waste (pressing, packing, etc.) before transfer to valorizing companies

- Lines for compaction of non-recyclable waste before transfer to their final destination (incineration, landfill, etc.)

B.2.3 Metal separation

A magnetic separator is necessary to remove all metallic elements (mainly ferrous component) and thus prevent contamination of bio-waste and degradation of the equipment.

Figure 43 : Principle of Magnetic separator – Source (Jupiter Magnetics) A recovery rate of 80% will be considered.



B.3 Storage Area

The collection area aims at storing the separated waste streams before treatment or transfer to other sites.

Figure 44 : Example of storage area

Storing zone can be composed of open air boxes or boxes under roofs. Considering the meteorological conditions in Bangladesh, and especially heavy rains, it is recommended to systematically use storage under roofs and to design an independent system for rainwater harvesting.

Note that depending on the type of waste considered and the storage time, waste can be disposed directly on the ground (inert) or in containers (paper).

Figure 46 : Boxes in open-air and under roof - Source IMOG

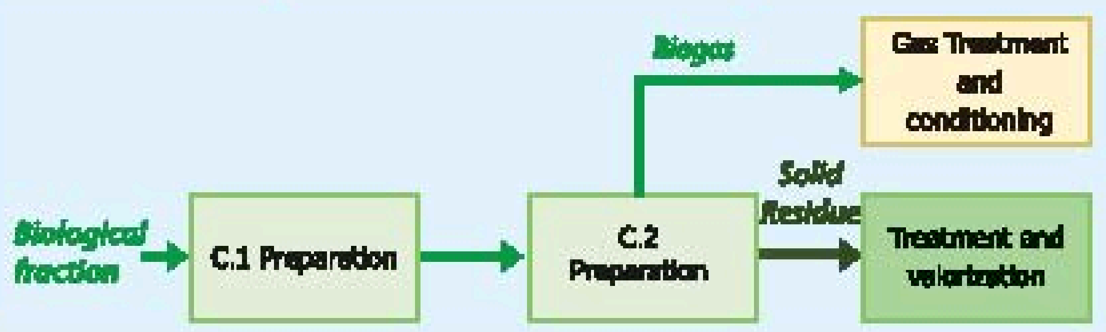
Special attention should be given to environmental issues, and especially regarding water management for leachate and rainwater.

Temporary storage areas have three main roles :

- Ensuring a continuous supply of the facility: waste production evolves with the periods of the year. Besides, it is strongly related to the collection efficiency that represents presently quite a challenge in Bangladesh. Although the facility will propose some kind of modularity, it can be necessary to have an area where feedstock can be stored in order to guarantee a constant supply of the facility throughout the year.

- Storing waste during maintenance of treatment infrastructure; during day-off, technical issues or maintenance periods of the infrastructure, it will not be possible to treat the amount of waste the installation was designed for. As a consequence, it is necessary to have buffer areas to store waste until the installation recovers its full capacity.
- Ensuring the separation of the waste stream before valorization: Because the sorting unit will generate many different waste stream, it will be necessary, after sorting, to store these streams before transfer to their final destination (valorizing companies, final disposal sites, etc.

Figure 47 : Flow Chart - Anaerobic Digestion

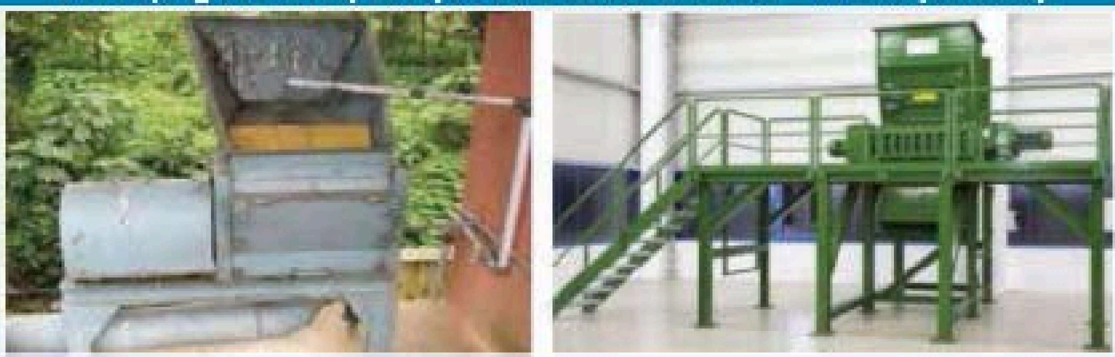


C.1 Biowaste Preparation

Reducing the size of particles and mixing the biological waste are at utmost importance: The more homogeneous the waste are, the more efficient the digestion will be because it increase the surface available for the bacteria to perform the degradation of biodegradable waste. Indeed, it is important to have as much as possible the same technical parameters (pH, humidity, composition, T°C etc.). As a consequence, the feedstock must be "prepared" (mixing and shredding) before the mixture being pumped and transferred into the bio digester.

Different equipment can be used for this purpose, from the simplest (manual mincing) to the most complex (power driven grinders). It is important to keep in mind that even if pretreatment is energy and labor intensive, this step is fundamental to ensure the performance of the further AD process.

Figure 48 : Mixing machine – Source (Anaerobic Digestion of Bio-waste in Developing Countries, 2014) / Power driven shredder – Source (Bonartic)



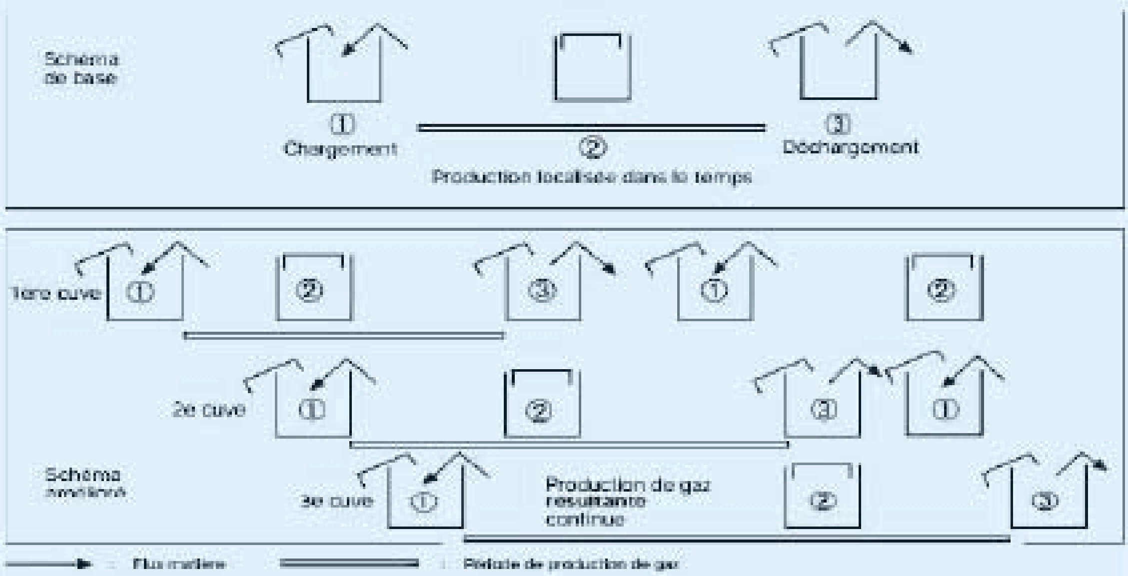
C.2 Anaerobic Digestion

Three types of anaerobic digesters can be used for waste treatment:

- **Dry discontinuous systems**
- **Dry continuous systems**
- **Wet Continuous**

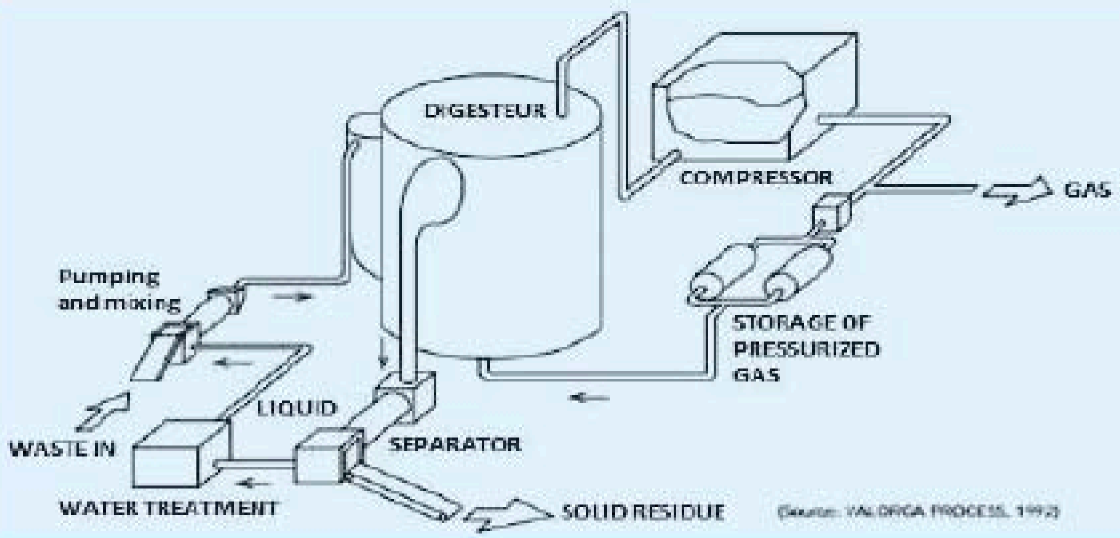
Systems : Dry batch systems

Figure 49 : Dry Batch system in series



(PACER, 1993) Dry continuous systems

Figure 50 : Plug flow reactor (continuous feeding)



Humid systems refer to a humidity of about 20-35%. This type of system are generally used for feedstock such as the biodegradable fraction of municipal solid ; waste wet processes being mostly developed for liquid waste like sludge from water treatment (dry matter content < 10%).

Therefore, dry systems are more adapted for municipal solid waste.

The proposed bioreactor will be designed as a rectangular concrete tank with:

- mixing devices to make the mixture homogeneous
- System for avoiding dead zone into the

Reactor Its technical parameters are given below.

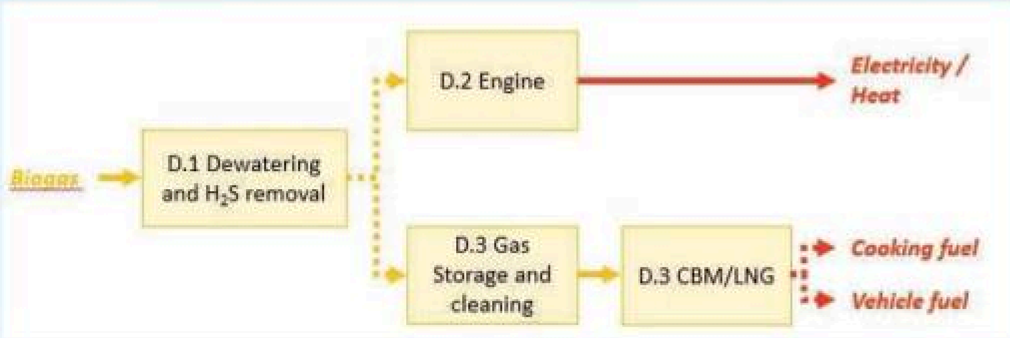
Table 31 : Reactor design parameters

Technical parameters	Unit	Value
Retention time	d	20
Correction factor	%	10
Type of storage	-	tank
Operational volume		
Width	m	5,6 or
Height	m	= width
Additional height for biogas		
Additional height	m	1

7.1.1.5. Cleaning and Conditioning of Biogas

The produced biogas can be used for multiple purposes. In the majority of the cases the biogas will be combusted in a co-generator which will produce electricity (for sale) and heat. The heat can be used in the own anaerobic digestion process. Depending on the local market situation, it can be profitable to store the biogas (after purification) in small gas containers as CBM (Compressed Bio Methane) or CNG (Compressed Natural gas). The CNG containers can be sold to household for cooking and heating purposes.

Figure 51 : Flow chart - Gas cleaning and valorization

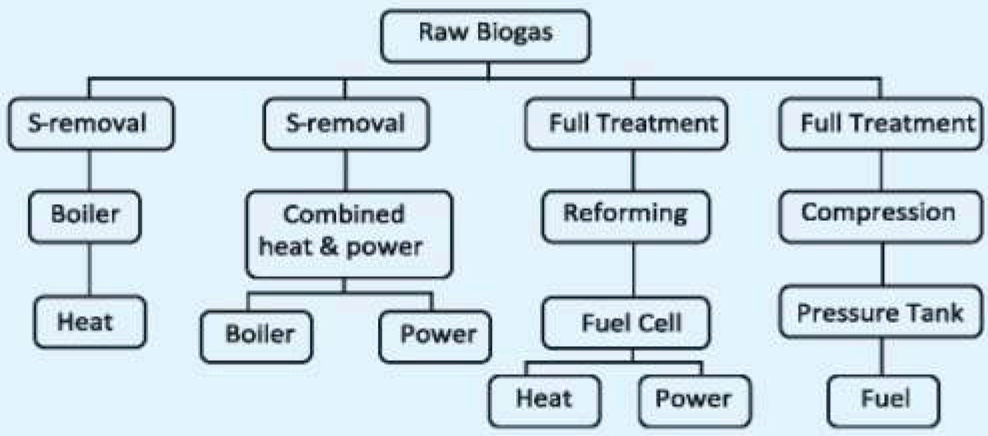


Details on both solutions are presented below, as such as the necessary treatment before use.

D.1 Cleaning

Anaerobic digestion produces biogas composed of approximatively 60% of methane and 40% of CO_2. However, it is also saturated with water vapor and may contain varying quantities of corrosive and toxic compounds such as H_2S. Depending on the use of the biogas, some of these fractions must be removed.

Figure 52 : Alternative biogas utilization and required cleanup – Source (Anaerobic Digestion : Biogas utilization and cleanup)



Water Removal

When leaving the digester, biogas is saturated with water vapor. However, water vapor can damage the system because of its corrosive properties; moreover, the condensation of vapor may lead to pipes clogging. Therefore, a condensation separator has to be installed at the lowest point of the pipeline in order to drain off the condensate.

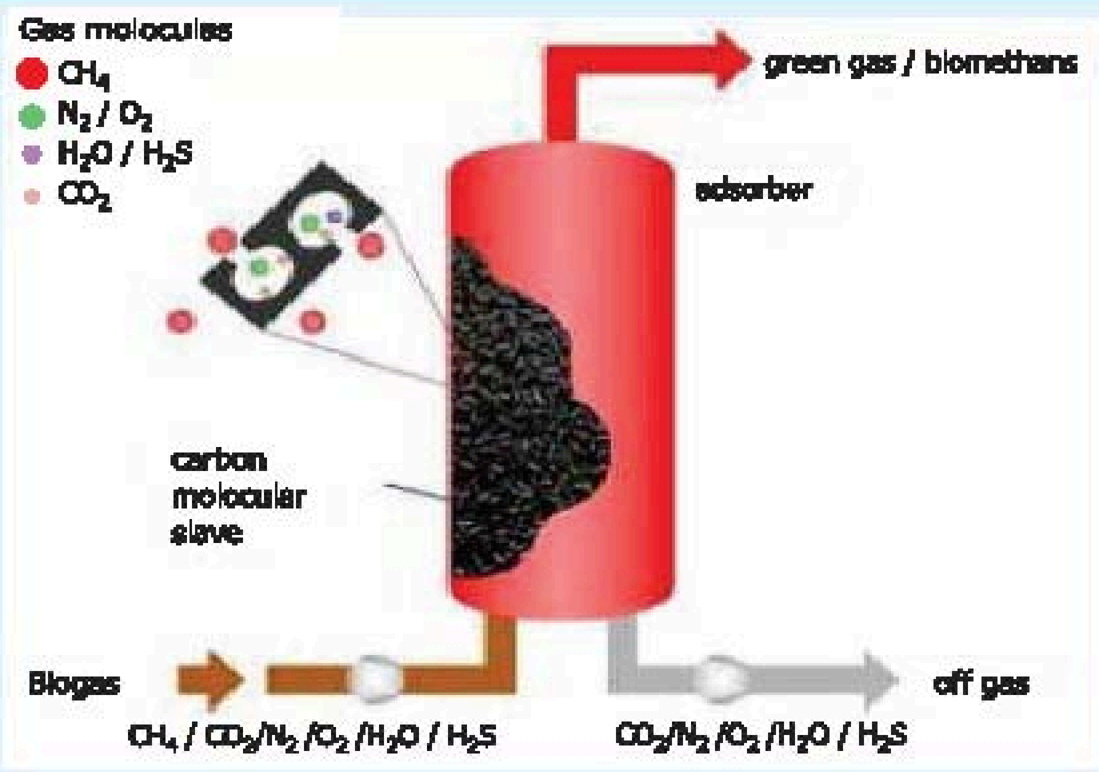
H_2S removal

It is important to clean biogas from H_2S, because of its toxic and corrosive properties. Hydrogen sulfide can be converted into sulfuric acid which causes substantial damages to the processing equipment by corrosion of metal. A biogas cleanup process must be added at the outlet of the bio digester or directly into the bio digester. Desulphurization of biogas can be performed by chemical treatment (iron salt treatment) as well as by biological treatment (addition of O_2 into the bio digester/storage tank, bio filter). According to practical experience all over the world, biological cleanup is very efficient even with small amount of H_2S, while capital costs for biological treatments of biogas are moderate and operational costs are low (S. Zafar, 2015). On the contrary, operational costs of chemical treatments may be important due to the costs of iron salt. However, this treatment does not require complex equipment as the only investment is for chemical storage tanks and dosing pumps.

Further treatments

When biogas production aims at producing vehicle fuel, it is important to increase the energy content of biogas and remove all components that can damages engines/equipment. Therefore, biogas cleaning systems are required, such as Pressure Swing System (PSA) that aims at absorbing CO_2, N_2 and O_2 onto the surface of the media of the adsorption filter.

Figure 53 : Principle of PSA technology – Source (S. Zafar, 2015)



CO_2 can also be removed by bubbling the gas through a mixture of water and alkaline chemical (Anaerobic Digestion of Bio-waste in Developing Countries, 2014).

It should be noticed that Biogas Upgradation Systems are expensive and quite complex, but they are absolutely necessary for the production of high quality bio methane.

D.2 Electricity Production

After desulphurization and dehumidification, biogas can be converted into power. In Europe, biogas is mainly valorized through cogeneration process with a gas engine.

Biogas has a high energy content, about 5.5 kWh/m³, and is perfectly suited for application in a biogas engine that generates electricity. The heat is also being recuperated and maximally re-applied in the process.

The most efficient way for biogas to energy conversion is the Block Type Thermal Power Station (BTTPS).

The following criteria will be met:

- The operation is automatic and happens individually per engine and for the overall supervision by the Distributed Control System (DCS);
- They will generate electricity on a level of 6,6 kV for a design cost of 0.8;
- The container or room is separated in at least two compartments; engine and utilities for water and oil : the electrical and control part; Each unit is to foresee in its own cooling on oil, turbo compressor, intercooler, engine jacket with an outdoor cooling. All water circuits are designed to safeguard the correct technical operation of the engine in an "own" mode, as well as in a connected mode to the external users. The coolers being correctly designed in the local weather conditions, no load decreasing due to outside temperature is allowed;
- Refreshing the oil is done in a continuous way without stopping the engine;
- Fresh air for the engine is filtered carefully in a dedicated filtering unit that is equipped for fine dust, with a pressure drop detection and easy to service;
- During operation all technical and legal requirements to noise, vibration and emissions are being met;
- Emission of the engine will be: CO < 700 mg/Nm^3, NOx < 550 mg/Nm^3 at reference 5% of O_2;
- Exhaust gases may be cooled with a dedicated cooler when the process needs the heat. In any case there will be a noise attenuator installed on the exhaust gases to meet the local requirements;
- On the electrical side the generators are protected with a synchrocheck (full adjustable), a vector jump function as well as rock-off (df/dt, dU/dt), further all the standard generator protections apply;
- The generators are suited to make a fault ride on the grid of U<0,65 Un for 2 seconds but release for external short circuits after 250 ms;
- When the signal "island-mode" comes from the turbine generator set, all biogas engines turn off immediately.

The availability of each motor is >94%, being in nominal working condition. In addition, typical features and efficiency of gas engine are provided below :

Table 32 : Features of gas engine Source (Valorisation électrique et thermique du biogas de méthanisation, 2008)

Features	
Techniques	4-cycle engine operating in learn burn mode
Power range	20 – 2,000 kWel
Rotation speed	1,000 – 1,500 tr/min
Outlet temperature	350°C – 500°C
Lambda Coefficient	1.45 – 1.6
Alternator	Synchronous
Minimal part of CH_4 into biogas	Min. 40%
Pressure	100 mbar
Efficiency	
Electric Power	20 – 2,000 kWel
Heat recovery	30 – 2,500 kWth
Electric efficiency	34% - 42%
Heat efficiency	40% – 50%
Total Efficiency	75% – 90%

The power of the engine will be chosen in order to :

- Ensure a sufficient production for covering the internal need of power of the site
- Limit the volume required for gas storage

D.4 Biofuel Production

The remaining part of biogas that has not been used in the engine can be converted into biofuel. Treatment and storage before conversion

Biogas production depends on feeding patterns (continuous vs batch); but it is theoretically produced day and night. As a consequence, storage facilities should be developed in order to collect the produced biogas pending its use or conversion into heat and/or electricity.

The main advantage of biogas is that it can be produced and stored without losing its energy content. However, if not compressed, biogas production will require large storage volume and thus significant surface areas, as its energy content per m³ is quite low.

Gas storage units can be composed of flexible structures (as shown on Figure 56) or rigid ones.

Besides, storage systems can be directly integrated to the anaerobic digester (Internal Biogas Storage Tank) or placed separately after the reactor (External Biogas Holders).

Figure 54 : Flexible gasholder and compressor– Source (GtS) Storage systems can be classified in three main types depending on the pressure.

Low pressure systems like flexible inflatable fabric are the least expensive and most trouble-free gas holders; they are commonly used in combination with plug-flow and complete-mix digesters. Another advantage of this system is that it is not sensitive to H_2S. The design of this type of gas storage unit is related to the gas production yield and the rate of biogas usage. The capacity of such gasholder is between 50 and 5,500m^3.

Typical pressures in medium-pressure storage are between 2 and 2,000 psi. Biogas is thus compressed before being store into the tank. Besides, because of the risks of corrosion of the processing equipment, H_2S must be removed (seenext section).

The third type of storage system is high-pressured (2,000 to 5,000 psi) which is mainly used to produce vehicle fuel. However, prior its storage and its use, biogas must be upgraded to biomethane by removing CO_2, H_2S, moisture and other unwanted components.

Conversion into biofuel

Depending on the requirement of the beneficiary, biogas will also be marketed by compressing into small containers. In some cases the market value of this portable containers for cooking purposes can be profitable.

To consider the storage and compression of biogas to sell it in containers on the local market following consideration should be made:

- Final use (heating, cooking, vehicle fuel, etc.);
- Needed volume per container;
- Removal of carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and water vapor
- (H_2O) is very important to increase the caloric value of the biogas, which give it an higher market value;
- Selling price and local demand.

Biogas can be stored for on-farm uses or closely located industrial use (e.g. direct heat production) or as temporarily storage. Depending on the use of the biogas, the biogas can be stored and compressed as:

- Low-Pressure Storage of Biogas;
- Medium-Pressure Storage of Cleaned Biogas.

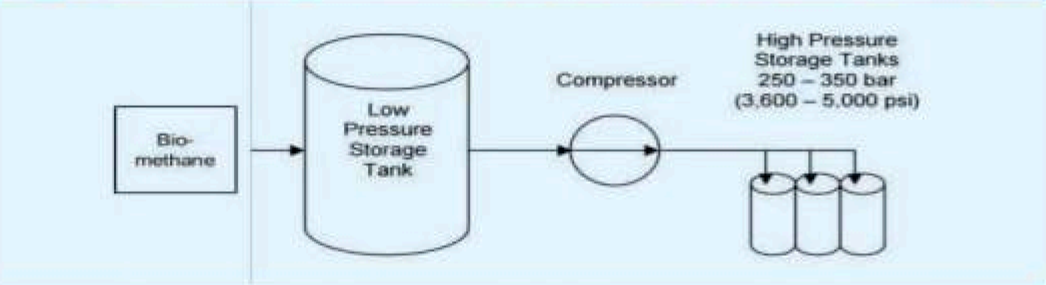
To enlarge the caloric value of the biofuel, methane can be extracted from the biogas. Bio-methane is less corrosive and is potentially more valuable as a fuel. The bio-methane can be stored and compressed as:

- High-Pressure Storage of Compressed Bio-methane (e.g. cooking fuel);
- Storage of Liquefied Bio-methane (e.g. car fuel).

In developing regions there is a high demand of household used gas, especially for cooking purposes. For this purpose the High-Pressure Storage of Compressed Bio-methane (CBM) could be a very useful end product.

As CBM, gas scrubbing is even more important because impurities such as H_2S and water are very likely to condense and cause corrosion. The gas is stored in steel cylinders, of which the volume can depend of the purpose. The cost of compressing gas to high pressures between 2,000 and 5,000 psi is much greater than the cost of compressing gas for medium-pressure storage. Because of these high costs, the biogas is typically upgraded to bio-methane, a more valuable product, and prior to compression. Compression to 2,000 psi requires nearly 49.5 kWh per 100 m^3 of bio-methane. If the biogas is upgraded to 97% methane and the assumed heat rate is 12,000 Btu/kWh, the energy needed for compression amounts to 17% of the energy content of the gas.

Figure 55 : Schematic presentation of onsite system for compressed biomethane



Biomethane can also be stored as Liquefied BioMethane (LBM). Through this system, biomethane can be easily transported. However, the price of such a system is quite important because of the costs for compression (S. Zafar, 2015).

Figure 56 : Biogas treatment and liquefaction unit – Source (GPP ® 4T system - GtS)

7.1.1.5 Treatment and Valorization of Digestate

Anaerobic digestion produces biogas but also a liquid slurry called digestate. This high moisture content residue is mainly composed of organic matter that has not been degraded by bacteria during the process. Due to its composition and the national regulation on waste water discharge into surface water, it is likely that the digestate cannot be released into the environment without treatment.

However, digestate has interesting properties (organic matter, nitrogen and phosphorus-rich substance, etc.), and can thus be used to produce valuable by-products, such as fertilizer.

One of the options for digestate valorization is to use directly this liquid slurry as fertilizer on field. Two factors will influence this way of recovery:

- Legislation on soil protection, which may allowed or banned digestate spreading
- Proximity of the spreading areas with the biogas plant (transport limitation)

It is important to keep in mind that anaerobic digestion does not ensure hygienization of the digestate (temperature too low). As a consequence, many pathogens still remains in this fluid. Storage in open air ponds is a technique used to reduce the number of pathogens but its efficiency is relative and does not eliminate all risks.

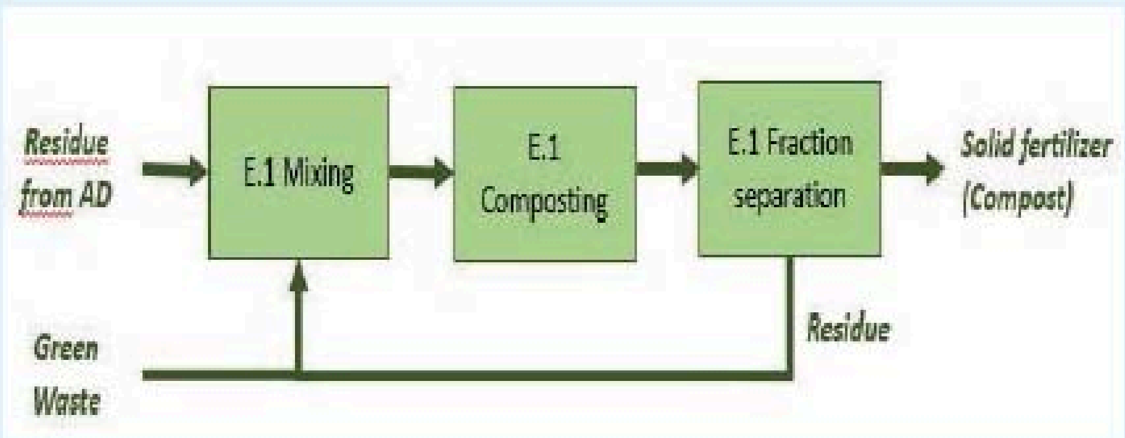
Therefore, another way of valorization is often set up: the conversion of the solid part of digestate into compost.

E.1 Solid Residue Treatment Through Compost
Several processes have been developed to valorize solid residue, also called Fibre :

- Composting and alkaline stabilization for Fertilizer production
- Enzymatic Hydrolysis for Biofuel production
- Drying for biofuel, heat and power production (through incineration, pyrolysis, etc.,)

Regarding Bangladesh conditions and needs in the country, preference will be given to composting.

Figure 67 : Flow chart - Composting



Therefore, the dewatered organic residues will be treated in a covered aerobic treatment facility.

The aim of the composting process is to transfer the substrate from the intensive treatment process into an aerobic condition. The composition of the digestate will require the mixing with green waste that will act as a structuring matter (equivalent to 20% of the mass input of digestate). Green waste can be provided from public parks / markets / agriculture. Note that a part of the structuring fraction will come from the final separation that will be applied on the mature compost in order to get compost with homogeneous fraction and free from impurities such as glass or plastic. The main advantage of this fraction is that it already contain the requested bacteria for composting.

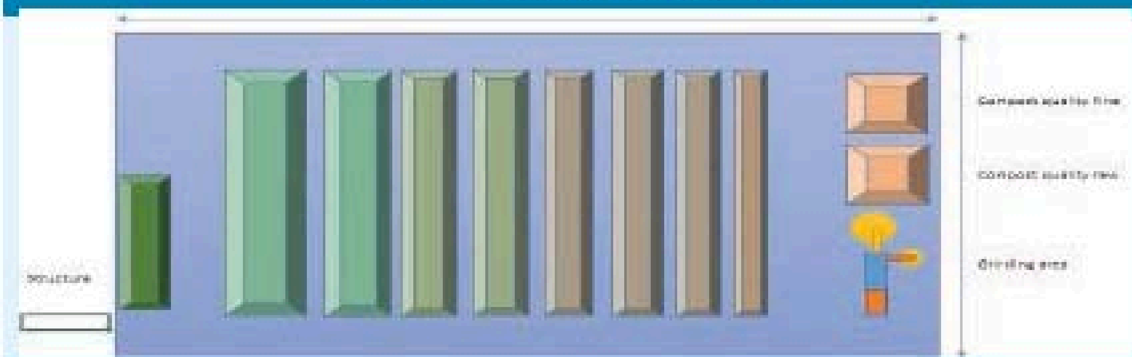
Figure 58 - Separation step (drum sieve) - Source (Mc Closkey)

Once the composting feedstock has the requested composition, it is transferred to the storage area, where it is kept for 90 days to completely mature and achieve the requested compost parameters.

Figure 59 : Example of composting hall

A composting hall will be designed, based on windrows of 2.5 meter height of compost.

Figure 60 : Principle of composting hall



After this process the organic residue can be sold as organic fertilizer.

Table 38 : Compost operation parameters

Compost	Unit	Value
Features		
Structuring Part	%	20%
Maturation time	week	12-15
Production of compost	%	40%
Fraction separation	%	65%

Note that a windrow turner will be required as well as an operator.

According to the Bangladesh Agricultural Development Corporation (BADC), there is a considerable market for compost in Bangladesh. The average price for compost is about 300 TK per bag of 100 kg.

Figure 61 : Composting – Windrows and equipment

E.2 Liquid Residue Treatment

The liquid fraction will be collected from the Preliminary Storage Area. It will be treated or sent to the local Wastewater treatment plant before being released into the Environment according to the Environment Conservation Rules. Note however that a part of the liquid fraction, called liquor, may be recirculated into the anaerobic digester in order to maintain a high humidity rate that enhances the biogas production.

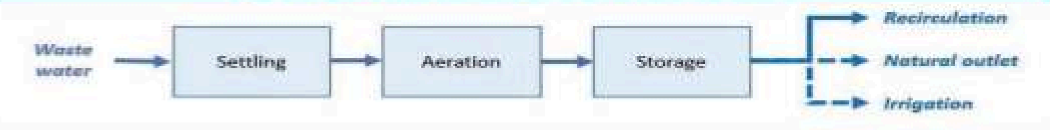
Depending on the concentration of BOD, Suspended Solids, Nitrate and Phosphate in the digestate, a biological treatment may be developed to comply with the Discharge Standards.

Intensive techniques, including reverse osmosis, evaporation and stripping have been developed to treat water and recover a valuable concentrate used as fertilizer (P and N-rich solutions). However, these processes are expensive and mainly used in Anaerobic Digestion with manure.

The proposed treatment has three steps :

- Settling : settling of suspended solid particles
- Aeration : biological treatment for organic matter treatment
- Storage : storage of water for recirculation on Anaerobic digester if adjustments of humidity content require

Figure 62 : Flow chart - Waste Water treatment



7.1.1.6 Valorization of other Waste

F.1 Recycling and Reuse

As mentioned in the Section Pretreatment, Municipal Waste will be sorted in order to separate :

- The biodegradable fraction necessary for the bio digester

- The other valuable fractions that can have a commercial value (plastic, paper, RDF, inert material, etc.)

- The waste that cannot be valorized

The success of this operation requires at least the recovery of the costs generated by the sorting and storage step.

It is therefore necessary to determine the investment and operating costs generated by the establishment of a sorting line specific to a type of waste and to ensure that there is a potential market for the resale of the products collected. The local market should be carefully assessed in order to determine which waste stream should be recovered.Regarding the local conditions in Bangladesh, the following waste streams might be recovered :

Plastics
Depending on the local industry sector, plastic can be valorized in the Plastic industry. However, those industries are mostly concentrated around Dhaka, Chittagong and Narayangang. According to a recent study on Plastic Recycling in Bangladesh (ARCADA, 2014) it appears that only very few plastic industries have equipment adapted for plastic recycling. These elements will have to be evaluated in each of the six Municipalities in order to determine how relevant it is to recycle plastic as material or to valorize it for its calorific properties.

Paper
Paper can be recycled in local paper-recycling factories that convert paper waste into card board, thin papers, and packets (Scenario of paper waste recycling and reusepractices in Khulna City of Banfladesh , 2014). Because of its calorific content, this waste stream can also valorized in thermal processes (incineration, etc.).

Textile
Textile can be recovered and used as combustion material or directly into anaerobic digestion if made with organic material.

Inert
Inert waste can be reused in construction road, especially for road construction.

However, it should be kept in mind that whatever the process and the technologies used, a residual part of waste will always remain (end-product from bio-digestion, waste fraction that could be recovered, etc.). Therefore, a final solution should be proposed.

F.2 Incineration
The residual waste can be used as Refuse Derived Fuel in an incinerator (on site or in another site). Because the residue will not contained biological humid waste, it can be concluded that the humidity of the waste and its calorific value will be more suitable than those of mixed waste (around 8 MJ/kg instead of 6, initially). Moreover, the quantity of waste to be treated will be much lower than the incoming waste amount, allowing to limit the size of the installation.

Heat generated by the process can be recovered for electricity production or directly in the biological processes (compost, Waste water treatment, etc.). Moreover, power can be generated and injected into the grid.

Note that as previously mentioned in the Interim report, this technology is expensive and complex and may be difficult to implement on site because of the investment costs and the lack of local competences. Moreover, this process still generates residue that should be taken care of (ashes).

Another solution can thus be imagined; the resale of this waste as a fuel for cement industry that can be seen as a win-win solution:

- This raw material will be available for cement industry at a lower price than traditional combustion material (fuel, etc.)
- The cost of final treatment for this part of waste will not impact the site management ; on the contrary, the resale may generate a revenue

However, both of these solutions require the compliance with two important points :

- Compliance with the current infrastructure of incineration ; that should be able to accept RDF as a fuel
- Compliance with the legislation in terms of air pollution

F.3 Landfilling

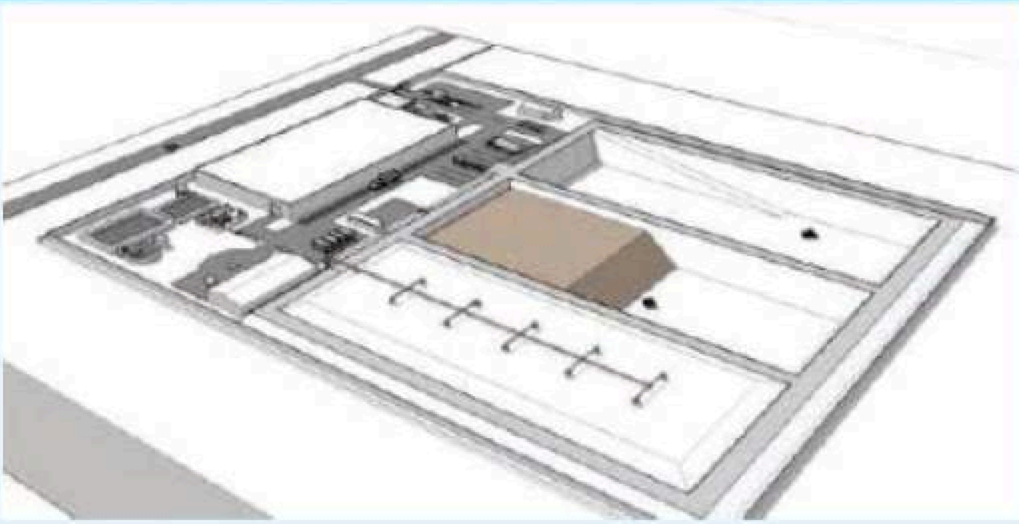
The most convenient solution for final residue is disposal into secured landfill. Only waste that could not be recycled or reused will be stored in such infrastructure, implying that the area requested will be limited to the strict necessary. Because of the surface required for such installation, a sanitary landfill should therefore be developed in another area.

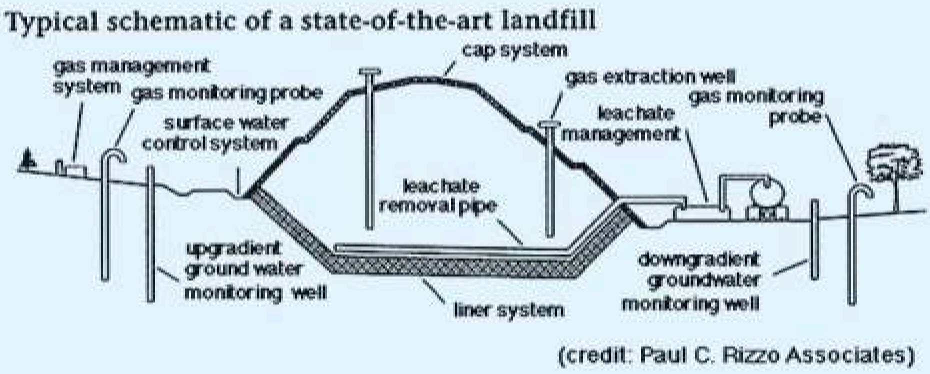
It should be designed, constructed, and operated in a manner that minimizes impacts to public health and the environment. In contrast to open dumpsites and controlled dumps, sanitary landfills undergo thorough planning right from the selection of the site up to post-closure management. Thus, although it requires substantial financial resources, cells can be constructed one after another, spreading the investment over time.

Sound Practices for Landfill Technology In planning a new landfill, the following sound practices should be adopted:

- Appropriate siting;
- Leachate management and environmental impact minimization;
- Gas management and risk reduction;
- Secure access and recording of waste inflow volumes and character;
- Compaction and daily cover;
- Documented operating procedures, and worker training and safety programs;

Figure 63 : Presents the principle of a sanitary landfill & a 3D model as an example of how such sanitary landfill can look like.

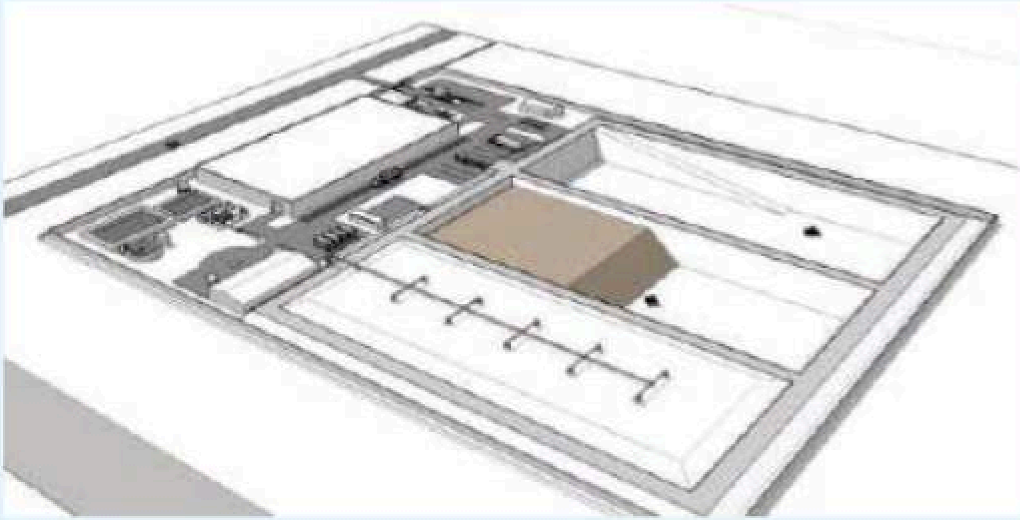




- Establishment and maintenance of good community relations;
- Closure and post closure planning.

It should be noted that because of the nature of the waste, leachate and gas production will be extremely limited; the requested equipment will be adapted accordingly.

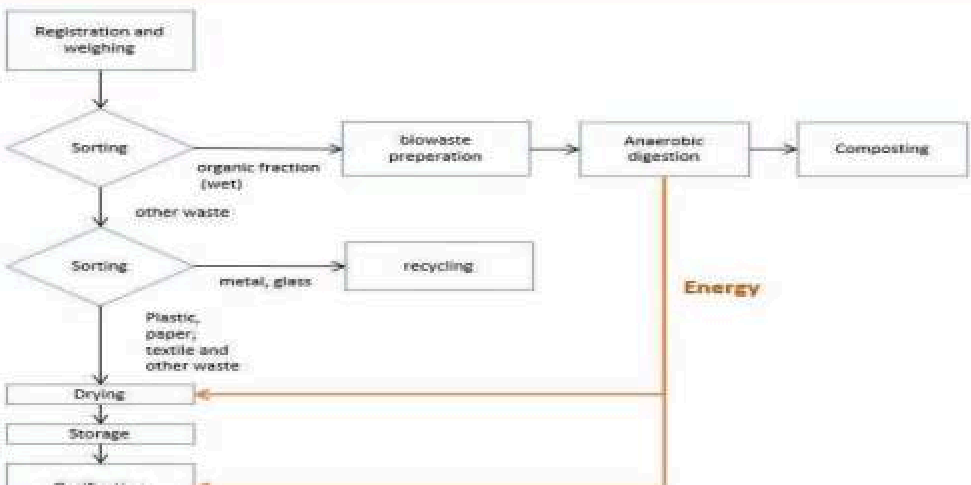
Figure 63: Principle and 3D design of a closed sanitary landfill



7.1.2 Modular Design 2: Anaerobic Digestion + Gasification + Composting

The concept of the second proposed design including a gasification module is made in such a way that the mixed solid waste stream is pretreated in order that the waste composition complies with the technical requirements of a down draft gasifier. Equally as in the first modular design, it will also present additional modules that can be added to the site to treat the other waste in order that the products of the MSW treatment are optimally valorised. The Flow Scheme of Modular Design 2 is shown in the figure below.

Figure 64: Modular Design 2: Gasification + Anaerobic Digestion + composing



In a first sorting step, the wet organic fration will be removed from the waste stream. In order to convert this wet organic waste stream maximally into energy, an anaerobic digestion facility remains the most appropriate technology. This brings in an extra asset for Modular Design 2 : the energy produced by Anaerobic digestion can be internally reused to dry the waste stream and initiate the gasification reaction (see Figure 66).

In a second sorting step, the metal and glass will be sorted out because of their negative calorific value. Since the humidity of the Bangladeshi MSW after the second sorting step remains >50%, this waste stream needs additional drying. Since humidity negatively correlates with the calorific value, it is beneficial to dry u to a level of 20% before entering the gasifier. The residual waste tonnage after drying is 25% of the initial tonnage of mixed MSW entering the Environmental park.

The Environmental Park of Modular Design 2 can be subdivided into following facilities:

- Preliminary storage area
- Storage
- Composting
- Anaerobic digestion
- Drying facility
- Gasifier

For a detailed description of most the parts of the plant, there is referred to Modular Design 1. The only differences between the two modular designs are that Modular Design 2 requires a drying pretreatment facility and a gasifier facility.

7.2 Technical Parameters and Concepts

7.2.1 Mymensingh

7.2.1.1 Background Information

Localization

Mymensingh, which is located on the banks of the Old Brahmaputra River, is a city in the north- central part of Bangladesh, in the Dhaka Division. It is the main city of the Mymensingh District (4396 sq. km).

Mymensingh Paurashava, which occupies 21.73 sq.km, is sub-divided in 21 wards (Geocode from 01 Ward N° - 01 to 21 – Ward N°. 21). The Mayor of the Paurashava is Mr Akmtaiqui Alom.

Climate

The city is situated in the south-central climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 12°C to 33.3°C and has an annual average precipitation of 2174 mm.

The average humidity is equal to 78.32%.

The Paurashava is situated at an average altitude between 15 and 20m.

Population

According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Mymensingh Paurashava rises from 227,204 persons in 2001 to 258,040 persons in 2011, implying an average population growth rate of 1.28%, which is slightly lower than the Upazila average population growth rate estimated at 1.39%. The population density of the Upazila is 2,037 cap/sq. km.

The following Table 34 and Figure 68 give the projection of Population for Mymensingh Paurashava according to various Population Growth Rate (PGR).

Table 34 : Mymensingh - Population Projection 2011 -2030

PGR	Average 2001-2011 Paurashava	Average 2001-2011 Upazila	Bangladesh Urban Dev.
	1.3%	1.4%	3.6%
2011	258	0	0
2013	264	258 040	258 040
2015	271	265 263	276 953
2016	274	272 689	297 253
2020	289	276 479	307 954
2025	308	292 175	354 752
2030	328	313 054	423 373

Figure 65 : Mymensingh - Population forecast

7.2.1.2 Concept preliminary

Storage Area Sketch of the building

Waste Generation

General projection on waste production

Several assumptions are proposed to evaluate the waste production over the next decade.

According to data from Waste Concern (2013) and ADB (projection 2025), the national Waste Growth Rate (WGR) will increase from about 1.5% annually. The same trend is therefore applied to Mymensingh's WGR.

No information is available on Waste Collection Rate by 2013. According to Waste Concern (I. Enayetullah et. al. 2005), the Waste Collection Rate of Paurashava by 2005 was about 55%. The data collected from the municipality shows that the waste management system in Mymensingh is not efficient yet; as a consequence, we will assume that the collection rate by 2013 is similar to the one of 2005. The development of WtE solution will require the improvement of the Waste Management System for which the collection rate is expected to increase gradually from 55% by 2013 to 98% by 2030. The table 35 shows the results of the projection :

Table 35 : Mymensingh - Waste Generation forecast

Parame ter	Unit	2013	2020	2025	2030
Population	inh.	264	289	308	328
Waste production					
Average Waste Generation Rate	kg/cap/	0.36	0.40	0.43	0.46
Daily average waste production	t/d	96	116	133	152
Annual average waste production	t/yr	35 057	42 408	48 584	55 660
Collection rate	%	55%	75%	90%	98%
Daily average waste for treatment	t/d	53	87	120	149
Annual average waste for treatment	t/yr	19 281	31 806	43 725	54 546

Waste streams

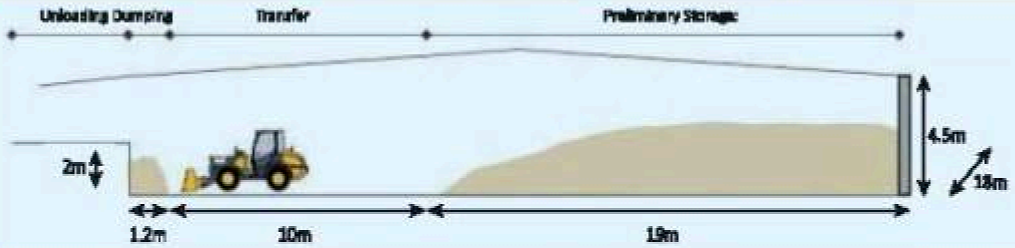
The waste composition is an important parameter because it gives precious information on the recycling/recovery potential of waste.

According to the hypothesis in the Interim Report, the waste composition of Mymensingh is considered similar to the one of Dhaka (I. Enayetullah et. al., 2005). Therefore, it is assumed that the composition will remain constant, although it would be useful to assess in a later stage the influence of seasonal variation on the organic fraction in a detailed study.

Table 35 : Mymensingh - Waste Composition

Waste streams	Unit	Compositio
Organic fraction (vegetable + wood)	%	70.3%
Plastic	%	4.1%
Paper	%	4.3%
Metal	%	0.2%
Textile waste	%	4.6%
Glass	%	0.1%
Other	%	16.5%

Figure 66 : Sketch of the Preliminary Storage zone for entering Mixed Waste



Unloading area

In order to allow the simultaneous unloading of 4 trucks in the unloading zone, a ramp of 18 meter width will be considered. This dimension will therefore fit the width of the building.

Dumping area

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone; according to the capacity of the dumping zone (about 40m³), this operation will have to be performed 4 times a day in 2020 and 7 times a day in 2030.

Transfer area

Estimating that the waste loader has a turning radius of 10m, it is necessary to create a transfer zone of at least this length to ensure the smooth moving of the machine.

Preliminary Storage

The preliminary storage area will be designed by considering a storing capacity of 4 days. This 4 days may correspond to facility maintenance period or period of religious/cultural day off during which the facility will not be operated. As a consequence, the volume to be stored must be equal to:

Parameters	Unit	2020	2030
Total capacity of the PSA	m^3	581	996

The average storage height is about 2.5 meters. Because some waste loaders have a magnitude of over 4 meters, it may be considered to store until 3.5m. These both criteria will be used to determine the minimal length of the storage area for both 2020 and 2030.

Through an iterative process, the optimal dimension of the storing zone is 19 meters; this length will ensure a storage height of waste of 2 meters in 2020 and of 3.5 meters in 2030.

Conclusion
According to the previous element, the Preliminary Storage Area will have the following dimensions:

- Height : 4.5 meters
- Width : 18 meters
- Length : 30 meters

Sorting Hall
Feedstock for Anaerobic Digestion (drum sieve)
According to practical experience, a recovery rate of 60% for organic material and of 10% for the other components will be considered.

The following mass balance can therefore be hypothesised:

Waste stream	Unit	2020	2030
Waste stream for AD	t/d	36.5	63
Biomass	t/d	34	59
Other	t/d	2.5	4
Elements	t/d	45	77
Waste for sorting	m^3/d	89	153

The operating time for this type of trammel is given below :

Average Operating time per	Unit	2020	2030
Capacity 30 m^3/h	h	5.4	9.3
Capacity 55 m^3/h	h	3	5.1
Capacity 80 m^3/h	h	2	3.5

Depending on the capacity, the number of machine and the possibility to use the trammel for other purposes (compost) will evolve.

The preliminary design of the sorting hall is given below :

- Length : 70 m
- Width : 36 m

Recyclable material

According to the recovery rate given above, the following amount of material that can be recovered is :

Sorting - Recovery	Unit	2020	2030
Plastic	t/d	1.5	2.6
Paper	t/d	1.3	2.2
Textile	t/d	2.5	4.3
Metal	t/d	0,1	0.2

A single line will be sufficient to sort the whole quantity of waste. The operating time for sorting will depend on the capacity of the drum siev

Technical parameters	Unit	2020	2030
Volume of waste to be sorted per day	m^3	89.2	122
Supply			
30 m^3/h drum sieve	h	3.0	4.1
55 m^3/h drum sieve	h	1.6	2.2
80 m^3/h drum sieve	h	1.1	1.5

Storage area

A storage area will be defined for temporary storage of recycled material. The storage capacity will depend on the number of removals that could be operated. This parameter will have to be defined after a deeper investigation and discussion with the potential recyclers. An example of storage design is given below.

Type of waste	Year	Storage capacity before	Type and capacity of containers
Plastic	2020	8 days	1 container of $40m^3$
	2030	4.7 days	1 container of $40m^3$
	2030	9.3 days	2 containers of $40m^3$
Paper	2020	2.7 days	1 container of $40m^3$
	2020	5.4 days	2 containers of $40m^3$
	2030	3.2 days	2 containers of $40m^3$
	2030	4.7 days	3 containers of $40m^3$
Textile	2020	7 days	1 box of 108 m^2
	2030	7 days	1 box of 108 m^2
Metal	2020	7 days	1 container of $1m^3$
	2030	5 days	2 containers of $1m^3$
Inert	/	/	1 box of 108 m^2 (capacity 320

Treatment and Recovery of Biowaste

Anaerobic digester

Considering a retention time of 25 days, the following reactor's volumes are required :

Anaerobic digestor - Parameters	Unit	2020	2030
Operational volume			
Feedstock	t/d	36.7	63.0
Operational volume	m^3	1010	1731

Therefore, an operational volume of about 1,800 m^3 will be proposed. The dimensions of the reactor are given below.

Reactor dimensions		
Length	m	28
Width	m	8
Height	m	9

Biogas storage and valorization

The gas production is estimated around :

- 3,300 Nm^3//d by 2020
- 5,700 Nm^3/d by 2030.

It is proposed to use a part of the biogas for electricity production with an engine ; the other part will be stored a flexible double membrane gas holder before treatment and conditioning or supply. The choice of the engine will be determined by the maximal capacity of the double membrane gas holder (50 – 5,500 Nm^3).

Because of the expecting production, it is proposed to start the electricity production onsite with a 150 kW engine.

The remaining fraction of biogas will be stored in a flexible double membrane gas holder before being converted into LNG or CBM.

A 4,000 Nm^3 gas holder will be selected, enabling a storage capacity of almost 3 days by 2020 and 1 day by 2030. Note that a second engine may be installed in a later phase in order to increase the production of electricity and the storage capacity.

Composting area

The composting hall will be designed according to the volume of biowaste by 2030.

E.2 Composting	Unit	2020	2030
Flow from digester	t/d	32.7	56.2
Str ucturing matter	t/d	6.5	11.2
Total input	t/d	39.3	67.4
Total output	t/d	16	27
Production of compost after	t/d	13.4	22.9
Residue from separation (structuring)	t/d	2.4	4.0
Need of structuring material	t/d	4.2	7.2

The preliminary design of the composting hall is given below:

Residue for landfill/incineration	Unit	2020	2030
Residue	t/d	39.3	67.4

- Length : 150 m
- Width : 85 m
- Height : 4.5 m

Other Streams

Waste Water

Considering closed building with separation of rainfall and leachate from the PSA, the waste water flow to be treated will be equal to

- 20 m^3/d by 2020
- 35 m^3/d by 2030

Residue for incineration/landfill

The recycling and biological treatment leads to a 52% reduction of the amount of residue that should be either incinerated or landfilled.

Location and area requirements

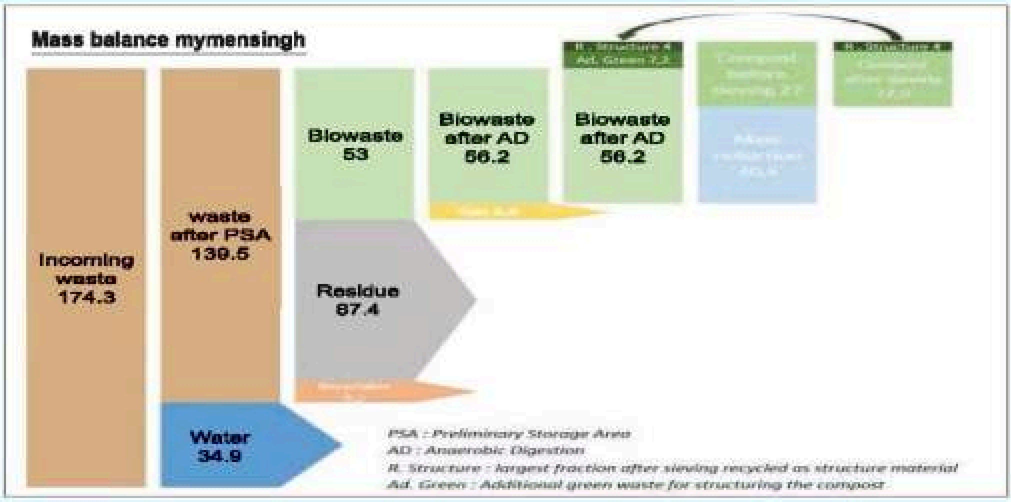
At the moment of the study, it was unclear to the Municipality where to locate the area for the waste treatment facility. When this information will become available, it should be integrated in a detailed study. The area requirements are described in section 7.4.

Logistical aspects

An efficient logistic system needs to be designed once the location of the environmental park is known. It must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway. Another important factor is that the feedstock must be located close to the waste treatment plant.

7.2.1.3 Mass Balance

Figure 67 : Mass balance - Case of Mymensingh



7.2.2 Cox's Bazar

7.2.2.1 Background Information

Localization

Cox's Bazar is a city in the south-eastern part of Bangladesh, in the Chittagong Division. It is the main city of the Cox's Bazar District (2,491 sq. km).

Cox's Bazar Paurashava, which stretches out on 7.94 sq.km, is sub-divided in 12 wards (Geocode from 01 – Ward N° - 01 to 12 – Ward N°C. 12). The Mayor of the Paurashava is Mr. Mahbubur Raitman Chowditurx.

The city is situated at the mouth of the Bakhali River, which flows north into the Gulf of Bengal.

Climate

The city is situated in the south-eastern climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 16.1°C to 34.8°C and annual average precipitation of 4,285 mm.

The region is regularly experiencing sea storms, tidal bores, hurricanes and cyclones. The Average Humidity is equal to 79.04%.

The Paurashava is situated at an average altitude between 2 and 4m.

Population

According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, Cox's Bazar Paurashava has experienced a significant urbanization from 2001 (51,918) to 2011 (167,477), with an average population growth rate of 12.43%, quite higher than the Upazila average population growth rate estimated at 2.76%. The population density of the Upazila is 2,011 cap/sq. km.

The following Table 37 and Figure 71 give the projection of Population for Cox's Bazar Paurashava according to various Population Growth Rate (PGR).

Table 37 : Cox's Bazar - Population Projection 2011 - 2030

PGR	Average 2001-2011 Paurashava	Average 2001-2011 Upazila	Bangladesh Urban Dev.
	12,4%	2,8%	3,6%
2011	167,457	167,457	167,457
2013	211,656	176,828	179,731
2015	267,521	186,724	192,904
2016	300,761	191,877	199,849
2020	480,482	213,954	230,219
2025	862,969	245,155	274,751
2030	15,49,937	2,80,906	327,898

Figure 68 : Cox's Bazar - Population forecast

Note that for this preliminary design, a population growth rate of 3.6% will be considered instead of the one of 12.3%; this rate being uncertain to be maintain over time and leading to multiply by ten the population in 15 years, implying huge consequences on the preliminary design. When developing a pilot plant, a thorough study on population and urbanization will be necessary in order to estimate realistically the population growth and the impact of tourism on the waste production.

Waste Generation

General projection on waste production

Several assumptions are proposed to evaluate the waste production over the next decade.

First, it is important to evaluate the average Waste Growth Rate (WGR). According to data from Waste Concern (2013) and ADB (projection 2025), the national WGR will increase from about 1.5% annually. The same trend will therefore be applied to Cox's Bazar's WGR.

No information is available on Waste Collection Rate by 2013. According to Waste Concern (I. Enayetullah et. al, 2005), the Waste Collection Rate of Paurashava by 2005 was about 55%. The data collected from the Municipality show that the waste management system in Cox's Bazar is not efficient yet; as a consequence, we will assume that the collection rate by 2013 was similar to the one of 2005. The development of WtE solution will require the enhancement of the Waste Management System; therefore, the collection rate will be increase gradually from 55% by 2013 to 98% by 2030.

Since there could be variation of waste generation in Cox's Bazar due to the touristic season, it is recommended to foresee extra storage area allowing preserving and postponing the valorisation of possible surplus of waste.

The Table 38 shows the results of the projection :

Table 38 : Cox's Bazar - Waste Generation forecast

Parameter	Unit	2013	2020	2025	2030
Population	inh.	179	230	274	327
Waste production					
Average Waste Generation Rate	kg/cap/	0.41	0.45	0.49	0.52
Daily average waste production	t/d	74	104	134	172
Annual average waste production	t/yr	26,834	38,034	48,796	62,604
Collection rate	%	55%	75%	90%	98%
Daily average waste for treatment	t/d	40	78	120	168
Annual average waste for treatment	t/yr	14,759	28,526	43,917	61,352

Waste streams

The waste composition is an important parameter because it gives precious information on the recycling/recovery potential of waste. According to the hypothesis taken in the Interim Report, the waste composition of Cox's Bazar will be considered similar to the one of Chittagong (I. Enayetullah et. al, 2005) and it will be assumed that the composition will remain constant.

Table 39 : Cox's Bazar - Waste Generation forecast

Wastest reams	Unit	Compositio
Organic fraction (vegetable + wood)	%	74.3%
Plastic	%	4.3%
Paper	%	5.7%
Metal	%	0.1%
Textile waste	%	4.7%
Glass	%	0.2%
Other	%	10.6%

7.2.2.2 Concept

Preliminary Storage Area

Unloading area

In order to allow the simultaneous unload of 2 trucks in the unloading zone, a ramp of 18 meter width will be considered. This dimension will therefore fix the width of the building.

Dumping area

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone; according to the capacity of the dumping zone (about 40m³), this operation will have to be performed 4 times a day in 2020 and 7 times a day in 2030.

Transfer area

Estimating that the waste loader has a turning radius of 10m, it is necessary to create a transfer zone of at least this length to ensure the smooth moving of the machine.

Preliminary Storage

The preliminary storage area will be designed by considering a storing capacity of 4 days. This 4 days may correspond to facility maintenance period or period of religious/cultural day off during which the facility will not be operated. As a consequence, the volume to be stored must be equal to:

Parameters	Unit	2020	2030
Total capacity of the PSA	m^3	521	1121

The average storage height is about 2.5 meters. Because some waste loaders have a magnitude of over 4 meters, it may be considered to store until 3.5m. These both criteria will be used to determine the minimal length of the storage area for both 2020 and 2030.

Through an iterative process, the optimal dimension of the storing zone is 13 meters; this length will ensure a storage height of waste of 1.4 meters in 2020 and of 3 meters in 2030.

Conclusion

According to the previous element, the Preliminary Storage Area will have the following dimensions:

- Height : 4.5 meters
- Width : 18 meters
- Length : 32 meters

Sorting Hall

Feedstock for Anaerobic Digestion (Drum sieve)

According to practical experience, a recovery rate of 60% for organic material and of 10% for the other components will be considered.

The following mass balance can therefore be hypothesised :

Waste stream	Unit	2020	2030
Waste stream for AD	t/d	35	74
Biomass	t/d	33	70
Other	t/d	2	4
Elements	t/d	39	83
Waste for sorting	m³/d	77	166

The operating time for this type of trammel is given below:

Average Operating time per	Unit	2020	2030
Capacity 30 m³/h	h	4,9	10,5
Capacity 55 m³/h	h	2,7	5,7
Capa city 80 m³/h	h	1,8	3,9

Depending on the capacity, the number of machine and the possibility to use the trammel for other purposes (compost) will evolve.

The preliminary design of the sorting hall is given below:

- Length : 70 m
- Width : 36 m

Recyclable material

According to the recovery rate given above, the following amount of material that can be recovered is:

Sorting - Recovery	Unit	2020	2030
Plastic	t/d	1,4	3,0
Paper	t/d	1,5	3,2
Textile	t/d	2,3	5,0
Metal	t/d	0,1	0,2

A single line will sufficient to sort the whole quantity of waste. The operating time for sorting will depend on the capacity of the drum sieve.

Technical parameters	Unit	2020	2030
Volume of waste to be sorted per day	m³	77,1	165,
Supply			
30 m³/h drum sieve	h	2,6	5,5
55 m³/h drum sieve	h	1,4	3,0
80 m³/h drum sieve	h	1,0	2,1

Storage area

A storage area will be defined for temporary storage of recycled material. The storage capacity will depend on the number of removal that could be operated. This parameter will have to be defined after a deeper investigation and discussion with the potential recyclers. An example of storage design is given below.

Type of waste	Year	Storage capacity before removal	Type and capacity of containers
Plastic	2020	8,5	1 container of 40m³
	2030	3,9	1 container of 40m³
	2030	7,9	2 containers of 40m³
Paper	2020	4,5	2 containers of 40m³
	2020	6,8	3 containers of 40m³
	2030	3,2	3 containers of 40m³
	2030	4,2	4 containers of 40m³
Textile	2020	7 days	1 box of 216 m³
	2030	7days	1 box of 216 m³
Metal	2020	9 days	1 container of 1m³
	2030	6 days	1 container of 1m³
Inert			1 box of 108 m² (capacity 320

Treatment and Recovery of Biowaste

Anaerobic digester

Considering a retention time of 25 days, the following reactor's volumes are required:

Anaerobic digester - Parameters	Unit	2020	2030
Operational volume			
Feedstock	t/d	34,4	74,0
Operational volume	m³	946	2034

Therefore, an operational volume of about 900 m³ will be proposed. The dimensions of the reactor are given below.

Reactor dimensions		
Length	m	32
Width	m	8
Height	m	9

Biogas storage and valorization

The gas production is estimated around:

- 4,000 Nm³/d by 2020
- 8,300 Nm³/d by 2030.

It is proposed to use a part of the biogas for electricity production with an engine; the other part will be stored a flexible double membrane gas holder before treatment and conditioning or supply. The choice of the engine will be determined by the maximal capacity of the double membrane gas holder (50 – 5,500 Nm^3).

Because of the expecting production, it is proposed to start the electricity production onsite with a 250 kW engine.

The remaining fraction of biogas will be stored in a flexible double membrane gas holder before being converted into LNG or CBM.

A 4,000 Nm^3 gas holder will be selected, enabling a storage capacity of almost 2 days by 2020 and less than 1 day by 2030. Note that a second engine may be installed in a later phase in order to increase the production of electricity.

Composting area

The composting hall will be designed according to the volume of biowaste by 2030.

E.2 Composting	Unit	2020	2030
Flow from dige ster	t/d	40.1	82.2
Structuring matter	t/d	8.0	16.4
Total input	t/d	48.2	98.7
Total output	t/d	19	39
Production of compost after	t/d	16.4	33.5
Residue from separation (structuring)	t/d	2.9	5,9
Need of structuring material	t/d	5.1	10.5

The preliminary design of the composting hall is given below :

- Length : 140 m
- Width : 100 m
- Height : 4.5 m

Other Streams

Waste Water

Considering closed building with separation of rainfall and leachate from the PSA, the waste water flow to be treated will be equal to

- 22 m^3/d by 2020
- 44 m^3/d by 2030

Residue for incineration/landfill

The recycling and biological treatment leads to the reduction by 65% of the amount of residue that should be either incinerated or landfilled.

Residue for landfill/incineration	Unit	2020	2030
Residue	t/d	37	76

Location and area requirements

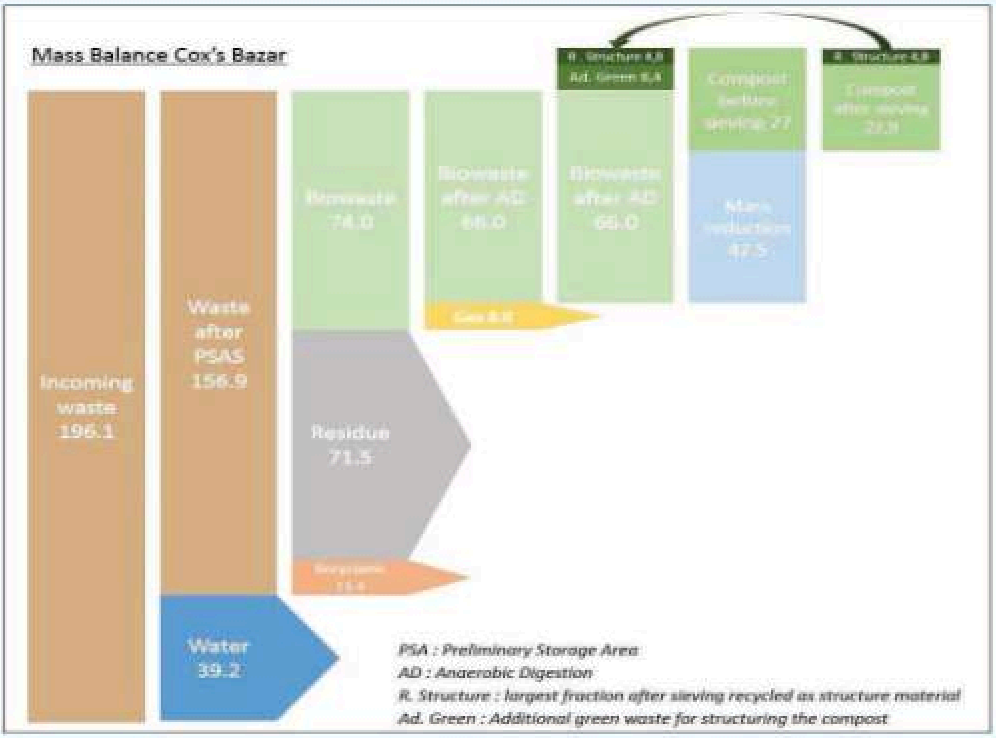
At the moment of the Study, it was unclear to the Municipality where to locate the area for the waste treatment facility. When this information will be available, it should become integrated in a detailed study. The area requirements are described in section 7.4. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway.

Logistical aspects

An efficient logistic system needs to be designed once the location of the Environmental park is known. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway. Another important factor is that the feedstock must be located close to the waste treatment plant.

Mass Balance

Figure 71 : Mass Balance - Case of Dinajpur



7.2.3 Dinajpur

7.2.3.1 Background Information

Localization

Dinajpur is a city in the north-western part of Bangladesh, in the Rangpur Division. It is the main city of the Dinajpur District (Zila).

Dinajpur Paurashava, which stretches out on 20.67 sq.km and rises on the bank of Punarbhaba River, is part of Dinajpur City together with 3 adjoining Mauzas. The Paurashava is sub-divided in 12 wards (Geo-codes 01-Ward No-01 to 12-Ward No-12) and 80 mahallas (Bangladesh Bureau of Statistic, 2014).

Climate

The City is situated in the north-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 10.5 °C to 33.5°C and an annual average precipitation of 2536 mm (Bangladesh Bureau of Statistic, 2014).

The Average Humidity is equal to 75.54%.

The Paurashava is situated at an average altitude between 30 and 50m.

Population

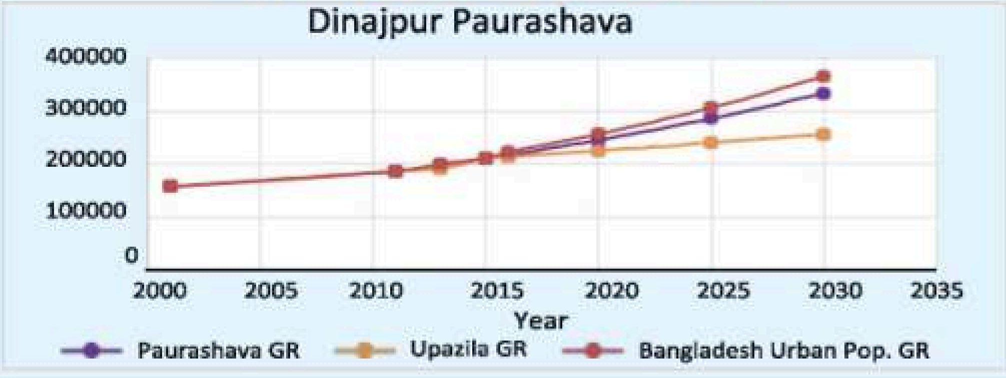
According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, Dinajpur Paurashava's population rises from 157,914 persons in 2001 to 186,727 persons in 2011, implying an average population growth rate of 1.69%, slightly higher than the Upazila average population growth rate estimated at 1.31%. The population density of the Upazila was 1,366 cap/sq. km.

The following Table 40 and Figure 73 give the projection of Population for Dinajpur Paurashava according to various Population Growth Rate (PGR).

Table 40 : Dinajpur- Population Projection 2011 - 2030

PGR	Average 2001-2011 Paurashava	Average 2001-2011 Upazila	Bangladesh Urban Dev.
	3.1%	1.3%	3.6%
2011	186,72	186,727	186,727
2013	198,47	191,651	200,413
2015	210,95	210,953	210,953
2016	217,48	213,716	222,847
2020	245,70	225,137	256,711
2025	286,17	240,275	306,368
2030	333,31	256,431	365,631

Figure 70 : Dinajpur - Population forecast



Note that the preliminary design will be based on the population growth rate of 3.1%.

Waste Generation

General projection on waste production

Several assumptions are proposed to evaluate the waste production over the next decade.

First, it is important to evaluate the average Waste Growth Rate (WGR). According to data from Waste Concern (2013) and ADB (projection 2025), the national WGR will increase from about 1.5% annually. The same trend will therefore be applied to Dinajpur's WGR.

No information is available on Waste Collection Rate by 2013. According to Waste Concern (I. Enayetullah & all, 2005), the Waste Collection Rate of Paurashava by 2005 was about 55%. The data collected from the Municipality show that the waste management system in Dinajpur is not efficient yet; as a consequence, we will assume that the collection rate by 2013 was similar to the one of 2005. The development of WtE solution will require the enhancement of the Waste Management System; therefore, the collection rate will be increase gradually from 55% by 2013 to 98% by 2030.

The Table 41 shows the results of the projection :

Table 41 : Dinajpur - Waste Generation forecast

Parameter	Unit	2013	2020	2025	2030
Population	inh.	198	245	286	333
Waste production					
Average Waste Ge neration Rate	kg/cap/	0.45	0.50	0.54	0.58
Daily average waste production	t/d	90	123	154	193
Annual average waste production	t/yr	32,767	44,888	56,204	70,372
Collection rate	%	55%	75%	90%	98%
Daily average waste for treatment	t/d	49	92	139	189
Annual average waste for treatment	t/yr	18,022	33,666	50,584	68,965

Waste streams

The waste composition is an important parameter because it gives precious information on the recycling/recovery potential of waste.

According to the hypothesis taken in the Interim Report, the waste composition of Dinajpur will be considered similar to the one evaluated for A-type Paurashava (Waste Concern survey done in 2014) and it will be assumed that the composition will remain constant.

Table 42 : Dinajpur - Waste Composition

Waste streams	Unit	Compositio
Organic fraction (vegetable + wood)	%	84.5%
Plastic	%	4.2%
Paper	%	3.7%
Metal	%	0.3%
Textile waste	%	1.5%
Glass	%	0.0%
Other	%	5.9%

7.2.3.2 Concept

Preliminary Storage Area

Unloading area

In order to allow the simultaneous unload of 4 trucks in the unloading zone, a ramp of 18 meter width will be considered. This dimension will therefore fix the width of the building.

Dumping area

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone; according to the capacity of the dumping zone (about 40m³), this operation will have to be performed 4 times a day in 2020 and 7 times a day in 2030.

Transfer area

Estimating that the waste loader has a turning radius of 10m, it is necessary to create a transfer zone of at least this length to ensure the smooth moving of the machine.

Preliminary Storage

The preliminary storage area will be designed by considering a storing capacity of 4 days. This 4 days may correspond to facility maintenance period or period of religious/cultural day off during which the facility will not be operated. As a consequence, the volume to be stored must be equal to:

Parameters	Unit	2020	2030
Total capacity of the PSA	m³	615	1,260

The average storage height is about 2.5 meters. Because some waste loaders have a magnitude of over 4 meters, it may be considered to store until 3.5m. These both criteria will be used to determine the minimal length of the storage area for both 2020 and 2030.

Through an iterative process, the optimal dimension of the storing zone is 24 meters; this length will ensure a storage height of waste of 1.7 meters in 2020 and of 3.5 meters in 2030.

Conclusion

According to the previous element, the Preliminary Storage Area will have the following dimensions:

- Height : 4.5 meters
- Width : 18 meters
- Length : 36 meters

Sorting hall

Feedstock for Anaerobic Digestion (Drum sieve)

According to practical experience, a recovery rate of 60% for organic material and of 10% for the other components will be considered.

The following mass balance can therefore be realized:

Waste stream	Unit	2020	2030
Waste stream for AD	t/d	45	92
Biomas	t/d	44	89
Other	t/d	1	3
elements	t/d	41	84
Waste for sorting	m³/d	82	169

The operating time for this type of trammel is given below:

Average Operating time per	Unit	2020	2030
Capacity 30 m³/h	h	5.7	11.8
Capacity 55 m³/h	h	3.1	6.4
Capacity 80 m³/h	h	2.2	4.4

Depending on the capacity, the number of machine and the possibility to use the trammel for other purposes (compost) will evolve.

The preliminary design of the sorting hall is given below :

- Length : 70 m
- Width : 36 m

Recyclable material

According to the recovery rate given above, the following amount of material that can be recovered is:

Sorting - Recovery	Unit	2020	2030
Plastic	t/d	1.6	3.3
Paper	t/d	1.1	2.3
Textile	t/d	0.9	1.8
Metal	t/d	0.2	0.4

A single line will sufficient to sort the whole quantity of waste. The operating time for sorting will depend on the capacity of the drum sieve.

Technical parameters	Unit	2020	2030
Volume of waste to be sorted per day Supply	m³	82.3	168.
30 m³/h drum sieve	h	2.7	5.6
55 m³/h drum sieve	h	1.5	3.1
80 m³/h drum sieve	h	1.0	2.1

Storage area

A storage area will be defined for temporary storage of recycled material. The storage capacity will depend on the number of removal that could be operated. This parameter will have to be defined after a deeper investigation and discussion with the potential recyclers. An example of storage design is given below.

Type of waste	Year	Storage capacity before	Type and capacity of containers
Plastic	2020	7.4 days	1 container of 40m³
	2030	3.6 days	1 container of 40m³
	2030	7,2	2 containers of 40m³
Paper	2020	3 days	1 container of 40m³
	2020	6 days	2 containers of 40m³
	2030	4 days	2 containers of 40m³
	2030	4.4 days	3 containers of 40m³
Textile	2020	7 days	1 box of 72 m²
	2030	7 days	1 box of 72 m²
Metal	2020	8 days	1 container of 5m³
	2030	8 days	2 containers of 1m³
Inert			1 box of 108 m² (capacity 320

Treatment and recovery of biowaste
Anaerobic digester
Considering a retention time of 25 days, the following reactor's volumes are required:

Anaerobic digester-Parameters	Unit	2020	2030
Operational volume			
Feedstock	t/d	45.0	92.2
Operational volume	m^3	1,237	2,535

Therefore, an operational volume of 2,500 m^3 will be proposed. The dimensions of the reactor are given below.

Reactor dimensions		
Length	m	40
Width	m	8
Height	m	9

Biogas storage and valorization

The gas production is estimated around:

- 4,000 Nm^3//d by 2020
- 8,300 Nm^3/d by 2030.

It is proposed to use a part of the biogas for electricity production with an engine; the other part will be stored a flexible double membrane gas holder before treatment and conditioning or supply. The choice of the engine will be determined by the maximal capacity of the double membrane gas holder (50 – 5,500 Nm^3).

Because of the expecting production, it is proposed to start the electricity production onsite with a 250 kW engine.

The remaining fraction of biogas will be stored in a flexible double membrane gas holder before being converted into LNG or CBM.

A 4,000 Nm^3 gas holder will be selected, enabling a storage capacity of almost 2 days by 2020 and less than 1 day by 2030. Note that a second engine may be installed in a later phase in order to increase the production of electricity.

Composting area
The composting hall will be designed according to the volume of biowaste by 2030.

E.2 Composting	Unit	2020	2030
Flow from dige ster	t/d	40.1	82.2
Structuring matter	t/d	8.0	16.4
Total input	t/d	48.2	98.7
Total output	t/d	19	39
Production of compost after	t/d	16.4	33.5
Residue from separation (structuring)	t/d	2.9	5,9
Need of structuring material	t/d	5.1	10.5

The preliminary design of the composting hall is given below :

- Length : 140 m
- Width : 100 m
- Height : 4.5m

Other Streams

Waste Water

Considering closed building with separation of rainfall and leachate from the PSA, the waste water flow to be treated will be equal to

- 22 m^3/d by 2020
- 44 m^3/d by 2030

Residue for incineration/landfill

The recycling and biological treatment leads to the reduction by 65% of the amount of residue that should be either incinerated or landfilled.

Residue for landfill/incineration	Unit	2 020	2030
Residue	t/d	37	76

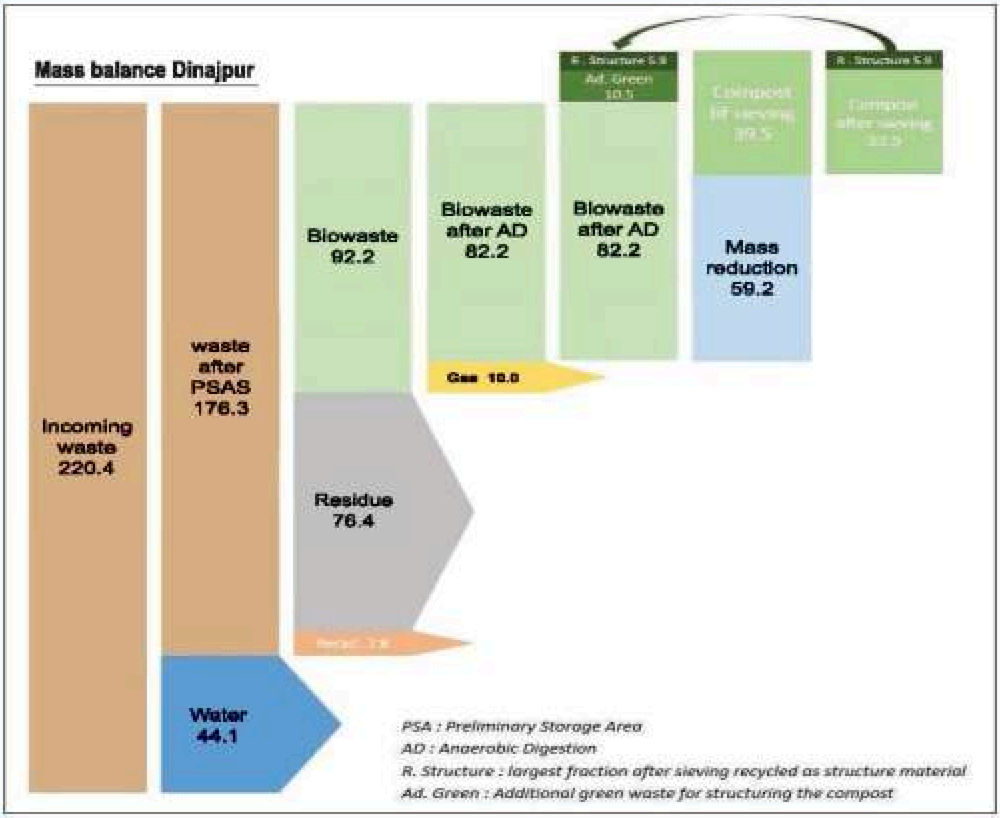
Location and area requirements

At the moment of the Study, it was unclear to the Municipality where to locate the area for the waste treatment facility. When this information will be available, it should become integrated in a detailed study. The area requirements are described in section 7.4. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway.

Logistical aspects

An efficient logistic system needs to be designed once the location of the Environmental park is known. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway. Another important factor is that the feedstock must be located close to the waste treatment plant.

Figure 71 : Mass Balance - Case of Dinajpur



7.2.4 Sirajganj

7.2.4.1 Background Information

Localization

Sirajganj is a city in the central part of Bangladesh, in the Rajshahi Division. It is the main city of the Siraganj District (2,402 sq. km). Siraganj Paurashava, measures 8.49 sq.km in surface, is sub-divided in 15 wards (Geocode from 01 – Ward N° - 01 to 15 – Ward N°. 15) and is administrated by Mr Abdur Rouf Mukter. The City is located on the banks of the Brahmaputra River.

Climate

The City is situated in the south-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 11.9°C to 34.6°C and an annual average precipitation of 1,610 mm.

Without information on Sirajganj, we will assume that the Average Humidity is similar to the one of Bogra with 77.39%

The Paurashava is situated at an average altitude between 9m and 15m.

Population

According to the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Siraganj Paurashava rises from 128,144 persons in 2001 to 158,913 persons in 2011, implying an average population growth rate of 2.18%, slightly higher than the Upazila average population growth rate estimated at 1.36%. The population density of the Upazila is 1734 cap/sq. km.

The following Table 43 and Figure 75 give the projection of Population for Sirajganj Paurashava according to various Population Growth Rate (PGR).

Table 43 : Sirajganj- Population Projection 2011 - 2030

PGR	Average 2001-2011 Paurashava	Average 2001-2011 Upazila	Bangladesh Urban Dev.
	2.2%	1.4%	3.6%
2011	158,91	158,913	158,913
2013	165,90	163,265	170,561
2015	173,19	167,736	183,062
2016	176,96	170,017	189,652
2020	192,87	179,456	218,473
2025	214,78	191,996	260,733
2030	239,18	205,412	311,168

Figure 72 : Sirajganj- Population forecast

Note that the preliminary design will be based on the population growth rate of 2.2%.

Waste Generation

General projection on waste production

Several assumptions are proposed to evaluate the waste production over the next decade.

First, it is important to evaluate the average Waste Growth Rate (WGR). According to data from Waste Concern (2013) and ADB (projection 2025), the national WGR will increase from about 1.5% annually. The same trend will therefore be applied to Sirajganj's WGR.

No information is available on Waste Collection Rate by 2013. According to Waste Concern (I. Enayetullah & all, 2005), the Waste Collection Rate of Paurashava by 2005 was about 55%. The data collected from the Municipality show that the waste management system in Sirajganj is not efficient yet; as a consequence, we will assume that the collection rate by 2013 was similar to the one of 2005. The development of WtE solution will require the enhancement of the Waste Management System; therefore, the collection rate will be increase gradually from 55% by 2013 to 98% by 2030.

The Table 44 shows the results of the projection:

Table 44 : Sirajganj - Waste Generation forecast

Parameter	Unit	2013	2020	2025	2030
Population	inh.	165	192	214	239
Waste production					
Average Waste Generation Rate	kg/cap/	0.24	0.27	0.29	0.31
Daily average waste production	t/d	40	52	62	74
Annual average waste production	t/yr	14,745	18,969	22,709	27,185
Collection rate	%	55%	75%	90%	98%
Daily average waste for treatment	t/d	22	39	56	73
Annual average waste for treatment	t/yr	8,110	14,227	20,438	26,641

Waste streams

The waste composition is an important parameter because it gives precious information on the recycling/recovery potential of waste.

According to the hypothesis taken in the Interim Report, the waste composition of Sirajganj will be considered similar to the one of Rajshahi (I. Enayetullah et. al., 2005) and it will be assumed that the composition will remain constant.

Table 45 : Sirajganj - Waste Composition

Waste streams	Unit	Compositio
Organic fraction (vegetable + wood)	%	73.4%
Plastic	%	8.0%
Paper	%	6.3%
Metal	%	0.0%
Textile waste	%	3.4%
Glass	%	1.3%
Other	%	7.5%

7.2.4.2 Concept

Preliminary Storage Area

Unloading Area

In order to allow the simultaneous unload of 4 trucks in the unloading zone, a ramp of 18 meter width will be considered. This dimension will therefore fix the width of the building.

Dumping area

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone; according to the capacity of the dumping zone (about 40m^3), this operation will have to be performed 4 times a day in 2020 and 7 times a day in 20.

Transfer area

Estimating that the waste loader has a turning radius of 10m, it is necessary to create a transfer zone of at least this length to ensure the smooth moving of the machine.

Preliminary Storage

The preliminary storage area will be designed by considering a storing capacity of 4 days. This 4 days may correspond to facility maintenance period or period of religious/cultural day off during which the facility will not be operated. As a consequence, the volume to be stored must be equal to:

Parameters	Unit	2020	2030
Total capacity of the PSA	m^3	260	487

The average storage height is about 2.5 meters. Because some waste loaders have a magnitude of over 4 meters, it may be considered to store until 3.5m. These both criteria will be used to determine the minimal length of the storage area for both 2020 and 2030.

Through an iterative process, the optimal dimension of the storing zone is 13 meters; this length will ensure a storage height of waste of 1.3 meters in 2020 and of 2.5 meters in 2030.

Conclusion

According to the previous element, the Preliminary Storage Area will have the following dimensions:

- Height : 4.5 meters
- Width : 18 meters
- Length : 24 meters

Sorting Hall

Feedstock for Anaerobic Digestion (Drum sieve)

According to practical experience, a recovery rate of 60% for organic material and of 10% for the other components will be considered.

The following mass balance can therefore be realized :

Waste stream	Unit	2020	2030
Waste stream for AD	t/d	17	32
Biomass	t/d	16	30
Other	t/d	1	2
Elements	t/d	19	36
Waste for sorting	m³/d	40	73

The operating time for this type of trammel is given below :

Average Operating time per	Unit	2020	2030
Capacity 30 m³/h	h	2.4	4.5
Capacity 55 m³/h	h	1.3	2.5
Capacity 80 m³/h	h	0.9	1.7

Depending on the capacity, the number of machine and the possibility to use the trammel for other purposes (compost) will evolve.

The preliminary design of the sorting hall is given below :

- Length : 70 m
- Width : 36 m

Recyclable material

According to the recovery rate given above, the following amount of material that can be recovered is :

Sorting - Recovery	Unit	2020	2030
Plastic	t/d	1.3	2.4
Paper	t/d	0.8	1.5
Textile	t/d	0.8	1.6

A single line will sufficient to sort the whole quantity of waste. The operating time for sorting will depend on the capacity of the drum sieve.

Technical parameters	Unit	2020	2030
Volume of waste to be sorted per day	m^3	38.8	72.6
Supply			
30 m^3/h drum sieve	h	1.3	2.4
55 m^3/h drum sieve	h	0.7	1.3
80 m^3/h drum sieve	h	0.5	0.9

Storage area

A storage area will be defined for temporary storage of recycled material. The storage capacity will depend on the number of removal that could be operated. This parameter will have to be defined after a deeper investigation and discussion with the potential recyclers. An example of storage design is given below.

Type of waste	Year	Storage capacity before removal	Type and capacity of containers
Plastic	2020	9.2 days	1 container of $40m^3$
	2030	4.9 days	1 container of $40m^3$
	2030	9.8 days	2 containers of $40m^3$
Paper	2020	4.1 days	1 container of $40m^3$
	2020	8.2 days	2 containers of $40m^3$
	2030	4.,4day	2 containers of $40m^3$
	2030	6.6 days	3 containers of $40m^3$
Textile	2020	7 days	1 box of 72 m^2
	2030	7 days	1 box of 72 m^2
Inert			1 box of 108 m^2 (capacity 320

Treatment & Recovery of Biowaste

Anaerobic digester

Considering a retention time of 25 days, the following reactor's volumes are required :

Anaerobic digester- Parameters	Unit	2020	2030
Operational volume			
Feedstock	t/d	17	31.8
Operational volume	m^3	467	875

Therefore, an operational volume of about 900 m^3 will be proposed. The dimensions of the reactor are given below.

Reactor dimensions		
Length	m	25
Width	m	6
Height	m	7

Biogas storage and valorization

The gas production is estimated around:

- 1,500 Nm^3/d by 2020
- 2,900 Nm^3/d by 2030.

It is proposed to use a part of the biogas for electricity production with an engine; the other part will be stored a flexible double membrane gas holder before treatment and conditioning or supply. The choice of the engine will be determined by the maximal capacity of the double membrane gas holder (50 – 5,500 Nm^3).

Because of the expecting production, it is proposed to start the electricity production onsite with a 50 kW engine.

The remaining fraction of biogas will be stored in a flexible double membrane gas holder before being converted into LNG or CBM.

A 4,000 Nm^3 gas holder will be selected, enabling a storage capacity of 2.5 days by 2020 and 1.5 day by 2030. Note that a second engine may be installed in a later phase in order to increase the production of electricity.

Composting area

The composting hall will be designed according to the volume of biowaste by 2030.

E.2 Composting	Unit	2020	2030
Flow from digester	t/d	15.2	28.4
Structuring matter	t/d	3.0	5.7
Total input	t/d	18.2	34.1
Total output	t/d	7	14
Production of compost after	t/d	6.2	11.6
Residue from separation (structuring)	t/d	1.1	2.0
Need of structuring material	t/d	1.9	3.6

The preliminary design of the composting hall is given below :

- Length : 120 m
- Width : 60 m
- Height : 4.5 m

Other Streams
Waste Water
Considering closed building with separation of rainfall and leachate from the PSA, the waste water flow to be treated will be equal to

- 9 m^3/d by 2020
- 17 m^3/d by 2030

Residue for incineration/landfill
The recycling and biological treatment leads to the reduction by 55% of the amount of residue that should be either incinerated or landfilled.

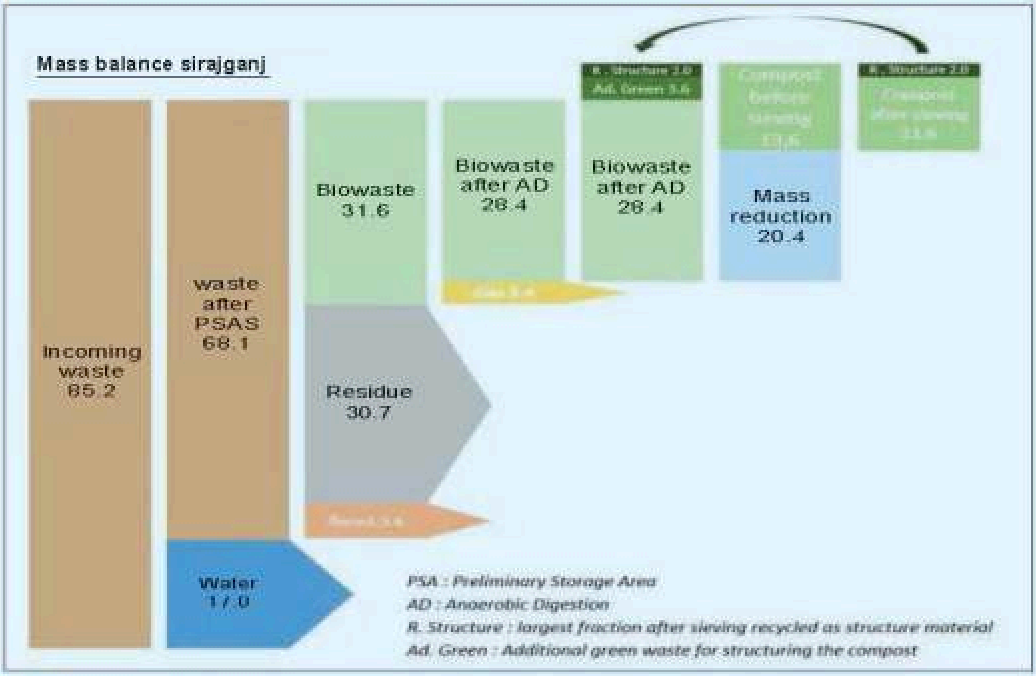
Residue for landfill/incineration	Unit	2020	2030
Residue	t/d	16.4	30.7

Location and area requirements
At the moment of the Study, it was unclear to the Municipality where to locate the area for the waste treatment facility. When this information will become available, it should be integrated in a detailed study. The area requirements are described in section 7.4. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway.

Logistical aspects
An efficient logistic system needs to be designed once the location of the Environmental park is known. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway. Another important factor is that the feedstock must be located close to the waste treatment plant.

7.2.4.3 Mass Balance

Figure 73 : Mass Balance - Case of Sirajganj



7.2.5 Habiganj

7.2.5.1 Background Information

Localization

Jessore is a city in the south-western part of Bangladesh, in the Khulna Division. It is the main city of the Jessore District (2,607 sq. km). Jessore Paurashava, which territory occupies 14,71 sq.km, is sub- divided in 9 wards (Geocode from 01 – Ward N° - 01 to 09– Ward N° 09). The Paurashava is administrated by MD Rantu Chakladar.

The City is situated on the banks of the Bhairab River.

Climate

The City is located in the south-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 11°C to 37°C and an annual average precipitation of 1,537 mm.

The Average Humidity is equal to 75.54%.

The Paurashava is situated at an average altitude between 15m and 20m.

Population

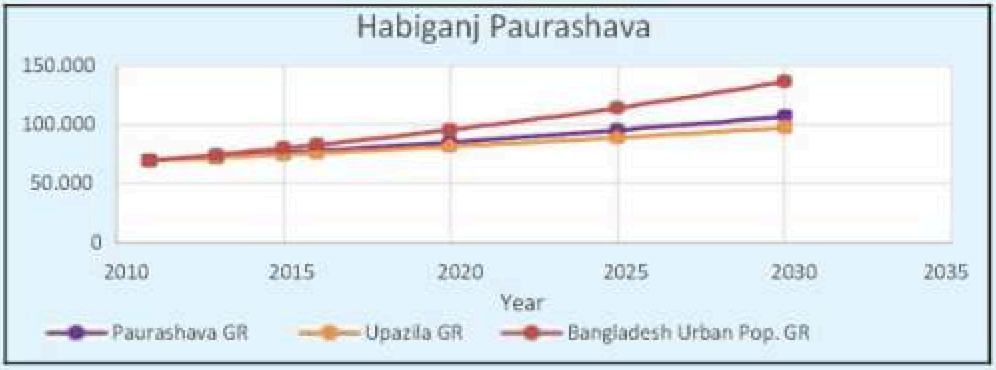
According to the questionnaire results and the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Habiganj Paurashava rises from 55,476 persons in 2001 to 69,512 persons in 2011, implying an average population growth rate of 2.28%, higher than the Upazila average population growth rate estimated at 1.78%. The population density of the Upazila is 1297 cap/sq. km.

The following Table 46 give the projection of Population for Habiganj Paurashava according to various Population Growth Rate (PGR).

Table 46 : Habiganj - Population Projection 2011 - 2030

PGR	Average 2001-2011 Paurashava	Average 2001-2011 Upazila	Bangladesh Urban Dev
	2.3%	1.8%	3.6%
2011	69,512	69,512	69,512
2013	72,719	72,009	74,607
2015	76,075	74,595	80,075
2016	77,810	75,923	82,958
2020	85,157	81,475	95,565
2025	95,323	88,989	114,050
2030	106,702	97,196	136,112

Figure 74 : Habiganj - Population forecast



Note that for this preliminary design, a population growth rate of 2.3% will be considered.

Waste Generation

Several assumptions are proposed to evaluate the waste production over the next decade.

First, it is important to evaluate the average Waste Growth Rate (WGR). According to data from Waste Concern (2013) and ADB (projection 2025), the national WGR will increase from about 1.5% annually. The same trend will therefore be applied to Habiganj's WGR.

No information is available on Waste Collection Rate by 2013. According to Waste Concern (I. Enayetullah & all, 2005), the Waste Collection Rate of Paurashava by 2005 was about 55%. The data collected from the Municipality show that the waste management system in Habiganj is not efficient yet; as a consequence, we will assume that the collection rate by

2013 was similar to the one of 2005. The development of WtE solution will require the enhancement of the Waste Management System; therefore, the collection rate will be increase gradually from 55% by 2013 to 98% by 2030.

The Table 47 shows the results of the projection:

Table 47 : Habiganj - Waste Generation

Parameter	Unit	2013	2020	2025	2030
Population	inh.	72	85 157	95	106
Waste production					
Average Waste Generation Rate	kg/cap/	0,31	0,35	0,37	0,40
Daily average waste production	t/d	23	30	36	43
Annualaverage waste production	t/yr	8 336	10 802	12	15 642
Collection rate	%	55%	75%	90%	98%
Daily average waste for treatment	t/d	13	22	32	42
Annual average waste for treatment	t/yr	4 585	8 102	11	15 329

Waste streams

The waste composition is an important parameter because it gives precious information on the recycling/recovery potential of waste.

According to the hypothesis taken in the Interim Report, the waste composition of Habiganj will be considered similar to the one of Sylhet (I. Enayetullah et. al., 2005) and it will be assumed that the composition will remain constant.

Table 48 : Habiganj - Waste Composition

Waste streams	Unit	Compositio
Organic fraction (vegetable + wood)	%	79,6%
Plastic	%	5,3%
Paper	%	5,2%
Metal	%	0,2%
Textile waste	%	1,6%
Glass	%	0,9%
Other	%	7,0%

7.2.5.2 Concept

Preliminary Storage Area

Unloading Area

In order to allow the simultaneous unload of 2 trucks in the unloading zone, a ramp of 12 meter width will be considered. This dimension will therefore fix the width of the building.

Dumping area

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone; according to the capacity of the dumping zone (about 24 m^3), this operation will have to be performed 4 times a day in 2020 and 7 times a day in 2030.

Transfer area

Estimating that the waste loader has a turning radius of 10m, it is necessary to create a transfer zone of at least this length to ensure the smooth moving of the machine.

Preliminary Storage

The preliminary storage area will be designed by considering a storing capacity of 4 days. This 4 days may correspond to facility maintenance period or period of religious/cultural day off during which the facility will not be operated. As a consequence, the volume to be stored must be equal to :

Parameters	Unit	2020	2030
Total capacity of the PSA	m^3	148	280

The average storage height is about 2.5 meters. Because some waste loaders have a magnitude of over 4 meters, it may be considered to store until 3.5m. These both criteria will be used to determine the minimal length of the storage area for both 2020 and 2030.

Through an iterative process, the optimal dimension of the storing zone is 13 meters; this length will ensure a storage height of waste of 1.1 meters in 2020 and of 2.2 meters in 2030.

Conclusion

According to the previous element, the Preliminary Storage Area will have the following dimensions:

- Height : 4.5 meters
- Width : 12 meters
- Length : 24 meters

Sorting Hall

Feedstock for Anaerobic Digestion (Drum sieve)

According to practical experience, a recovery rate of 60% for organic material and of 10% for the other components will be considered.

The following mass balance can therefore be realized:

Waste stream	Unit	2020	2030
Waste stream for AD	t/d	10.3	19.5
Biomass	t/d	10	19
Other	t/d	0.3	0.5
Elements	t/d	10.4	20
Waste for sorting	m^3/d	21	39

The operating time for this type of trammel is given below:

Average Operating time per	Unit	2020	2030
Capacity 30 m^3/h	h	1.4	2.6
Capacity 55 m^3/h	h	0.8	1.4
Capacity 80 m^3/h	h	0.5	1.0

Depending on the capacity, the number of machine and the possibility to use the trammel for other purposes (compost) will evolve.

The preliminary design of the sorting hall is given below:

- Length : 70 m
- Width : 36 m

Recyclable material

According to the recovery rate given above, the following amount of material that can be recovered is:

Sorting - Recovery	Unit	2020	2030
Plastic	t/d	0.5	0.9
Paper	t/d	0.4	0.7
Textile	t/d	0.2	0.4
Metal	t/d	0.0	0.1

A single line will sufficient to sort the whole quantity of waste. The operating time for sorting will depend on the capacity of the drum sieve.

Technical parameters	Unit	2020	2030
Volume of waste to be sorted per day	m^3	20.8	39.3
Supply			
30 m^3/h drum sieve	h	0.7	1.3
55 m^3/h drum sieve	h	0.4	0.7
80 m^3/h drum sieve	h	0.3	0.5

Storage area

A storage area will be defined for temporary storage of recycled material. The storage capacity will depend on the number of removal that could be operated. This parameter will have to be defined after a deeper investigation and discussion with the potential recyclers. An example of storage design is given below.

Type of waste	Year	Storage capacity before	Type and capacity of containers
Plastic	2020	6 days	1 container of 10m³
	2030	3.2 days	1 container of 10m³
	2030	6.4 days	2container of 10m³
Paper	2020	4.6days	1 container of 20m³
	2020	8.7 days	2 containers of 20m³
	2030	4 .4days	2 containers of 20m³
	2030	6.9 days	3 containers of 20m³
Textile	2020	12.4days	1 container of 40m³
	2030	6.5days	1 container of 4 0m³
Metal	2020	9 days	1 container of 1m³
	2030	5 days	1 container of 1m³
Inert			1 box of 108 m² (capacity 320

Treatment And Recovery Of Biowaste

Anaerobic digester

Considering a retention time of 25 days, the following reactor's volumes are required:

Anaerobic digester - Parameters	Unit	2020	2030
Operational volume			
Feedstock	t/d	10	19.5
Operational volume	m³	284	537

Therefore, an operational volume of about 550 m³ will be proposed. The dimensions of the reactor are given below.

Reactor	m	22
dimensions	m	5
Length	m	6

Biogas storage and valorization

The gas production is estimated around:

- 950 Nm³/d by 2020
- 1,800 Nm³/d by 2030.

It is proposed to use a part of the biogas for electricity production with an engine; the other part will be stored a flexible double membrane gas holder before treatment and conditioning or supply. The choice of the engine will be determined by the maximal capacity of the double membrane gas holder (50 – 5,500 Nm³).

Because of the expecting production, it is proposed to start the electricity production onsite with a 50 kW engine.

The remaining fraction of biogas will be stored in a flexible double membrane gas holder before being converted into LNG or CBM.

A 4,000 Nm³ gas holder will be selected, enabling a storage capacity of about 4 days by 2020 and 2 days by 2030. Note that a second engine may be installed in a later phase in order to increase the production of electricity.

Composting area
The composting hall will be designed according to the volume of biowaste by 2030.

E.2 Composting	Unit	2020	2030
Flow from digestor	t/d	9.2	17.4
Structuring matter	t/d	1.8	3.5
Total input	t/d	11.0	20.9
Total output	t/d	4	8
Production of compost after	t/d	3.8	7.1
Residue from separation (structuring)	t/d	0.7	1.3
Need of structuring material	t/d	1.2	2.2

The preliminary design of the composting hall is given below :

- Length : 100 m
- Width : 55 m
- Height : 4.5 m

Other Streams
Waste Water
Considering closed building with separation of rainfall and leachate from the PSA, the waste water flow to be treated will be equal to

- 5 m³/d by 2020
- 10 m³/d by 2030

Residue for incineration/landfill

The recycling and biological treatment leads to the reduction by 55% of the amount of residue that should be either incinerated or landfilled.

Residue for landfill/incineration	Unit	2020	2030
Residue	t/d	9.2	17.5

Location and area requirements
At the moment of the Study, it was unclear to the Municipality where to locate the area for the waste treatment facility. When this information will become available, it should be integrated in a detailed study. The area requirements are described in section 7.4. There must be taken into account that the site should be easily accessible to elaborate efficient

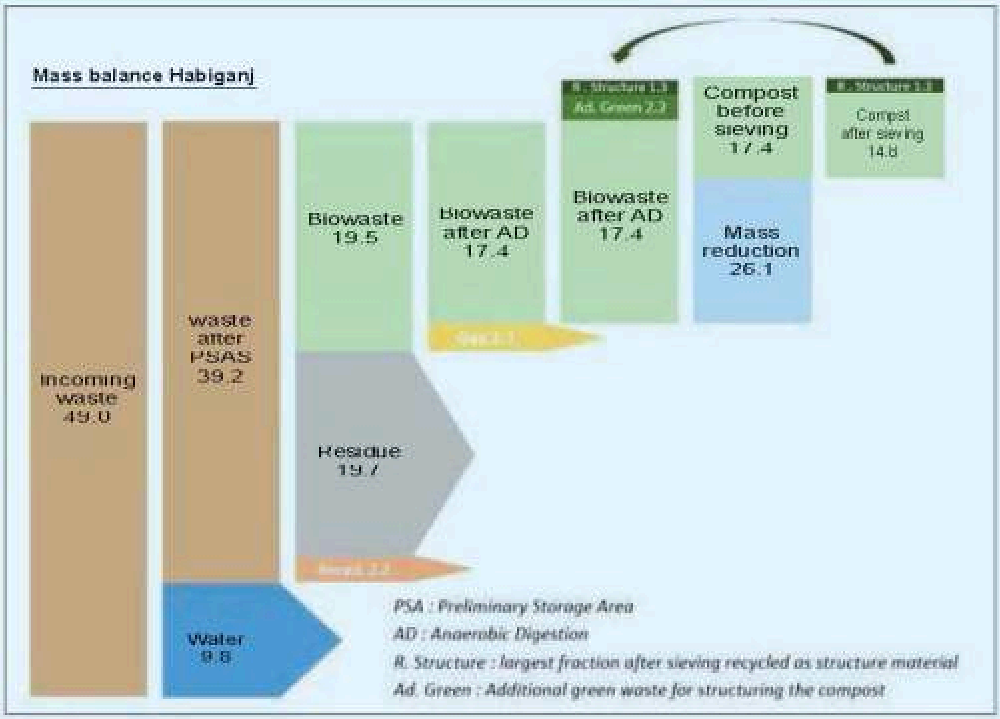
transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway.

Logistical aspects

An efficient logistic system needs to be designed once the location of the Environmental Park is known. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway. Another important factor is that the feedstock must be located close to the waste treatment plant.

7.2.5.3 Mass Balance

Figure 75 : Mass Balance - Case of Habiganj



7.2.6 Jessore

7.2.6.1 Background Information

Localization

Jessore is a city in the south-western part of Bangladesh, in the Khulna Division. It is the main city of the Jessore District (2,607 sq. km). Jessore Paurashava, which territory occupies 14,71 sq.km, is sub- divided in 9 wards (Geocode from 01 – Ward N° - 01 to 09– Ward N° 09). The Paurashava is administrated by MD Rantu Chakladar.

The City is situated on the banks of the Bhairab River.

Climate

The City is located in the south-western climatic sub-region (Rashid, Haroun Er), characterized by temperatures from 11°C to 37°C and an annual average precipitation of 1,537 mm.

The Average Humidity is equal to 77.96%.

The Paurashava is situated at an average altitude between 4m and 9m.

Population

According to the questionnaire results and the Population and Housing Census 2011 performed by the Bangladesh Bureau of Statistics, the population of Jessore Paurashava rises from 176,655 persons in 2001 to 201,796 persons in 2011, implying an average population growth rate of 1.34%, slightly higher than the Upazila average population growth rate estimated at 1.42%. The population density of the Upazila is 1707 cap/sq. km.

The following Table 49 and Figure 79 give the projection of Population for Jessore's Paurashava according to various Population Growth Rate (PGR).

Table 49 : Jessore - Population Projection 2011 - 2030

PGR	Average 2001-2011 Paurashava	Average 2001-2011 Upazila	Bangladesh Urban Dev.
	1.3%	1.4%	3.6%
2011	202,29	202,296	202,296
2013	207,75	208,082	217,123
2015	213,35	214,033	233,038
2016	216,21	217,073	241,427
2020	228,03	229,668	278,115
2025	243,71	246,444	331,913
2030	260,48	264,445	396,116

Figure 76 : Jessore - Population forecast

Note that for this preliminary design, a population growth rate of 1.3% will be considered.

Waste Generation

General projection on waste production

Several assumptions are proposed to evaluate the waste production over the next decade.

First, it is important to evaluate the average Waste Growth Rate (WGR). According to data from Waste Concern (2013) and ADB (projection 2025), the national WGR will increase from about 1.5% annually. The same trend will therefore be applied to Jessore's WGR.

No information is available on Waste Collection Rate by 2013. According to Waste Concern (I. Enayetullah et. al, 2005), the Waste Collection Rate of Paurashava by 2005 was about 55%. The data collected from the Municipality show that the waste management system in Jessore is not efficient yet; as a consequence, we will assume that the collection rate by 2013 was similar to the one of 2005. The development of WtE solution will require the enhancement of the Waste Management System; therefore, the collection rate will be increase gradually from 55% by 2013 to 98% by 2030.

The Table 50 shows the results of the projection :

Parameter	Unit	2013	2020	2025	2030
Population	nh.	207	228	243	260
Waste production					
Average Waste Generation Rate	kg/cap/	0,24	0,27	0,29	0,31
Daily average waste production	t/d	50	60	69	80
Annual average waste production	t/yr	18,177	22,078	25,367	29,145
Collection rate	%	55%	75%	90%	98%
Daily average waste for treatment	t/d	27	45	63	78
Annual average waste for treatment	t/yr	9,997	16,558	22,830	28,562

Waste streams

The waste composition is an important parameter because it gives precious information on the recycling/recovery potential of waste.

According to the hypothesis taken in the Interim Report, the waste composition of Jessore will be considered similar to the one mentioned in the study realized by the University of Jessore (Characteristics of Household Solid Waste and its Management Options in the Urban Areas, Jessore, Bangladesh, 2014) and it will be assumed that the composition will remain constant.

Table 51 : Jessore - Waste Composition

Waste streams	Unit	Compositio
Organic fraction (vegetable + wood)	%	91,3%
Plastic	%	1,2%
Paper	%	1,7%
Metal	%	0,7%
Textile waste	%	0,6%
Glass	%	1,5%
Other	%	3,1%

7.2.6.2 Concept

Preliminary Storage Area

Unloading Area

In order to allow the simultaneous unload of 4 trucks in the unloading zone, a ramp of 18 meter width will be considered. This dimension will therefore fix the width of the building.

Dumping area

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone; according to the capacity of the dumping zone (about 40m³), this operation will have to be performed 4 times a day in 2020 and 7 times a day in 2030.

Transfer area

Estimating that the waste loader has a turning radius of 10m, it is necessary to create a transfer zone of at least this length to ensure the smooth moving of the machine.

Preliminary Storage

The preliminary storage area will be designed by considering a storing capacity of 4 days. This 4 days may correspond to facility maintenance period or period of religious/cultural day off during which the facility will not be operated. As a consequence, the volume to be stored must be equal to:

Parameters	Unit	2020	2030
Total capacity of the PSA	m^3	302	522

The average storage height is about 2.5 meters. Because some waste loaders have a magnitude of over 4 meters, it may be considered to store until 3.5m. These both criteria will be used to determine the minimal length of the storage area for both 2020 and 2030.

Through an iterative process, the optimal dimension of the storing zone is 13 meters; this length will ensure a storage height of waste of 1.6 meters in 2020 and of 2.7 meters in 2030.

Conclusion
According to the previous element, the Preliminary Storage Area will have the following dimensions:

- Height : 4.5 meters
- Width : 18 meters
- Length : 24 meters

Sorting Hall
Feedstock for Anaerobic Digestion (Drum sieve)
According to practical experience, a recovery rate of 60% for organic material and of 10% for the other components will be considered.

The following mass balance can therefore be realized:

Waste stream	Unit	2020	2030
Waste stream for AD	t/d	24	41
Biomass	t/d	23	40
Other	t/d	1	1
Elements	t/d	19	32
Waste for sorting	m^3/d	38	65

The operating time for this type of trammel is given below

Average Operating time per	Unit	2020	2030
Capacity 30 m^3/h	h	2.8	4.9
Capacity 55 m^3/h	h	1.5	2.7
Capacity 80 m^3/h	h	1.1	1.8

Depending on the capacity, the number of machine and the possibility to use the drum sieve for other purposes (compost) will evolve.

The preliminary design of the sorting hall is given below :

- Length : 70 m
- Width : 36 m

Recyclable material
According to the recovery rate given above, the following amount of material that can be recovered is:

Sorting - Recovery	Unit	2020	2030
Plastic	t/d	0.2	0.4
Paper	t/d	0.3	0.4
Textile	t/d	0,2	0.3
Metal	t/d	0,2	0.4

A single line will sufficient to sort the whole quantity of waste. The operating time for sorting will depend on the capacity of the drum sieve.

Technical parameters	Unit	2020	2030
Volume of waste to be sorted per day	m^3	37.6	64.8
30 m^3/h drum sieve	h	1.3	2.2
55 m^3/h drum sieve	h	0.7	1.2
80 m^3/h drum sieve	h	0.5	0.8

Storage area

A storage area will be defined for temporary storage of recycled material. The storage capacity will depend on the number of removal that could be operated. This parameter will have to be defined after a deeper investigation and discussion with the potential recyclers. An example of storage design is given below.

Type of waste	Year	Storage capacity before	Type and capacity of
Plastic	2020	13.2 days	1 container of 10m^3
	2030	7.7 days	1 container of 10m^3
Paper	2020	6.7 days	1 container of 20m^3
	2030	3.9 days	1 container of 20m^3
	2030	7.7days	2 containers of 20m^3
Textile	2020	15.5 days	1 container of 40m^3
	2030	9 days	1 container of 40m^3
Metal	2020	7 days	1 container of 5m^3
	2030	4 days	1 container of 5m^3
	2030	9 days	2 containers of 5m^3
Inert			1 box of 108 m^2 (capacity 320

Treatment And Recovery of Biowaste

Anaerobic digester

Considering a retention time of 25 days, the following reactor's volumes are required :

Anaerobic digestor - Parameters	Unit	2020	2030
Operational volume			
Feedstock	t/d	23.6	40.6
Operational volume	m^3	648	1117

Therefore, an operational volume of about 1,100 m^3 will be proposed. The dimensions of the reactor are given below.

Reactor dimensions		
Lenght	m	32
Width	m	6
Height	m	7

Biogas storage and valorization
The gas production is estimated around:

- 2,100 Nm^3/d by 2020
- 3,700 Nm^3/d by 2030.

It is proposed to use a part of the biogas for electricity production with an engine; the other part will be stored a flexible double membrane gas holder before treatment and conditioning or supply. The choice of the engine will be determined by the maximal capacity of the double membrane gas holder (50 – 5,500 Nm^3).

Because of the expecting production, it is proposed to start the electricity production onsite with a 50 kW engine.

The remaining fraction of biogas will be stored in a flexible double membrane gas holder before being converted into LNG or CBM.

A 4,000 Nm^3 gas holder will be selected, enabling a storage capacity of about 2.5 days by 2020 and

1.5 days by 2030. Note that a second engine may be installed in a later phase in order to increase the production of electricity.

Composting area
The composting hall will be designed according to the volume of biowaste by 2030.

E.2 Composting	Unit	2020	2030
Flow from digestor	t/d	21.0	36.2
Structuring matter	t/d	4.2	7.2
Total input	t/d	25.2	43.5
Total output	t/d	10	17
Production of compost after	t/d	8.6	14.8
Residue from separation (structuring)	t/d	1.5	2.6
Need of structuring material	t/d	2.7	4.6

The preliminary design of the composting hall is given below:

- Length : 110 m
- Width : 70 m
- Height : 4.5 m

Other Streams
Waste Water
Considering closed building with separation of rainfall and leachate from the PSA, the waste water flow to be treated will be equal to

- 11 m^3/d by 2020
- 18 m^3/d by 2030

Residue for incineration/landfill

The recycling and biological treatment leads to the reduction by 58% of the amount of residue that should be either incinerated or landfilled.

Residue for landfill/incineration	Unit	2020	2030
Residue	t/d	17.9	30.9

Location and area requirements

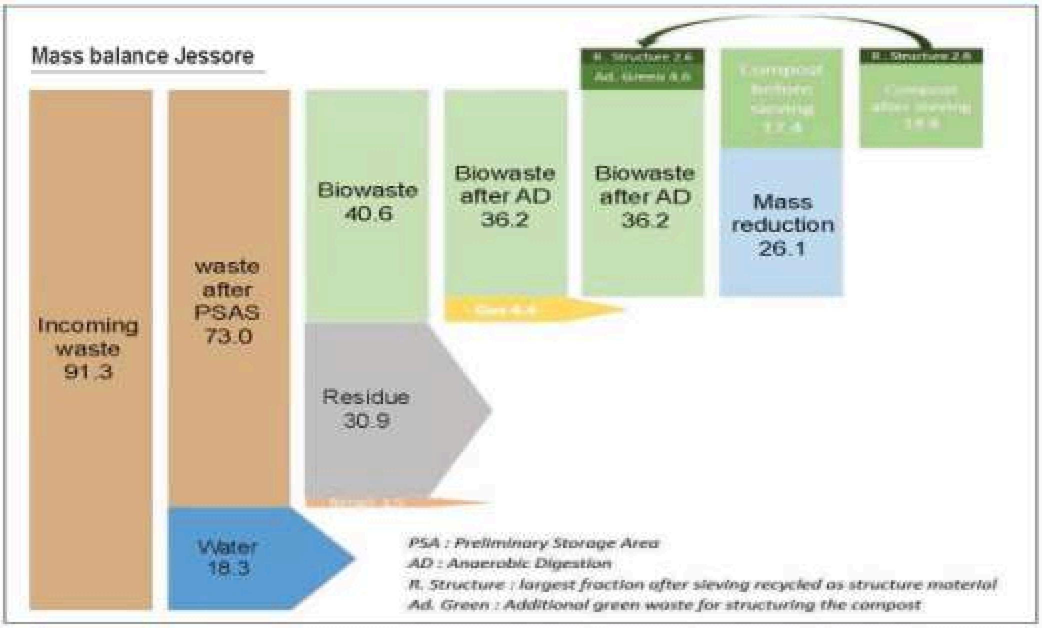
At the moment of the Study, it was unclear to the Municipality where to locate the area for the waste treatment facility. When this information will become available, it should be integrated in a detailed study. The area requirements are described in section 7.4. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway.

Logistical aspects

An efficient logistic system needs to be designed once the location of the Environmental park is known. There must be taken into account that the site should be easily accessible to elaborate efficient transport systems, either for trucks by laying out paved roads and/or for ships by choosing the location close to a waterway. Another important factor is that the feedstock must be located close to the waste treatment plant.

7.2.6.3 Mass Balance

Figure 77 : Mass Balance - Case of Jessore



7.3 General Layout Plan of The Environmental Park Modular Design 1

The Plan below presents the overall concept of the Demonstration Plant of Modular Design 1. Note that the design and the location of each infrastructure will be adapted to the local situation once the implementation site will have be defined in full cooperation with the Local Authorities.

Figure 78: General layout plan of the environmental park

7.4 Area Requirements of Proposed Projects

7.4.1 Area Requirements Modular Design 1: Ad+Recycling + Composting

The table below summarizes the required sizes of each major installation on the layout plan of the Environmental Park of Modular Design 1. If in a later stage the Client prefers not to treat the digestate on the territory of the environmental park, the composting module could be left out of the equation, resulting in a total surface area of about half of the initial environmental park surface. One can remark that the variation between municipalities of the total surface required is related to the variation of the forecasted population size.

Table 52: Modular area requirements (m²) for Modular Design 1 for the six Municipalities for basis scenario

Area (m²)	Mymensingh	Cox's Bazar	Dinajpur	Sirajganj	Habiganj	Jessore
prelimina ry storage area	648	648	648	432	288	432
Sorting hall	2520	2520	2520	1400	840	1400
Storage	432	432	432	360	360	360
Composting	10833	11146	13003	7531	6327	8553
Anaerobic digestion	4629	2469	2025	1080	1041	964
TOTAL infrastructure	19061	17214	18628	10803	8856	11709
TOTAL SURFACE (inclusive roads, sides, water treatment, fences)	23159	20910	22.633	13126	10760	14227

Table 53: Total area requirements (m^2) for Modular Design 1 for the six Municipalities basis and large scenario

Amount (dollar)	Modular Design 1		Modular Design 2 (gasification with recuperation of energy)	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Mymensingh	23.159	26.415	28.339	33.321
Cox's Bazar	20.910	26.918	26.095	33.824
Dinajpur	22.633	26.241	27.813	33.147
Habiganj	10.760	14.495	15.940	21.401
Jessore	14.227	20.236	19.406	27.142
Sirajganj	13.127	20.280	18.306	27.186

7.4.2 Area Requirements Modular Design 2: Ad + Gasification + Composting

As a matter of comparison, the table below summarizes the area requirements of Modular Design 2 for Mymensingh, next to the area requirements of Modular design 1.

Table 54: Comparison table area requirements Mymensingh between Modular Design 1 and Modular Design 2

	Modular Design 1: AD + recycling+composting (m^2)	Modular Design 2 AD + gasification + composting (m^2)
Preliminary storage area	648	648
Sorting hall	2520	2520
Storage	432	432
Composting	10833	10833
Anaerobic digestion	4629	3086
Drying facility + Gasification	-	4455
TOTAL infrastructure	19061	23516

It can be remarked that the essential pretreatment step, requiring drying and the gasification installation itself, occupies requires additional space, which is not needed in Modular Design 1.

7.5 Financial Aspects

7.5.1 Estimation of Investment Costs

The total investment costs of the integrated WtE facilities, i.e. the maximum amount for the installation for all the modules of the proposed project depending on the characteristics of the Municipality concerned. Of course, when certain modules would be left out of the calculation, investment cost would be reduces along with the associated revenues from the eliminated module.

Note that this evaluation has been performed using international prices, and therefore constitute a preliminary estimation that has to be supported by a detailed financial analysis, as proposed in the Conclusion.

7.5.1.1 Estimation of investment costs modular

Design 1 Mymensingh

Table 55: Total investment cost of the integrated W2E facilities of modular design 1 and 2 for all municipalities.

N°	Description	Unit	Amount	Unit Price USD	Total USD
1	Entrance Area				
1.1	Entrance gate	FR	1	5.000	5.000
1.2	Weighbridge	FR	2	37.000	74.000
1.3	Wheel washing	FR	2	10.000	20.000
1.4	Fences	m	665	13	8.645
1.5	Administrative building and sanitary block	FR	1	130.00	130.000
1.6	Pavement and roads	m^2	1800	25	45.000
	Subtotal - Entrance Area				282.645
2	Pretreatment				
2.1	Preliminary Storage Area				
2.1.1	Civil Engineering	FR	1		460.500
	Slab- floor	m^2	648	500	324.000
	Ramp area	m^2	198	200	39.600
	Roof	m^2	646	150	96.900
2.1.2	Buldozer (Loader)	U	1	100.00	100.000
2.2	Sorting area				
2.2.1	Civil Engineering	FR	1	929.00	929.000
	Concrete area around the installation	m^2	2.520	160	403.200
	Light covering structure	m^2	2.627	200	525.400
2.2.2	Sorting line	FR	1	127.00	127.000
	Conveyor belt	FR	1	58.000	58.000
	Hopper	FR	1	69.000	69.000
2.3	Storage area				
2.3.1	Civil Engineering	FR	1	166.00	166.000
	Concrete area around the installation	m^2	432	160	69.120
	Light covering structure	m^2	481	200	96.200
	Sub total - Pretreatment				1.782.50
3	Anaerobic Digestion				
3.1	Civil Engineering	m^2	8857	95	841.429
3.2	Pretreatment (mixing)	FR	1	264.40	264.400
3.3	Biodigester	m^2	960	2.600	2.496.00
3.4	CHP	FR	1	212.000	212.000
		kW	200	1.060	212.000
3.5	Post -treatment	FR	1	159.000	159.000
3.6	Technical building - HV/LV- SPS - Piping	FR	1	529.000	529.000
3.7	Additional costs (stakes for stability, etc.)	FR	1		
			150	2.000	
	Sub total - Anaerobic Digestion				4.501.829
4	Composting				
4.1	Civil Engineering	FR	1	3.129.94	3.129.947
	Concrete area around the installation	m^2	10.83	85	920.774
	Light covering structure	m^2	11.04	200	2.209.174
4.2	Buldozer (Loader)	U	1	100.000	100.000
4.3	Sieving equipment + spare sieves 0/40 0/25 0/10	U	1	185.000	185.000
4.4	Crusher equipment (crusher, conveyor belt, hopper)	U	1	360.000	360.000
4.5	Turner	U	1	50.000	50.000
	Sub Total -Composting				3.824.947
5	Water treatment				
5.1	Retention tank	m^2	475	480	228.043
5.2	Water treatment	m^3	2375	160	380.071
5.3	Intermediate Storage	m^3	475	420	199.537
5.4	Equipment	FT	1	370.160	370.160
	Mixers		1	211.520	
	Pump		1	158.640	
	Sub total - Water treatment				1.177.811
	Sub total				11.569.732
	Contingencies / Other expenses :	20			1.988.661
	TOTAL	%			13.558.392

Cox's Bazar

N°	Description	Unit	Amount	Unit Price USD	Total USD
1	Entrance Area				
1.1	Entrance gate	FR	1	5.000	5.000
1.2	Weighbridge	FR	2	37.000	74.000
1.3	Wheel washing	FR	2	10.000	20.000
1.4	Fences	m	665	13	8.645
1.5	Administrative building and sanitary	FR	1	130.00	130.00
1.6	Pavement and roads	m^2	1800	25	45.000
	Sub total Entrance Area				282.64
2	Pretreatment				
2.1	Preliminary Storage Area				
2.1.1	Civil Engineering	FR	1		477.60
	Slab floor	m^2	648	500	324.000
	Ramp area	m^2	198	200	39.600
	Roof	m^2	760	150	114000
2.1.2	Buldozer (Loader)	U	1	100.00	100.00
2.2	Sorting area				
2.2.1	Civil Engineering	FR	1	929.00	929.00
	Concrete area around the installation	m^2	2.520	160	403.200
	Light covering structure	m^2	2.627	200	525.400
2.2.2	Sorting line	FR	1	127.000	127.000
	Conveyor belt	FR	1	58.000	58.000
	Hopper	FR	1	69.000	69.000
2.3	Storage area				
2.3.1	Civil Engineering	FR	1	166.000	166.000
	Concrete area around the installation	m^2	432	160	69.120
	Light coverin gstructure	m^2	481	200	96.200
	Sub total - Pretreatment				1.799.600
3	Anaerobic Digestion				
3.1	Civil Engineering	m^2	2069	95	196.514
3.2	Pretreatment (mixing)	FR	1	264.400	264.400
3.3	Biodigester	m^2	256	2.600	665.600
3.4	CHP	FR	1	159.000	159.000
		kW	150	1.060	159.000
3.5	Post-treatment	FR	1	159.000	159.000
3.6	Technical building-HV/LV- SPS - Piping	FR	1	529.000	529.000
3.7	Additional costs (stakes for stability, etc.)	FR	1		
			150	2.000	
	Sub total Anaerobic Digestion				1.973.5 14
4	Composting				
4.1	Civil Engineering	FR	1	3.219.71	3.219.712
	Concrete area around the installation	m^2	11.14	85	947.398
	Light covering structure	m^2	11.36	200	2.272.314
4.2	Buldozer (Loader)	U	1	100.000	100.000
4.3	Sieving equipment + spa re sieves 0/40 0/25 0/10	U	1	185.000	185.000
4.4	Crusher equipment (crusher, conveyor belt, hopper)	U	1	360.000	360.000
4.5	Turner	U	1	50.000	50.000
	Sub total Composting				3.914.712

5	Water treatment				
5.1	Retention tank	m³	246	480	118.152
5.2	Water treatment	m³	1231	160	196.920
5.3	Intermediate Storage	m³	246	420	103.383
5.4	Equipment	FT	1	370.160	370.160
	Mixers		1	211.520	
	Pump		1	158.640	
	Sub total - Water treatment				788.615

Sub total			8.759.086
Contingencies / Other expenses :	20		1.505.554
TOTAL	%		10.264.639

DINAJPUR

N°	Description	Unit	Amount	Unit Price USD	Total USD
1	Entrance Area				
1.1	Entrance gate	FR	1	5.000	5.000
1.2	Weighbridge	FR	1	37.000	37.000
1.3	Wheel washing	FR	1	10.000	10.000
1.4	Fences	m	665	13	8.645
1.5	Administrative building and sanitary block	FR	1	130.000	130.000
1.6	Pavement and roads	m²	1800	25	45.000
	Sub total - Entrance Area				235.645
2	Pretreatment				
2.1	Preliminary Storage Area				
2.1.1	Civil Engineering	FR	1		481.200
	Slab - floor	m²	648	500	324.000
	Ramp area	m²	216	200	43.200
	Roof	m²	760	150	114.000
2.1.2	Buldozer (Loader)	U	1	100.000	100.000
2.2	Sorting area				
2.2.1	Civil Engineering	FR	1	929.000	929.000
	Concrete area around the installation	m²	2.520	160	403.200
	Light covering structure	m²	2.627	200	525.400
2.2.2	Sorting line	FR	1	127.000	127.000
	Conveyor belt	FR	1	58.000	58.000
	Hopper	FR	1	69.000	69.000
2.3	Storage area				
2.3.1	Civil Engineering	FR	1	166.000	166.000
	Concrete area around the installation	m²	432	160	69.120
	Light covering structure	m²	481	200	96.200
	Sub total - Pretreatment				1.803.200
3	Anaerobic Digestion				
3.1	Civil Engineering	m²	6350	95	603.250
3.2	Pretreatment (mixing)	FR	1	264.400	264.400
3.3	Biodigester	m²	700	1.800	1.260.000
3.4	CHP	FR	1	212.000	212.000
		kW	200	1.060	212.000
3.5	Post-treatment	FR	1	159.000	159.000
3.6	Technical building HV/LV- SPS- Piping	FR	1	529.000	529.000
3.7	Additional costs (stakes for stability, etc.)	FR	1	2.000	
	Sub total-Anaerobic Digestion				3.027.650

4	Composting				
4.1	Civil Engineering	FR	1	3.751.92	3.751.922
	Concrete area around the installation	m²	13.00	85	1.105.254
	Light covering structure	m²	13.23	200	2.646.668
4.2	Buldozer (Loader)	U	1	100.000	100.000
4.3	Sieving equipment + spare sieves 0/40 0/250/10	U	1	185.000	185.000
4.4	Crusher equipment (crusher, conveyor belt, hopper)	U	1	360.000	360.000
4.5	Turner	U	1	50.000	50.000
	Sub total - Composting				4.446.922
5	Water treatment				
5.1	Retention tank	m³	628	480	301.583
5.2	Water treatment	m³	3141	160	502.638
5.3	Intermediate Storage	m³	628	420	263.885
5.4	Equipment	FT	1	370.16	370.160
	Mixers		1	211.520	
	Pump		1	158.640	
	Sub total - Water treatment				1.438.266
	Sub tota l				10.951.683
	Contingencies / Other expenses :	20			1.882.428
	TOTAL	%			12.834.110

SIRAJGANJ

N°	Description	Unit	Amount	Unit Price USD	Total USD
1	Entrance Area				
1.1	Entrance gate	FR	1	5.000	5.000
1.2	Weighbridge	FR	1	37.000	37.000
1.3	Wheel washing	FR	1	10.000	10.000
1.4	Fences	m	665	13	8.645
1.5	Administrative building and sanitary block	FR	1	130.00	130.00
1.6	Pavement and roads	m²	1800	25	45.000
	Sub total-Entrance Area				235.64
2	Pretreatment				
2.1	Preliminary Storage Area				
2.1.1	Civil Engineering	FR	1		335.400
	Slab - floor	m²	432	500	216.000
	Ramp area	m²	198	200	39.600
	Roof	m²	532	150	79.800
2.1.2	Buldozer (Loader)	U	1	100.00	100.000
2.2	Sorting area				
2.2.1	Civil Engineering	FR	1	520.00	520.000
	Concrete area around the installation	m²	1.400	160	224.000
	Light covering structure	m²	1.479	200	295.800
2.2.2	So rting line	FR	1	127.00	127.000
	Conveyor belt	FR	1	58.000	58.000
	Hopper	FR	1	69.000	69.000
2.3	Storage area				
2.3.1	Civil Engineering	FR	1	139.00	139.000
	Concrete area around the installation	m²	360	160	57.600
	Light covering structure	m²	403	200	80.600
	Sub total - Pretreatment				1.221.40

3	Anaerobic Digestion				
3.1	Civil Engineering	m^2	680	95	64.600
3.2	Pretreatment (mixing)	FR	1	264.40	264.40
3.3	Biodigester	m^2	112	2.600	291.20
3.4	CHP	FR	1	106.00	106.00
		kW	100	1.060	106.00
3.5	Post -treatment	FR	1	159.000	159.000
3.6	Technical building -HV/LV- SPS - Piping	FR	1	529.000	529.000
3.7	Additional costs (stakes for stability, etc.)	FR	1		
			150	2.000	
	Sub total - Anaerobic Digestion				1.414.200
4	Composting				
4.1	Civil Engineering	FR	1	2.183.99	2.183.997
	Concrete area around the installation	m^2	7.532	85	640.201
	Light covering structure	m^2	7.719	200	1.543.796
4.2	Buldozer (Loader)	U	1	100.000	100.000
4.3	Sieving equipment + spare sieves 0/40 0/25 0/10	U	1	185.000	185.000
4.4	Crusher equipment (crusher, conveyor belt, hopper)	U	1	360.000	360.000
4.5	Turner	U	1	50.000	50.000
	Sub total - Composting				2.878.997
5	Water treatment				
5.1	Retention tank	m^3	67	480	32.179
5.2	Water treatment	m^3	335	160	53.632
5.3	Intermediate Storage	m^3	67	420	28.157
5.4	Equipment	FT	1	370.160	370.160
	Mixers		1	211.520	
	Pump		1	158.640	
	Sub total - Water treatment				484.128
	Sub total				6.234.369
	Contingencies / Other expenses :	20			1.071.593
	TOTAL	%			7.305.963

HABIGANJ

N°	Description	Unit	Amount	Unit Price USD	Total USD
1	Entrance Area				
1.1	Entrance gate	FR	1	5.000	5.000
1.2	Weighbridge	FR	1	37.000	37.000
1.3	Wheel washing	FR	1	10.000	10.000
1.4	Fences	m	665	13	8.645
1.5	Administrative building and sanitary block	FR	1	130.00	130.00
1.6	Pavement and roads	m^2	1800	25	45.000
	Sub total - Entrance Area				235.64

2	Pretreatment				
2.1	Preliminary Storage Area				
2.1.1	Civil Engineering	FR	1		225.00
	Slab - floor	m²	288	500	144.000
	Ramp area	m²	132	200	26.400
	Roof	m²	364	150	54.600
2.1.2	Buldozer (Loader)	U	1	65.000	65.000
2.2	Sorting area				
2.2.1	Civil Engineering	FR	1	314.00	314.00
	Concrete area around the installation	m²	840	160	134.400
	Light cov ering structure	m²	899	200	179.800
2.2.2	Sorting line	FR	1	127.00	127.00
	Conveyor belt	FR	1	58.000	58.000
	Hopper	FR	1	69.000	69.000
2.3	Storage area				
2.3.	Civil Engineering	FR	1	139.000	139.000
	Con crete area around the installation	m²	360	160	57.600
	Light covering structure	m²	403	200	80.600
	Sub total - Pretreatment				870.000
3	Anaerobic Digestion				
3.1	Civil Engineering	m²	641	95	60.936
3.2	Pretreatment (mixing)	FR	1	264.400	264.400
3.3	Biodigester	m²	108	1.800	194.400
3.4	CHP	FR	1	53.000	53.000
		kW	50	1.060	53.000
3.5	Post -treatment	FR	1	159.000	159.000
3.6	Technical building - HV/LV- SPS - Piping	FR	1	529.000	529.000
3.7	Additional costs (stakes for stability, etc.)	FR	1		
			150	2.000	
	Sub total - Anaerobic Digestion				1.260.736
4	Composting				
4.1	Civil Engineering	FR	1	1.838.61	1.838.613
	Concrete area around the installation	m²	6.327	85	537.758
	Light covering structure	m²	6.504	200	1.300.854
4.2	Buldozer (Loader)	U	1	65.000	65.000
4.3	Sieving equipment + spare sieves 0/40 0/25 0/10	U	1	185.000	185.000
4.4	Crusher equipment (crusher, conveyor belt, hopper)	U	1	155.000	155.000
4.5	Turner	U	1	50.000	50.000
	Sub total - Composting				2.293.613
5	Water treatment				
5.1	Retention tank	m³	41	480	19.734
5.2	Water treatment	m³	206	160	32.891
5.3	Intermediate Storage	m³	41	420	17.268
5.4	Equipment	FT	1	258.000	258.000
	Mixers		1	165.000	
	Pump		1	93.000	
	Sub total - Water treatment				327.893
	Sub total				4.987.886
	Contingencies / Other expenses :	20			857.341
	TOTAL	%			5.845.227

JESSORE

N°	Description	Unit	Amount	Unit Price USD	Total USD
1	Entrance Area				
1.1	Entrance gate	FR	1	5.000	5.000
1.2	Weighbridge	FR	1	37.000	37.000
1.3	Wheel washing	FR	1	10.000	10.000
1.4	Fences	m	665	13	8.645
1.5	Administrative building and sanitary block	FR	1	130.00	130.00
1.6	Pavement and roads	m^2	1800	25	45.000
	Sub total - Entrance Area				235.64
2	Pretreatment				
2.1	Preliminary Storage Area				
2.1.1	Civil Engineering	FR	1		335.400
	Slab - floor	m^2	432	500	216.000
	Ramp area	m^2	198	200	39.600
	Roof	m^2	532	150	79.800
2.1.2	Buldozer (Loader)	U	1	100.000	100.000
2.2	Sorting area				
2.2.1	Civil Engineering	FR	1	520.000	520.000
	Concrete area around the installation	m^2	1.400	160	224.000
	Light covering structure	m^2	1.479	200	295.800
2.2.2	Sorting line	FR	1	127.000	127.000
	Conveyor belt	FR	1	58.000	58.000
	Hopper	FR	1	69.000	69.000
2.3	Storage area				
2.3.1	Civil Engineering	FR	1	139.000	139.000
	Concrete areaaround the installation	m^2	360	160	57.600
	Light covering structure	m^2	403	200	80.600
	Sub total - Pretreatment				1.221.40
3	Anaerobic Digestion				
3.1	Civil Engineering	m^2	564	95	53.607
3.2	Pretreatment (mixing)	FR	1	264.400	264.400
3.3	Biodigester	m^2	100	2.600	260.000
3.4	CHP	FR	1	127.200	127.200
		kWE	120	1.060	127.200
3.5	Post -treatment	FR	1	159.000	159.000
3.6	Technical building - HV/LV- SPS - Piping	FR	1	529.000	529.000
3.7	Additional costs (stakes for stability, etc.)	FR	1		
			150	2.000	
	Sub total - Anaerobic Digestion				1.393.20

4	Composting				
4.1	Civil Engineering	FR	1	2.476.62	2.476.62
	Concrete area around the installation	m^2	8.553	85	726.996
	Light covering structure	m^2	8.748	200	1.749.629
4.2	Buldo zer (Loader)	U	1	100.000	100.000
4.3	Sieving equipment + spare sieves 0/40 0/25 0/10	U	1	185.000	185.000
4.4	Crusher equipment (crusher, conveyor belt, hopper)	U	1	360.000	360.000
4.5	Turner	U	1	50.000	50.000
	Sub total - Composting				3.171.62

5	Water treatment				
5.1	Retention tank	m^3	64	480	30.721
5.2	Water treatment	m^3	320	160	51.201
5.3	Intermediate Storage	m^2	64	420	26.880
5.4	Equipment	FT	1	370.160	370.160
	Mixers		1	211.520	
	Pump		1	158.640	
	Sub total - Water treatment				478.9 62

Sub total		6.500.839
Contingencies / Other expenses : TOTAL	20 %	1.117.395 7.618.234

7.5.1.2 Estimation of Investment Costs Modular Design 2

As a matter of comparison, the investment costs are calculated for Mymensingh for the basis scenario of Modular design 2, and presented next the investment figures of the basis scenario of Modular design 1.

	Modular design 1	Modular design 2
Entrance Area	282 645	282 645
Pretreatment	1 728 500	1 728 500
Anaerobic digestion	4.501.829	4.501.829
Composting	3.824.947	3.824.947
Water treatment	1.177.811	1.177.811
Gasifier + drying facility	-	5.408.031
TOTAL without contingencies	11.569.732	13.883.678

It can be concluded that the investment cost of Modular Design 2 is higher than Modular Design 1, since the capital needed to install the gasifier and associated drying facility for Modular Design 2 has to be added to the total investment amount.

7.5.1.3 Comparison Of Investment Cost Between Modular Design 1 And Modular Design 2

An overview of the total investment costs of the integrated WtE facilities of Modular Designs 1 and 2 are shown for all Municipalities in the table below.

Table 56: Total investment costs of the integrated WtE facilities of Modular Designs 1 and 2 for all Municipalities

(dollar)	Modular Design 1		Modular Design 2	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Mymensingh	13.558.392	16.217.579	20.475.267	35.254.847
Cox"s Bazar	10.264.640	15.613.638	17.181.514	25.700.050
Dinajpur	12.834.110	16.055.866	19.710.906	30.205.433
Habiganj	5.845.228	8.979.579	12.541.671	15.989.970
Jessore	7.618.234	12.481.284	14.401.514	20.089.512
Sirajganj	7.305.963	11.271.914	14.543.939	18.429.259

7.5.2 Opportunities of Funding

It is important to note that possible cost reductions for Municipalities or are possible on investment, as such as the generation of revenue that can finance operational costs.

Investments

Subvention and funding

As an example, the conversion of biowaste into energy (biogas and power) is considered as a renewable energy that reduces carbon emission. Therefore the Project may be eligible to CDM and earn certified emission reduction credits

Moreover, International institutions (like IFC) have developed a panel of tools (preferential credits, investment aids, etc.) to help local Governments and Authorities in the development of Projects

promoting Sustainable Development, Climate Change Mitigation, Development of Urban Infrastructures, etc. A detailed financial analysis will identified the most adapted opportunity.

Public Private Partnership and Public Service Delegation

Depending on the financial resources, different types of contracts can be developed in partnership with private company in order to prevent Municipalities from bearing the costs of investments:

- Design-Build-Finance-Operate-Maintain(-Transfer) : through this type of contracts, the local Authority entrusts a private operator (or group of operators) for the design, the construction, the financing, the operation and the maintenance of the infrastructure over a defined or undefined period of time ; the operator recovers its costs through direct fees paid by the users
- Build-Own-Operate (-Transfer): the operator is in charge of the construction and the financing of the infrastructure over a defined or undefined period of time. It is considered as the owner of the site and will thus proceed to the site operation and management. Investments, operation and maintenance costs will be recovered through the payment of predefined tariff, fees and charges by users
- Build-Operate (-Transfer) : through this type of contracts, the local Authority entrusts a private operator (or group of operators) for the

construction, the financing, the operation and the maintenance of the infrastructure over a defined or undefined period of time ; the operator recovers its costs through direct fees paid by the users

Operation

Payment for services

Collection and treatment services will be charged to the users through the payment of tariffs, taxes and charges adapted to the revenue of the households.

In order to have an estimation of the revenue of such taxes, a simulation have been done by considering an average waste collection fee per household for waste collection of 120 tk/month.

From Population projection, it is possible to estimate the possible annual revenue.

Methodology

In order to evaluate on a preliminary basis the revenue from such taxes, the following steps have been developed

- Step 1 : Determination of the population (cf. Section 4.1.3)
- Step 2 : Determination of the number of Households.

In this step, it has been assumed that the number of persons per household will remain constant from 2011 to 2030. As such, this ratio has been calculated via the data of census 2011.

Step 3 : Evaluation of the revenue by multiplying the number of estimated households by the average revenue collection rate (120 TK/month/HH)

Results

Mymensingh

Forecasting revenue from collection (Mio BDT)	Collection fee (Tk/m)	2020	2030
Collection rate 120 tk/month	120	89	101
CR + 20Tk (+5%)	126	93	106
CR + 50Tk (+15%)	138	102	116
CR + 100Tk (+30%)	156	115	131
CR + 100Tk (+50%)	180	133	151

Cox's Bazar

Forecasting revenue from collection (Mio BDT)	Collection fee (Tk/m)	2020	2030
Collection rate 120 tk/month	120	60	85
CR + 20Tk (+5%)	126	63	89
CR + 50Tk (+15%)	138	69	98
CR + 100Tk (+30%)	156	78	111
CR + 100Tk (+50%)	180	90	128

Dinajpur

Forecasting revenue from collection (Mio BDT)	Collection fee (Tk/m)	2020	2030
Collection rate 120 tk/month	120	78	105
CR + 20Tk (+5%)	126	81	110
CR + 50Tk (+15%)	138	89	121
CR + 100Tk (+30%)	156	101	137
CR + 100Tk (+50%)	180	116	158

Sirajganj

Forecasting revenue from collection (Mio BDT)	Collection fee (Tk/m)	2020	2030
Collection rate 12 0 tk/month	120	63	78
CR + 20Tk (+5%)	126	66	82
CR + 50Tk (+15%)	138	72	90
CR + 100Tk (+30%)	156	82	101
CR + 100Tk (+50%)	180	94	117

Habiganj

Forecasting revenue from collection (Mio BDT)	Collection fee (Tk/m)	2020	2030
Collection rate 120 tk/month	120	23	29
CR + 20Tk (+5%)	126	24	31
CR + 50Tk (+15%)	138	27	33
CR + 100Tk (+30%)	156	30	38
CR + 100Tk (+50%)	180	35	44

Jessore

Forecasting revenue from collectio n (Mio BDT)	Collection fee (Tk/m)	2020	2030
Collection rate 120 tk/month	120	75	85
CR + 20Tk (+5%)	126	79	90
CR + 50Tk (+15%)	138	86	98
CR + 100Tk (+30%)	156	97	111
CR + 100Tk (+50%)	180	112	128

- Through the possibility of recovering material, revenues can be generated by the resale of such material to industries/companies using it as raw material. In addition to develop circular economy, this resale can be seen as a win-win partnership between the Waste Treatment Site and the private sector as:
- Through tariff agreements, industries will buy this raw material at a lower tariff than those implied by the use of, non-recyclable' material (that generally requires importation)
- Part of the operation costs of the Treatment Site can be covered by the sale of such products
- The order of magnitude of revenue generated through this resale will be done according to the characterization of waste stream available in the Interim Report and the Table 28 of market price. Note that it is unlikely that the recovered material from sorting will be pure; and additional treatment will need to be applied. As a consequence, it will consider a factor of effective recovery of 50%. A business plan will be required in a further step (with detailed analysis of recovery costs, identification and discussion of companies interested by these new sources of raw material, quality constraints, etc.), in order to give a precise overview of costs and expenses of such a site. Note moreover that the development of a demonstration Plant will be used for the final evaluation of the revenue, by implementing a detailed monitoring of costs and confronting the theoretical analysis with the reality of the field; the result of this follow-up will allow the development of new sites based on the same model in Bangladesh.

Mymensingh

Type of waste	Unit	2020	2030
Plastic			
Production	t/y	548	939
Prevision	Range Min – Max (Mio	5.8 13.1	9.9 22 .5
Paper			
Production	t/y	459	786
Prevision	Range Min – Max (Mio	3.9 4.6	6.7 7.9
Metal			
Production	t/y	28	48
Prevision	Range Min – Max (Mio	0.5 0.6	0.8 1.0
Textile			
Production	t/y	916	1,570
Prevision	Range Min – Max (Mio	4.6 7.8	7.9 13.3
Compost			
Production	t/y	4,877	8,364
Prevision	Mio	14.6	25.1

Cox's Bazar

Type of waste	Unit	2020	2030
Plastic			
Production	t/y	516	1111
Prevision	Range Min – Max (Mio	5,7 12,9	12,2 27,8
Paper			
Production	t/y	549	1181
Prevision	Range Min – Max (Mio	3,8 4,4	8,3 9,4
Metal			
Production	t/y	27	58
Prevision	Range Min – Max (Mio	0,5 0,5	1,0 1,1
Textile			
Production	t/y	850	1828
Prevision	Range Min – Max (Mio	4,3 6,8	9,1 14,6
Compost			
Produc tion	t/y	4 568	9 825
Prevision	Mio	13,7	29,5

Dinajpur

Type of waste	Unit	2020	2030
Plastic			
Production	t/y	592	1213
Prevision	Range Min – Max (Mio	5,3 13,0	10,9 26,7
Paper			
Production	t/y	414	849
Prevision	Range Min – Max (Mio	2,9 3,5	5,9 7,2
Metal			
Production	t/y	75	154
Prevision	Range Min – Max (Mio	1,2 1,3	2,4 2,7
Textile			
Production	t/y	314	643
Prevision	Range Min – Max (Mio	1,6 2,0	3,2 4,2
Compost			
Production	t/y	5 977	12 2 43
Prevision	Mio	17,9	36,7

Sirajganj

Type of waste	Unit	2020	2030
Plastic			
Production	t/y	477	894
Prevision	Range Min – Max (Mio	4,5 10,0	8,5 18,8
Paper			
Production	t/y	302	566
Prevision	Range Min – Max (Mio	2,6 3,0	4,8 5, 7
Metal			
Production	t/y	0	0
Prevision	Range Min – Max (Mio	0,0 0,0	0,0 0,0
Textile			
Production	t/y	306	572
Prevision	Range Min – Max (Mio	1,5 2,0	2,9 3,7
Compost			
Production	t/y	2 257	4 227
Prevision	Mio	6,8	12,7

Habiganj

Type of waste	Unit	2020		2030	
Plastic					
Production	t/y	182		344	
Prevision	Range / Mio BDT	2,0	4,2	3,8	7,9
Paper					
Production	t/y	142,1		268,9	
Prevision	Range / Mio BDT	1,1	1,2	2,0	2,3
Metal					
Production	t/y	13,1		24 ,7	
Prevision	Range / Mio BDT	0,2	0,2	0,4	0,5
Textile					
Production	t/y	83,7		158,4	
Prevision	Range / Mio BDT	0,4	0,6	0,8	1,2
Compost					
Production	t/y	1 371		2 594	
Prevision	Mio	4,1		7,8	

Jessore

Type of waste	Unit	2020		2030	
Plastic					
Production	t/y	83		143	
Prevision	Range Min – Max (Mio	1,0	2,2	1,7	3,7
Paper					
Production	t/y	92,9		160,3	
Prevision	Range Min – Max (Mio	0,8	0,9	1,4	1,6
Metal					
Production	t/y	79,0		136,3	
Prevision	Range Min – Max (Mio	1,3	1,5	2,3	2,7
Textile					
Production	t/y	66,8		115,2	
Prevision	Range Min – Max (Mio	0,3	0,6	0,6	1,0
Compost					
Production	t/y	3 129		5 397	
Prevision	Mio	9,4		16,2	

Other revenues will also be generated from electricity and biofuel production. They should be assessed in a detailed business plan.

7.5.3 Detailed Financial Analysis

7.5.3.1 Financial Analysis Modular Design 1

For each of the selected cities there has been conducted a detailed financial analysis in depth. The financial model is built in a flexible way in order that it can be easily reused for equal simulations assessing the optimal capacity for equal designs to be installed in other contexts. In that case, appropriate variable input parameters specific to the municipality in question need to be entered in the model, based on characterisation studies describing energy prices, population size, waste collection rates, organic matter content, etc.

The methodology is based on an evaluation of the direct operational costs and indirect revenues. First, a cost-benefit analysis is done including the indirect cost, i.e. revenues through collection tax, carbon emission savings and savings on health care. Second, the same analysis is done excluding indirect revenues.

The Direct Operational Costs

As the title states, these costs are all directly influenced by investments and related operational cost factors. To better understand these factor they are individually explained :

- Investments : a detailed list of equipment and buildings is provided in the beginning of this chapter. In order to evaluate them as a financial parameter they are grouped into specific groups : machines necessary for the treatment – electricity production – rolling equipment constructions and buildings – preparation and engineering and a margin foreseen for changes during development. These categories have different depreciations and are taken into account as a complete loan with a fixed interest.

- Maintenance : these costs are directly related to the operation of the installations and are calculated as a direct factor of the investment. For the biogas engine there is a different approach since it is expressed more as a cost per hour of operation, due to the importance of reliability and saving on the cost electricity from the national grid.

- Personnel : the facility is run by a dedicated staff foreseen as local management and administration – maintenance crew and operators that are active in the pre-treatment line. This personnel is working in one shift during daytime.

- Insurances : operating a facility for waste treatment brings up liabilities to third parties and protection to risks such as fire and indirect damage to neighbours. Specific insurances are taken into account for personnel, fire and weather effects and failure of machinery.

- Consumables related to treatment : for the maintenance and operation of the plant and its machinery there is a need for dedicated products such as polymer in the waste water treatment unit as well as chemicals for rinsing, grease and oil for rolling machinery as fuel for the front wheel loader.

- Waste output and recuperation : all the excess flows that are not recyclable are considered to be brought to the landfill on the site. Materials that are recyclable such as paper and metal generate an income.
- Products from waste : besides the recuperation of valuables in the pre-treatment there is the electricity and heat from the biogas-engine and the compost that is produced. Electricity is a valuable directly related to the project and injected to the grid where the compost is a quality product that is to be applied as a soil improver with substantial nutrient value. The process to obtain the compost complies with hygienization standards (minimum four days at a temperature of 65°C) and material specifications. A marketable product is being produced and traded to the local market.
- Energy production and consumption: due to the implementation of anaerobic treatment we can convert the biogas in a combined heat and power unit to electricity and hot water. The electricity is consistently available and is sufficient to provide all the local consumption related to the operation of the project. Some excess electricity is injected to the grid what gives a positive effect on the balance as income from the electricity produced for distribution. The heat on the other hand is not being applied to the facility and is simply cooled to the atmosphere.

Indirect Cost Factors

Waste treatment is to be integrated in the management of a city and if not done properly it will generate costs on other fields such as safety and health as well as environmental.

- Renewable energy and GHG-saving: biogas is considered as a renewable source of energy and therefore saves on CO_2-emissions. These can be traded under ETS or similar support mechanisms that value the carbon emission reductions.
- Collecting the waste: partners will have to start the local collection of the waste in collaboration with the city council and its services so they will contribute to the supply of all waste to the treatment facility. Through collection contracts they will guarantee that all the waste is brought to the waste treatment facility.
- Health factors: it is known2 that a proper organisation and treatment of waste generates additional costs to the health system. In particular for Bangladesh a significant increase for more than 15 $ per inhabitant is noted in the last decade. Waste brings along emission of odour but also negative effects on the water and vermin that spreads diseases. It has to be taken into account that the curing of diseases generates a considerable cost for the treatment of hazardous waste from hospitals etc. For these reasons we take into account a saving of 1,5 $/inh.

2 Asia pacific observatory, Bangladesh Health System Review [Vol 5 N°3 2015] and thesis of 2014-n°301 on Medical Waste Management systems in Dhaka City south Bangladesh

Excluded Costs

The following costs are not incorporated in the model, since they could not be fully assessed at the time of the study.

- Acquisition cost of the land: this can be done either by procurement of the land or by concession to be payed to local authorities of which the latter is often more recommended.
- Sanitation costs of polluted grounds.

Figure 79: Adverse health effect of waste

Results of The Analysis Including Indirect Revenues For Mymensingh

For each municipality a detailed calculation of the costs and benefits is presented the tables here below for a basis scale scenario and a large scale scenario. The large scale scenario is approximately a multiplication with a factor 4 of the basis case scenario.

Table 56: Financial analysis for the installation of Modular Design 1 in Mymensingh for the basis scenario inclusive indirect revenues

LIFE CYCLE Assessment (LCA) - Basis scenario 19.281 ton waste/year Modular Design 1

	interest	depreciation	al investment
-machines for treatment:	3,0%	12 yr	4.433.276 $
-gas engine:	3,0%	8 yr	212.000 $
-rolling machines :	3,0%	8 yr	795.000 $
-construction and buildings:	2,8%	15 yr	6.129.456 $
-engineering :	3,0%	15 yr	1.018.136 $
-reserve :	3,0%	15 yr	970.525 $

Year	TOTAL	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	5.344.514	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376			
Gas engine (3% 8y)	453.011	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201
Rolling machine (3% 8y)	1.064.577	113.253	113.253	113.253	113.253	113.253	113.253	113.253	113.253	22.651	22.651	22.651	22.651	22.651	22.651	22.651
Constructions - buildings (2.8%, 15y)	7.590.670	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045
Engineering (8.8%, 15y)	1.279.267	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286
Reserve (7.71%, 15y)	1.219.463	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment	348.000	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200
Maintenance cost	2.014.944	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330
Opera tion costs	483.063	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204
Insurance costs	519.323	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622
Total cost (A)	20.316.851	1.483.813	1.483.813	1.483.813	1.483.813	1.483.813	1.483.813	1.483.813	1.483.813	1.395.211	1.395.211	1.395.211	1.395.211	949.835	949.835	949.835
Total electricity production, kWhr		1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011
Total electricity local consumption, KWhr		1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164
Remaining electricity feed to grid, kWhr		398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847
Revenue (B)		year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of CO2		1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222
Social benefit due to saving on health cost		397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038	397.038
Revenue from waste collection (Tax)		192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814
Revenue from electricity local consumption	2.585.334	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356
Revenue from electricity grid feed	358.963	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931
Revenue from metal/plastic/paper/glass sales	2.255.089	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339
Revenue from selling compost	1.692.242	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816
Total Revenu (B)	15.757.755	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517	1.050.517
Net profit/loss = (B-A)	-4.559.096	-435.296	-435.296	-435.296	-435.296	-435.296	-435.296	-435.296	-435.296	-344.694	-344.694	-344.694	-344.694	100.682	100.682	100.682

- positive values represent profit -15,2 $/ton

Table 57: Financial analysis for the installation of Modular Design 1 in Mymensingh for the large scenario inclusive indirect revenues

LIFE CYCLE Assessment (LCA) - Large scenario

80.183 ton waste/year

Modular Design 1

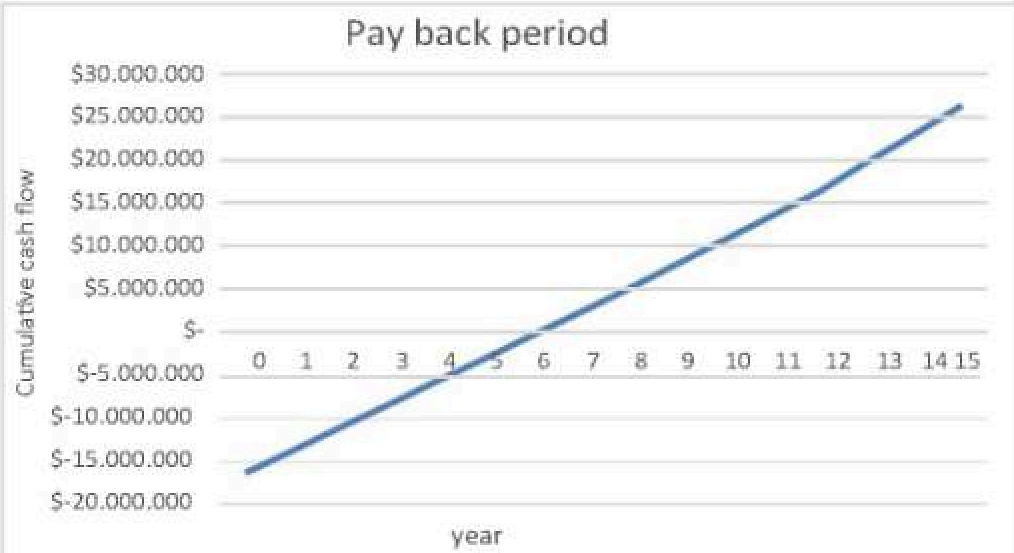
	interest	depreciation	investment
-machines for treatment:	3,0%	12 yr	4.620.186 $
-gas engine:	3,0%	8 yr	756.000 $
-rolling machines :	3,0%	8 yr	1.590.000 $
-construction and buildings:	2,8%	15 yr	6.872.698 $
-engineering :	3,0%	15 yr	1.217.822 $
-reserve :	3,0%	15 yr	1.160.872 $

Year	TOTAL	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	5.569.843	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154			
Gas engine (3% 8y)	1.615.455	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697
Rolling machine (3% 8y)	2.129.153	226.506	226.506	226.506	226.506	226.506	226.506	226.506	226.506	45.301	45.301	45.301	45.301	45.301	45.301	45.301
Constructions - buildings (2,8%, 15y)	8.511.098	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406
Engineering (8,8%, 15y)	1.530.192	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013
Reserve (7,71%, 15y)	1.458.634	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment	802.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500
Maintenance cost	3.030.012	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001
Operation costs	1.383.920	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261
Insurance costs	641.392	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759
Total cost (A)	26.672.198	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.774.335	1.774.335	1.774.335	1.774.335	1.310.181	1.310.181	1.310.181
Total electricity production, kWhr		5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552
Total electricity local consumption, KWhr		1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674
Remaining electricity feed to grid, kWhr		4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878
Revenue (B)		year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of CO2		4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592	4.592
Social benefit due to saving on health cost		724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621	724.621
Revenue from waste collection (Tax)		801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832
Revenue from electricity local consumption	3.819.049	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270
Revenue from electricity grid feed	3.625.090	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673
Revenue from metal/plastic/paper/glass sales	12.539.329	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955
Revenue from selling compost	7.037.309	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154
Total Revenu (B)	50.086.448	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097	3.339.097
Net profit/loss = (B-A)	23.414.250	1.383.557	1.383.557	1.383.557	1.383.557	1.383.557	1.383.557	1.383.557	1.383.557	1.564.762	1.564.762	1.564.762	1.564.762	2.028.915	2.028.915	2.028.915
- *positive values represent profit*	19,5 $/ton															

The above calculation for Mymensingh shows that, based on the values for the different products and local prices, the cost to treat the waste is 15,8 $/ton for the basis scenario inclusive indirect revenues, giving an Internal rate of return (IRR) of 2,26% and a Pay Back Period exceeding 15 years.

On the contrary, the financial analysis of the large scenario inclusive indirect revenues shows Mymensingh can make a revenue of 19,5 $/ton, giving an Internal rate of return (IRR) of 14,71% and a Pay Back Period of 5.9 years, as illustrated in the figure below:

Figure 80: Pay Back Period Mymensingh Large scenario inclusive indirect revenues



It can be concluded that with increasing volume of waste stream treated, the installation becomes more economically viable. Besides the income due to waste collection, also the resale of recycled materials is an important source of revenue. In particularly, the sales of compost as a fertilizer significantly contributes to the profitability of the plant.

Another variable is the sales price of energy for local consumption or injection into the grid. There has been calculated with a price of 0.153 $/kWh and 0.06 $/kWh respectively. If these prices would go up, the profitability of the facility would increase accordingly

Results of The Analysis Excluding Indirect Revenues For Mymensingh

An overview of the financial analysis results without taking into account the indirect revenues for Mymensingh is shown in the tables below for the basis and the large scale scenario.

Table 58: Financial analysis for the installation of a domestic waste treatment facility in Mymensingh for the basis scenario exclusive indirect revenues

LIFE CYCLE Assessment (LCA) - Basis scenario

19.281 ton waste/year

Modular Design 1

	interest	depreciation	al investment
-machines for treatment:	3,0%	12 yr	4.433.276 $
-gas engine:	3,0%	8 yr	212.000 $
-rolling machines :	3,0%	8 yr	795.000 $
-construction and buildings:	2,8%	15 yr	6.129.456 $
-engineering :	3,0%	15 yr	1.018.138 $
-reserve :	3,0%	15 yr	970.525 $

Year	TOTAL	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	5.344.514	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376			
Gas engine (3% 8y)	453.011	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201
Rolling machine (3% 8y)	1.064.577	113.253	113.253	113.253	113.253	113.253	113.253	113.253	113.253	22.651	22.651	22.651	22.651	22.651	22.651	22.651
Constructions - buildings (2.8%, 15y)	7.590.670	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045
Engineering (8.8%, 15y)	1.279.287	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286	85.286
Reserve (7.71%, 15y)	1.219.463	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298	81.298
Land lease/Acquisition	$															
Sanitation cost	$															
Management cost/employment	348.000	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200	23.200
Maintenance cost	2.014.944	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330	134.330
Operation costs	483.063	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204	32.204
Insurance costs	519.323	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622	34.622
Total cost (A)	20.316.851	1.485.813	1.485.813	1.485.813	1.485.813	1.485.813	1.485.813	1.485.813	1.485.813	1.395.211	1.395.211	1.395.211	1.395.211	949.835	949.835	949.835
Total electricity production, kWhr		1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011	1.528.011
Total electricity local consumption, KWhr		1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164
Remaining electricity feed to grid, kWhr		398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847	398.847
Revenue (B)		year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of CO2																
Social benefit due to saving on health cost																
Revenue from waste collection (Tax)																
Revenue from electricity local consumption	2.585.334	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356
Revenue from electricity grid feed	358.963	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931	23.931
Revenue from metal/plastic/paper/glass sales	2.255.089	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339	150.339
Revenue from selling compost	1.692.242	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816
Total Revenue (B)	6.891.627	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442	459.442
Net profit/loss = (B-A)	-13.425.224	-1.026.371	-1.026.371	-1.026.371	-1.026.371	-1.026.371	-1.026.371	-1.026.371	-1.026.371	-935.769	-935.769	-935.769	-935.769	-490.393	-490.393	-490.393

- positive values represent profit -46,4 $/ton

Table 59: Financial analysis for the installation of a domestic waste treatment facility in Mymensingh for the large scenario exclusive indirect

LIFE CYCLE Assessment (LCA) - Large scenario

80.183 ton waste/year

Modular Design 1

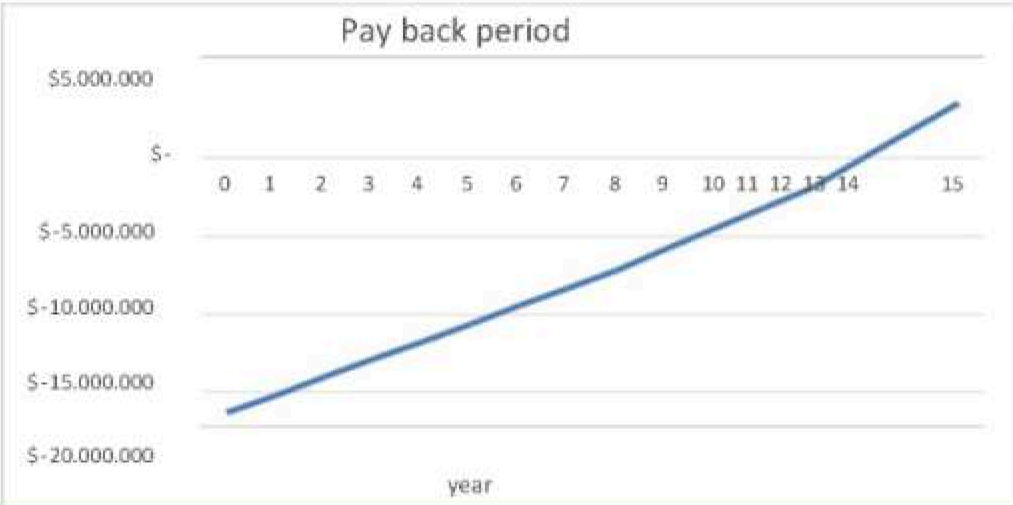
revenues

	interest	depreciation	al investment
-machines for treatment:	3,0%	12 yr	4.620.186 $
-gas engine:	3,0%	8 yr	756.000 $
-rolling machines :	3,0%	8 yr	1.590.000 $
-construction and buildings:	2,8%	15 yr	6.872.698 $
-engineering :	3,0%	15 yr	1.217.822 $
-reserve :	3,0%	15 yr	1.160.872 $

Year	TOTAL	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	5.569.843	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154			
Gas engine (3% 8y)	1.615.455	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697
Rolling machine (3% 8y)	2.129.153	226.506	226.506	226.506	226.506	226.506	226.506	226.506	226.506	45.301	45.301	45.301	45.301	45.301	45.301	45.301
Constructions - buildings (2.8%, 15y)	8.511.096	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406
Engineering (8.8%, 15y)	1.530.190	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013	102.013
Reserve (7.71%, 15y)	1.458.634	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242	97.242
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment	802.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500	53.500
Maintenance cost	3.030.012	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001	202.001
Operation costs	1.383.920	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261	92.261
Insurance costs	641.390	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759	42.759
Total cost (A)	26.672.198	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.955.539	1.774.335	1.774.335	1.774.335	1.774.335	1.310.181	1.310.181	1.310.181
Total electricity production, kWhr		5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552	5.739.552
Total electricity local consumption, KWhr		1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674	1.711.674
Remaining electricity feed to grid, kWhr		4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878	4.027.878
Revenue (B)	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15	
Social benefit due to reduction of CO2																
Social benefit due to saving on health cost																
Revenue from waste collection (Tax)																
Revenue from electricity local consumption	3.919.049	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270	261.270
Revenue from electricity grid feed	3.625.090	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673	241.673
Revenue from metal/plastic/paper/glass sales	12.539.329	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955	835.955
Revenue from selling compost	7.037.309	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154	469.154
Total Revenue (B)	27.120.778	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052	1.808.052
Net profit/loss = (B-A)	448.580	-147.488	-147.488	-147.488	-147.488	-147.488	-147.488	-147.488	-147.488	33.717	33.717	33.717	33.717	497.871	497.871	497.871
- positive values represent profit	0,4 $/ton															

The above calculation for Mymensingh shows that, based on the values for the different products and local prices, the cost to treat the waste is 46,4 $/ton for the basis scenario exclusive indirect revenues. In can be concluded that the basis scenario is not profitable, so the investment will not be paid back in a period of 15 years, resulting in a negative IRR. On the contrary, the financial analysis of the large scenario exclusive indirect revenues shows the environmental park can make a revenue of 0,4 $/ton, corresponding with a IRR of 2,44% and a PBP of 12,4 years as shown in the figure here below.

Figure 81: Pay Back Period Mymensingh large scenario exclusive indirect revenues



Results of The Analysis Including And Excluding Indirect Revenues For

All Six Municipalities

A summary of the results of the financial analysis including and excluding indirect revenues of all Municipalities are presented in the tables here below.

Table 60: Financial analysis for Modular Design 1 in Mymensingh for basis & large scale scenario inclusive and exclusive indirect revenues

	Including indirect revenues		Excluding Indirect revenues	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Total energy production (kWh/yr)	1.528.011	5.739.552	1.528.011	5.739.552
Capacity (ton/yr)	19.281	80.183	19.281	80.183
Cost/profit($/ton)	-15,8	19,5	-46,4	0,4
IRR (%)	-2,26	14,86	-13,0	2,4
NPV ($)	-4.904.651	17.059.434	-11.755.348	-685.722
PBP (years)	>15	5,9	>15	12,4

Table 61: Financial analysis for Modular Design 1 in Cox's Bazar for basis & large scale scenario inclusive and exclusive indirect revenues

	Including indirect revenues		Excluding Indirect revenues	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Total energy production (kWh/yr)	1.221.532	4.464.096	1.221.532	4.464.096
Capacity (ton/yr)	14.759	61.352	14.759	61.352
Cost/profit ($/ton)	-15,8	14,3	-44,1	-3,8
IRR (%)	-2,43	9,95	-12,69	-0,3
NPV ($)	-3.773.672	9.124.728	-8.620.232	-3.728.065
PBP (years)	>15	7,6	>15	>15

Table 62: Financial analysis for Modular Design 1 in Dinajpur for basis & large scale scenario inclusive and exclusive indirect revenues

	Including indirect revenues		Excluding Indirect revenues	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Total energy production (kWh/yr)	1.653.617	6.341.408	1.653.617	6.341.408
Capacity (ton/yr)	18.022	72.413	18.022	72.413
Cost/profit ($/ton)	-21,9	14,5	-48,4	-2,9
IRR (%)	-4,14	11,14	-14,7	0,0
NPV ($)	5.981.687	11.098.592	-11.536.295	-3.437.606
PBP (years)	>15	7,1	>15	>15

Table 63: Financial analysis for Modular Design 1 in Habiganj for basis & large scale scenario inclusive and exclusive indirect revenues

	Including indirect revenues		Excluding Indirect revenues	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Total energy production (kWh/yr)	398.580	1.506.632	398.580	1.506.632
Capacity (ton/yr)	4.585	19.928	4.585	19.928
Cost/profit ($/ton)	-59,3	-1,5	-93,2	-22,0
IRR (%)	-7,25	1,44	-15,6	-7,4
NPV ($)	3.711.865	1.034.611	-5.511.206	-5.769.807
PBP (years)	>15	13,4	>15	>15

Table 64: Financial analysis for Modular Design 1 in Jessore for basis & large scale scenario inclusive and exclusive indirect revenues

	Including indirect revenues		Excluding Indirect revenues	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Total energy production (kWh/yr)	956.5	3.507.504	956.5	3.507.504
Capacity (ton/yr)	9.997	39.987	9.997	39.987
Cost/profit ($/ton)	-11,3	9,1	-52,6	-14,6
IRR (%)	-0,66	6,45	-13,8	-6,6
NPV ($)	1.973.683	3.444.974	-6.753.121	-7.562.231
PBP (years)	>15	9,4	>15	>15

Table 65: Financial analysis for Modular Design 1 in Sirajganj for basis & large scale scenario inclusive and exclusive indirect revenues

	Including indirect revenues		Excluding Indirect revenues	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Total energy production (kWh/yr)	658.563	1.913.184	658.563	1.913.184
Capacity (ton/yr)	8.110	26.641	8.110	26.641
Cost/profit ($/ton)	-18,8	14,5	-59,5	-15,4
IRR (%)	-1,66	6,81	-12,5	-4,9
NPV ($)	2.375.387	3.441.841	-6.205.697	-5.776.448
PBP (years)	>15	9,2	>15	>15

The variations of the unit price between different municipalities can be mainly explained by the difference in investment cost per ton of waste produced: if the capacity of the plant is substandard, the investment cost and the related maintenance and insurance cost is too high to be covered by the income from energy production and recycling of materials. Another slight variation comes from the personnel cost which becomes lower once the plant scales up. Therefore, plants must be designed big enough to arrive a profitable value, taken into consideration of the expected population growth in the coming decade generating an increasing amount of waste.

Furthermore, it can be concluded that Modular Design 1 cannot be profitable without indirect revenues expect for the large scale scenario for Mymensingh. As such, it is recommended to at least include a collection tax as an income for the waste treatment facility. This can be considered as an "eco-tax" since it contributes to the awareness and responsibility of the population of the financial impact of waste production, and because it is a world-wide recognized and important income for the profitability of a waste treatment facility in general.

7.5.3.2 Financial Comparison of Modular Design 1 Versus Modular Design 2

If one now compares the two proposed Modular Designs in financial terms for Mymensingh (Table 66), it can be overall concluded that Modular Design 1 is the preferable proposed project to get started with in the context of Mymensingh. The same conclusion can be drawn for other the other Municipalities.

Table 66: Financial comparison of Modular Design 1 versus Modular Design 2

	Modular Design 1				Modular Design 2	
	Including indirect revenues		Excluding Indirect revenues		Excluding Indirect revenues with reuse of energy	
	Basis scenario	Large scenario	Basis scenario	Large scenario	Basis scenario	Large scenario
Investment cost ($)	13.558.392	16.217.579	13.558.392	16.217.579	20.475.267	35.254.847
Energy production (kWh/yr)	1.528.011	5.739.552	1.528.011	5.739.552	5.279.011	16.738.011
Capacity (ton/yr)	19.281	80.183	19.281	80.183	19.281	80.183
Cost/profit ($/ton)	-15,8	19,5	-46,4	0,4	-90,1	-33,3
IRR (%)	-2,26	14,86	-13,0	2,4	-16,5	-9,9
NPV ($)	-4.904.651	17.059.434	-11.755.348	-685.722	-18.900.042	-24.808.133

7.5.3.3 Financial Analysis Modular Design 2

Equally as for Modular Design 1, the same Financial Analysis is conducted for Modular Design 2. Though, for Modular Design 2, the Financial Analysis is limited to the calculation without taking into account indirect revenues.

In Modular Design 2, there is proposed to reuse the energy produced by anaerobic digestion for pre- treating, i.e. drying, the waste stream and for initiating the gasification reaction. In order to clearly show the difference in financial results whether or not this energy is reused, the financial analysis is done in both cases for all municipalities, equally for the basis scale scenario as for the large scale scenario.

The results for Mymensingh are presented in the tables here below.

Table 67: Financial analysis for the installation of Modular Design 2 in Mymensingh for the basis scenario with energy reuse

LIFE CYCLE Assessment (LCA) - Basis scenario 19.281 ton waste/year Modular Design 2 - with energy reuse

	interest	depreciation/amortisation	
-machines for treatment:	3.0%	12 yr	4.433.276 $
-gas engine:	3.0%	8 yr	212.000 $
-thermal gasifier + engine	3.0%	8 yr	5.902.350 $
-rolling machines :	3.0%	8 yr	795.000 $
-construction and buildings:	2.8%	15 yr	6.129.456 $
-engineering :	3.0%	15 yr	1.537.543 $
-reserve :	3.0%	15 yr	1.465.642 $

	Investment	loan repayment														
Year	TOTAL	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	5.344.514	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376			
Gas engine (3% 8y)	453.011	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201	30.201
Gasifier and engine	12.612.412	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827
Rolling machine (3% 8y)	1.064.577	113.253	113.253	113.253	113.253	113.253	113.253	113.253	113.253	22.651	22.651	22.651	22.651	22.651	22.651	22.651
Constructions - buildings (2.8%, 15y)	7.590.678	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045
Engineering (3.0%, 15y)	1.931.921	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795	128.795
Reserve (7.71%, 15y)	1.841.577	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772	122.772
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment	519.000	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600
Maintenance cost	4.373.660	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577	291.577
Operation costs	559.563	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304	37.304
Insurance costs	675.978	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065	45.065
Total cost (A)	38.366.853	2.595.815	2.595.815	2.595.815	2.595.815	2.595.815	2.595.815	2.595.815	2.595.815	2.505.213	2.505.213	2.505.213	2.505.213	2.059.837	2.059.837	2.059.837
Total electricity production, kWhr		5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011
Total electricity local consumption, KWhr		1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164	1.129.164
Remaining electricity feed to grid, kWhr		4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847	4.149.847
Revenue (B)		year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of CO2																
Social benefit due to saving on health cost																
Revenue from waste collection (Tax)																
Revenue from electricity local consumption	2.585.334	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356	172.356
Revenue from electricity grid feed	3.734.863	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991	248.991
Revenue from metal/glass sales	1.692.242	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816
Revenue from selling compost	2.892.216	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814
Total Revenu (B)	10.904.654	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977	726.977
Net profit/loss = (B-A)	-26.062.229	-1.868.838	-1.868.838	-1.868.838	-1.868.838	-1.868.838	-1.868.838	-1.868.838	-1.868.838	-1.778.236	-1.778.236	-1.778.236	-1.778.236	-1.332.860	-1.332.860	-1.332.860

- positive values represent profit -90,1 $/ton

Table 68: Financial analysis for the installation of Modular Design 2 in Mymensingh for the large scenario with energy reuse

LIFE CYCLE Assessment (LCA) - Large scenario 80.183 ton waste/year Modular Design 2 - with energy reuse

	interest	depreciation/amortisation	
-machines for treatment:	3.0%	12 yr	4.620.186 $
-gas engine:	3.0%	8 yr	756.000 $
-thermal gasifier + engine	3.0%	8 yr	16.245.000 $
-rolling machines :	3.0%	8 yr	1.590.000 $
-construction and buildings:	2.8%	15 yr	6.872.698 $
-engineering :	3.0%	15 yr	2.647.382 $
-reserve :	3.0%	15 yr	2.523.581 $

Investment Loan repayment

Year	TOTAL	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	5.569.843	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154			
Gas engine (3% 8y)	1.615.455	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697	107.697
Gasifier and engine	34.713.063	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204
Rolling machine (3% 8y)	2.129.153	226.506	226.506	226.506	226.506	226.506	226.506	226.506	226.506	45.301	45.301	45.301	45.301	45.301	45.301	45.301
Constructions - buildings (2.8%, 15y)	8.511.098	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406
Engineering (8.8%, 15y)	3.326.432	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762	221.762
Reserve (7.73%, 15y)	3.170.876	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392	211.392
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment	595.500	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700
Maintenance cost	10.380.012	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001
Operation costs	1.181.420	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761	78.761
Insurance costs	1.068.488	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233	71.233
Total cost (A)	72.261.337	4.994.815	4.994.815	4.994.815	4.994.815	4.994.815	4.994.815	4.994.815	4.994.815	4.813.611	4.813.611	4.813.611	4.813.611	4.349.457	4.349.457	4.349.457
Total electricity production, kWhr		16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011
Total electricity local consumption, KWhr		2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164	2.429.164
Remaining electricity feed to grid, kWhr		14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847	14.308.847
Revenue (B)		year1	year2	year3	year 4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of C02																
Social benefit due to saving on health cost																
Revenue from waste collection (Tax)																
Revenue from electricity local consumption	5.561.814	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788	370.788
Revenue from electricity grid feed	12.877.963	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531	858.531
Revenue from metal/glass sales	1.692.242	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816
Revenue from selling compost	12.027.487	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832
Total Revenu (B)	32.159.506	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967	2.143.967
Net profit/loss = (B-A)	-40.101.831	-2.850.848	-2.850.848	-2.850.848	-2.850.848	-2.850.848	-2.850.848	-2.850.848	-2.850.848	-2.669.644	-2.669.644	-2.669.644	-2.669.644	-2.205.490	-2.205.490	-2.205.490
- positive values represent profit	-33,3 $/ton															

Table 69: Financial analysis for the installation of Modular Design 2 in Mymensingh for the basis scenario without energy reuse

LIFE CYCLE Assessment (LCA) - Basis scenario 19.281 ton waste/year Modular Design 2 - without energy reuse

	interest	depreciation/amortisation	
-machines for treatment:	3.0%	12 yr	4.433.276 $
-gas engine:	3.0%	8 yr	255.009 $
-thermal gasifier + engine	3.0%	8 yr	5.902.350 $
-rolling machines :	3.0%	8 yr	795.000 $
-construction and buildings:	2.8%	15 yr	6.129.456 $
-engineering :	3.0%	15 yr	1.541.328 $
-reserve :	3.0%	15 yr	1.469.250 $

	Investment	Loan repayment														
Year	year0	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	4,433,276	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376	445.376			
Gas engine (3% 8y)	255.009	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328	36.328
Gasifier and engine	5,902,350	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827	840.827
Rolling machine (3% 8y)	795.000	113.253	113.253	113.253	113.253	113.253	113.253	113.253	113.253	22.651	22.651	22.651	22.651	22.651	22.651	22.651
Constructions - buildings (2.8%, 15y)	6.129.456	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045	506.045
Engineering (8.8%, 15y)	1.541.328	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112	129.112
Reserve (7.71%, 15y)	1,469.250	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074	123.074
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment		34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600	34.600
Maintenance cost		302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330	302.330
Operation costs		211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151	211.151
Insurance costs		45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253	45.253
Total cost (A)		2.787.348	2.787.348	2.787.348	2.787.348	2.787.348	2.787.348	2.787.348	2.787.348	2.696.745	2.696.745	2.696.745	2.696.745	2.251.369	2.251.369	2.251.369
Total electricity production, KWhr		5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011	5.279.011
Total electricity local consumption, KWhr		1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714	1.316.714
Remaining electricity feed to grid, KWhr		3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297	3.962.297
Revenue (B)	year0	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of CO2		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Social benefit due to saving on health cost		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Revenue from waste collection (Tax)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Revenue from electricity local consumption		200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983	200.983
Revenue from electricity grid feed		237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738	237.738
Revenue from metal/glass sales		112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816
Revenue from selling compost		192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814	192.814
Total Revenu (B)		744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352	744.352
Net profit/loss = (B-A)	-28.674.597	-2.042.996	-2.042.996	-2.042.996	-2.042.996	-2.042.996	-2.042.996	-2.042.996	-2.042.996	-1.952.394	-1.952.394	-1.952.394	-1.952.394	-1.507.018	-1.507.018	-1.507.018
- positive values represent profit	99,1 $/ton															

Table 70: Financial analysis for the installation of Modular Design 2 in Mymensingh for the large scenario without energy reuse

LIFE CYCLE Assessment (LCA) - Large scenario 80.183 ton waste/year Modular Design 2 - without energy reuse

	interest	depreciation/amortisation	
-machines for treatment:	3,0%	12 yr	4.620.186 $
-gas engine:	3,0%	8 yr	934.856 $
-thermal gasifier + engine	3,0%	8 yr	16.245.000 $
-rolling machines :	3,0%	8 yr	1.590.000 $
-construction and buildings:	2,8%	15 yr	6.872.698 $
-engineering :	3,0%	15 yr	2.663.121 $
-reserve :	3,0%	15 yr	2.538.584 $

	Investment	Loan repayment														
Year	year0	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Machine for treatment (3%, 12y)	4.620.186	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154	464.154			
Gas engine (3% 8y)	934.856	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176	133.176
Gasifier and engine	16.245.000	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204	2.314.204
Rolling machine (3% 8y)	1.590.000	226.506	226.506	226.506	226.506	226.506	226.506	226.506	226.506	45.301	45.301	45.301	45.301	45.301	45.301	45.301
Constructions - buildings (2.8%, 15y)	6.872.698	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406	567.406
Engineering (8.8%, 15y)	2.663.121	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081	223.081
Reserve (7.73%, 15y)	2.538.584	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648	212.648
Land lease/Acquisition	?															
Sanitation cost	?															
Management cost/employment		39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700	39.700
Maintenance cost		692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001	692.001
Operation costs		801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715	801.715
Insurance costs		72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012	72.012
Total cost (A)		5.746.603	5.746.603	5.746.603	5.746.603	5.746.603	5.746.603	5.746.603	5.746.603	5.565.398	5.565.398	5.565.398	5.565.398	5.101.245	5.101.245	5.101.245
Total electricity production, kWhr		16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011	16.738.011
Total electricity local consumption, KWhr		3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664	3.189.664
Remaining electricity feed to grid, kWhr		13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347	13.548.347
Revenue (B)	year0	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	Year11	Year12	Year13	Year14	year15
Social benefit due to reduction of CO2			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Social benefit due to saving on health cost			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Revenue from waste collection (Tax)			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Revenue from electricity local consumption		486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870	486.870
Revenue from electricity grid feed		812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901	812.901
Revenue from metal/glass sales		112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816	112.816
Revenue from selling compost		801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832	801.832
Total Revenu (B)		2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420	2.214.420
Net profit/loss = (B-A)	-50.321.855	-3.532.183	-3.532.183	-3.532.183	-3.532.183	-3.532.183	-3.532.183	-3.532.183	-3.532.183	-3.350.979	-3.350.979	-3.350.979	-3.350.979	-2.886.825	-2.886.825	-2.886.825
- positive values represent profit	-41,3 $/ton															

It can be concluded that the cashflows for Modular Design 2 stay negative, this means that over a life cycle of 15 years, an environmental park which combines an anaerobic digestion for the wet fraction and a gasification for the residual fraction (after metal, glass and other inorganic material) are sorted out, can neither generate a positive Internal Rate of Return and Net Present nor a reasonable Pay Back Period. If it is so for Mymensingh, this will be certainly be the case for the other municipalities. This is confirmed by the financials indicators presented in the tables below, for every municipality:

Table 71: Financial analysis for Modular Design 2 in Mymensingh for basis & large scale scenario exclusive indirect revenues with and without reuse of energy

	With reuse of energy		Without reuse of energy	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Energy production (kWh/yr)	5.279.011	16.738.011	5.279.011	16.738.011
Capacity (ton/yr)	19.281	80.183	19.281	80.183
Cost/profit ($/ton)	-90,1	-33,3	-99,1	-41,8
IRR (%)	-16,5	-9,9	-21,62	-17,59
NPV ($)	-18.900.042	-24.808.133	- 20.899.482	-32.625.576

Table 72: Financial analysis for Modular Design 2 in Cox's Bazar for basis and large scale scenario exclusive indirect revenues with and without reuse of energy

	With reuse of energy		Without reuse of energy	
	Basis scenario	Large scenari o	Basis scenario	Large scenario
Energy production (kWh/yr)	3.959.032	13.075.032	3.959.032	13.075.032
Capacity (ton/yr)	14.759	61.352	14.759	61.352
Cost/profit ($/ton)	-105,8	- 29,7	-114,4	-37,8
IRR (%)	-19,8	- 9,7	Outside calculation limits	-8,35
NPV ($)	-16.552.638	-18.367.893	-18.015.101	-24.043.106

Table 73: Financial analysis for Modular Design 2 in Dinajpur for basis and large scale scenario exclusive indirect revenues with and without reuse

	With reuse of energy		Without reuse of energy	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Energy production (kWh/yr)	4.803.617	13.803.617	4.803.617	13.803.617
Capacity (ton/yr)	18.022	72.413	18.022	72.413
Cost/profit ($/ton)	-100,7	-31,4	-109,5	-44,3
IRR (%)	-22,3	-10,4	Outside calculation limits	Outside calculation limits
NPV ($)	-19.845.276	22.068.644	-21.670.846	-15.390.767

Table 74: Financial analysis for Modular Design 2 in Habiganj for basis and large scale scenario exclusive indirect revenues with and without reuse of energy

	With reuse of energy		Without reuse of energy	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Energy production (kWh/yr)	1.897.007	4.151.007	1.897.007	4.151.007
Capacity (ton/yr)	4.585	19.928	4.585	19.928
Cost/profit ($/ton)	-312,9	-80,0	-320,7	-87,9
IRR (%)	Outside calculation limits	Outside calculation limits	Outside calculation limits	Outside calculation limits
NPV ($)	-14.651.225	-16.513.231	-15.060.544	-18.319.559

Table 75: Financial analysis for Modular Design 2 in Jessore for basis and large scale scenario exclusive indirect revenues with and without reuse of energy

	With reuse of energy		Without reuse of energy	
	Basis scenario	Large scenario	Basis scenario	Large scenario
Energy production (kWh/yr)	2.472.413	9.076.413	2.472.413	9.076.413
Capacity (ton/yr)	9.997	39.987	9.997	39.987
Cost/profit ($/ton)	-159,5	-37,1	-168,5	-45,4
IRR (%)	Outside calculation limits	Outside calculation limits	Outside calculation limits	-17,44
NPV ($)	-16.570.664	-15.121.747	-17.608.497	-18.905.942

Table 76: Financial analysis for Modular Design 2 in Sirajganj for basis and large scale scenario exclusive indirect revenues with and without reuse of energy

	With reuse of energy		Without reuse of energy	
Energy production (kWh/yr)	2.154.563	5.558.563	2.154.563	5.558.563
Capacity (ton/y r)	8.110	26.641	8.110	26.641
Cost/profit ($/ton)	-186,6	-68,7	-189,7	-76,1
IRR (%)	Outside calculation limits	Outside calculation limits	Outside calculation limits	Outside calculation limits
NPV ($)	-15.674.102	-19.532.215	-15.860.932	-21.794.111

7.6 Management & Operational Aspects for Modular Design 1

The management and the operation of the "Environmental Zone" of Modular Design 1 for Waste treatment and valorisation will require diverse workforce and equipment. It will also require an appropriate management structure. Acquisition of the land can be done either by procurement of the land or by concession to be payed to local authorities. In this case, public private partnerships could be a suitable solution. Experienced construction companies and operators can contribute to a successful project implementation.

7.6.1 Workforce

The table below presents the diverse positions necessary to ensure the effective and performant management of the site.

Table 77: Workforce

Position and Number	Function	Localization
3 guard (if Entry non automatized) => 3 shifts per	Control of the entries	Entrance Area
3 – 5 technicians (with loader license and competences in mechanic and electric devices) 6-12 sorters (shifts possible)	Control of incoming waste trucks Transfer and storage of waste in the PSA Transfer of waste into the sorting hall operation of the drum sieve Transfer of waste into the storage area Transfer of waste into the biologic zone Control and maintenance of the mechanical equipment Sorting of waste	Entire site Pretreatment
2-5 Supporting staff	Cleaning, etc.	Entire site
1 Electrical	Control and monitoring of electrical equipment	Entire site
1 Process Engineer	Control and monitoring of the biological	Entire site
1 Secretary	Administrative work	Administration
1 Site Manager	Management of the Site	Entire site

7.6.2 Equipment

The table below presents the diverse positions necessary to ensure the effective and performant management of the site.

Table-78: Financial comparison of Modular Design 1 versus Modular Design 2

Position and Number	Function	Localization
1 or 2 Loader(s), depending on the waste volume	Transfer of waste	Entire site
1 Mobile Drum Sieve	Separation of organic material from the waste and sieving of compost into different fractions	Pretreatment Composting
1 Sorting line (hopper + conveyor	Sorting of recy clable waste	Pretreatment
1 Metal separator	Recovery of metal from waste	Pretreatment
1 Mobile Shredder/Crusher	Homogenization of the organic matter and green waste	Biological treatment
1 Windrow turner	Aeration and homogenization of the compost	Composting hall

7.7 Social and Environmental Considerations

One of the most important objectives of such a Project is the improvement of the local situation with regards to social and environmental aspects. It is important to develop an integrated concept that will fix the current environmental and social issues (water and soil pollution, hygiene issues, informal employment, etc.) instead of transferring them in a less visible place.

For each project, a detailed Environmental and Social Impacts Assessment will have to be performed in conformity with local Regulations. Preliminary important considerations on social and environmental protection are nevertheless recalled below.

7.7.1 Social Considerations

7.7.1.1 Employment

- Use of local workforce and companies during the construction works for increasing the dynamism of local job market ;
- Use of local technicians and engineers for the operation and maintenance
- Integration of the local waste scavengers in the formal system in order to secure their work conditions and guarantee a fix revenue ;

7.7.1.2 Protection of Population and Workers

- Conception of the site with integration of measures to avoid/limit noise, odors and pollution because the "Environmental Park" may be surrounded by dwellings ;
- Respect of the expropriation rules
- Progressive rehabilitation of the open-air dumpsite
- Temporary fences to prevent accessing the site and avoid heath issues
- Development of an efficient temporary storage system adapted to local needs
- Development of risk management plan because of the biogas installation
- Training sessions of workers (security, environment, health, etc.), and access to protection equipment
- Design of infrastructure in such a way to ensure the aeration of the building (ventilated hall, passive aeration, etc.)

7.7.1.3 Development of Corporate Citizenship

- Integration of the population along the chain of development of the Project to guarantee its commitment (agreement on taxes amount to ensure their payment) and its support (modification of current behavior, control by citizens of waste management procedure in the ward, etc.)

- Creation of citizen local committee by wards on Environment and Waste Issues that will be considered as key players/voice of the community in the decision process with the local Authorities and the other stakeholders of Waste Management (local feedback on key issues, etc.)
- Information meetings
- Participatory meetings
- Awareness rising campaigns on hygiene, good practices, etc.
- Etc.
- Awareness campaigns and training of Municipal agents ; those persons representing the image of the Municipality commitment towards the improvement of the local situation ;
- Development of training sessions at school and University on hygiene, challenges of sustainable development, tools for applying the 3R principle in everyday life, etc. and development of pilot project (selective collection, visit of the Environmental Park, etc.) in order to reinforce the awareness of young people.

7.7.2 Environmental Considerations

- Conception of the site that should include a total site isolation and a regular monitoring of pollution parameters to prevent possible contamination
- Contaminated liquid should be collected and transferred to a waste water treatment plants
- Chemicals/Oils must be stored in a secured and waterproof building
- Development of solution for separate collection (and treatment) of rainwater and waste water
- Rainwater can be used on site for maintenance, humidification needs, etc. through temporary storage
- Waste water should be treated in waste water treatment plant before being released into the environment (esp. surface waters next to the site)
- As much as possible, use of local material and equipment to limit transports and its related effects (air pollution, traffic, noise, etc.)
- Ensuring a quality of compost (destruction of pathogens) and output water in order to prevent human diseases (soil and surface water contamination, accumulation of pathogens in plants/vegetables, etc.)
- Necessity to develop specific landscape design to integrate the project into its urban Environment (green wall to conceal infrastructures and limit noises and odor, green areas to increase infiltration and evacuation of rainwater)
- Concept including energetic independence of the site (use of biogas/solar panels, etc.) and low carbon emission (monitoring of biogas, use of low emission equipment, green space development, etc.)

7.8 Compliance With Regulations

Over the last decades, Bangladesh has developed legislations and regulations to frame waste management but also to rule related subjects such as environment protection, soil protection, water management, air emission, energy production, etc. These regulations aim at developing sustainable and secured conditions for human development and protection.

The following elements give precisions on the potential studies and necessary requirements that will have to be implemented for the development of such a Project.

7.8.1 General Rules

7.8.1.1 Environment

According to the current legislation on Environmental Protection, it is more likely that such a ¨project will require the development of a full and detailed Environmental and Social Impact Assessment in each specific site. This study will take into consideration the specific aspects of each site, especially concerning the local fauna and flora, the protection of waters (drinking water areas, surface water, groundwater, etc.),

Water

The Environment Conservation Rules have fixed standards for Sewage Discharge into the Environment for a list of industrial activities including, among others, Power Plants, Sewage Treatment Plants, Water Treatment Plants and Industry using acid and salt.

Table 79 : Standards for Sewage Discharge – Source (Environment Conservation Act)

Parameter	Unit	Standard Limit
BOD	miligram/1	40
Nitrate	,,	250
Phosphate	,,	35
Suspended Solids (SS)	,,	100
Temperature	Degree Centigrade	30
Coliform	number per 100 ml	1000

The future site will have to respect such criteria before releasing water into the environment.

Air Quality

The infrastructure must comply with regulation in terms of air quality. Regarding this parameter, UNEP did a research in 2015 that states that national air quality policy does not exist in a standalone document and that these issues are addressed in the ECA 1995 and ECR 1997. The National Ambient air quality standards should meet WHO Interim Targets except NO_2 and SO_2. National ambient air quality standards (NAAQS) have been enshrined in the Environment Conservation Rules 1997 (ECR). The Government was considering the revision of the existing NAAQS to meet WHO air quality guiding values.

7.8.2 Specific Issues
7.8.3 Biogas Production
Minimal requirement for biogas production are given below :

- Gas quantities : min. of 80 Liter / kg input
- Methane concentration : > 55 % by volume

(Input means kg waste as received in the Anaerobic Digestion and Compost plant)

If the biogas is used for compressing purposes (CNG or CBM), then carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and water vapor (H_2O) should be removed. It is important to increase the caloric value of the biogas and decrease the corrosive feature of the biogas.

To extract only the methane out of the biogas, the market value of your cooking fuel will increase.

7.8.4 Compost Production
The required standards for the most important compost parameters (compost used for growing plants) are shown in the table below.

Table 80: Compost quality parameter

Parameter	Quality standard
Sanitation	No evidence of pathogenic germs, seeds of plants able to
Disturbing Materials	Maximum 0.8 % of weight in the dry matter of materials larger than
Suitability for	No toxic reac tion in growing tests, no fixation of nitrogen
Degree of Maturation	Degree IV or V
Moisture Content	Loose compost 15 %
Organic Matter	Minimum 15 % in the dry matter analyzed by loss on ignition
Heavy Metal Content	Content in mg/kg Dry Matte r
	Pb 50 Cd 1.5
	Cr 80 Cu 100
	Ni 50 Hg 1.0
	Zn 400
Declaration	Size
	Specific weight
	pH value
	Salt Content
	Content of nutrients (N, P_2O_5, K_2O, MGO, CaO)
	organic matter

7.8.5 Others
Regulations on landownership, urbanization, expropriation, etc. will have to be carefully taken into consideration for the further steps of this study (business plan, detailed engineering, etc.)

7.9 GHG Emission

7.9.1 Presentation of The Problem

Municipal solid waste can generate tremendous quantities of gas during its decomposition. In this biological process, microorganisms decompose organic waste in anaerobic conditions to produce mainly carbon dioxide and methane but also small quantities of other gases.

A simple equation for the production of the principal biogas from cellulose (organic matter) can be expressed as follows:

$C_6H_{10}O_5 + H_2O \ 3CH_4 + 3CO_2$

Due to the composition of Municipal Solid Waste, mainly organic compounds in Bangladesh, landfills (and open dump sites) offer suitable conditions for the development of this reaction. However, without proper biogas management system (storage, flare, etc.), biogas accumulates within the waste layers. Because of its volatility, biogas may be released directly into the Environment through migration phenomena (convection and diffusion). However, biogas may also ignite under certain conditions and causes waste fires with thick black smoke and gas release.

Both events cause dramatic impacts on Environment because biogas and smoke are mainly composed with GHG and particles that contributes to global warming. For example, the main gases produced in a landfill are CO_2 and methane. The both gases have a significant impact on Global Warming due to their residence time into the atmosphere (12 years for methane and 100 years for CO_2) and their global warming potential (over a 20 years period : 1 for CO_2 and 72 for methane). Therefore, it is at utmost importance to provide solutions to avoid both phenomena.

The development of designed landfilled with gas storage or flaring or the development of alternative process such as anaerobic digestion are solutions currently used in Western Countries.

In Bangladesh and especially in the 6 studied Paurashavas, such infrastructure are not developed yet and the open dumpsite contributes dramatically to the global warming.

The development of new infrastructure, as presented in this Study, will aim at reducing such effects by providing alternative techniques that take into account biogas generation.

7.9.2 Scope

This chapter will aim at illustrating the potential of GHG emission of current open dumpsites in the Paurashavas studied and at showing the potential of reduction in GHG emission with the closure of such unsuitable waste storage sites.

7.9.3 Methodology

In order to perform this analysis, the GHG emission has been estimated via the software LandGem, whose presentation is given in Section 7.9.3.1.The technical parameters related to waste used in this software are described in Section 7.9.3.2. Finally, three scenarios have been compared for each Paurashava ; they are presented in Section 7.9.3.3.

7.9.3.1 Presentation Of The Software

LandGEM is an automated estimation tool for emission rates for total landfill gas, methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from municipal solid waste landfills. LandGEM can use either site-specific data to estimate emissions or default parameters if no site-specific data are available.

LandGEM uses the following first-order decomposition rate equation to estimate annual emissions over a specified time period.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_0 \left(\frac{M_i}{10} \right) e^{-k t_{ij}}$$

where

- Q_{CH_4} = annual methane generation in the year of the calculation (m3/year);
- i = 1 year time increment;
- n = (year of the calculation) - (initial year of waste acceptance);
- j = 0.1 year time increment;
- k = methane generation rate (year-1);
- Lo = potential methane generation capacity (m^3/Mg);
- Mi = mass of waste accepted in the ith year (Mg);
- tij = age of the jth section of waste mass Mi accepted in the ith year (decimal years, e.g., 3.2 years).

In order to perform the simulation, these parameters have to be defined, either by measures on field or by using the pre-defined parameters of the software. The objective of this section is to get an order of magnitude of the potential of GHG emission generated by open dumpsite. As a consequence, the set of default values (the inventory defaults) of the LandGEM model have been used. The inventory default values in the model are based on emission factors from the U.S. Environmental Protection Agency"s „Compilation of Air Pollutant Emission Factors, AP-42" (EPA, 1998) The inventory default values provide emission estimates that should reflect typical municipal solid waste landfill emissions and are the values suggested for use in developing estimates for state inventories. In Table 81, the used parameters are summarized.

Table 81 : Default values used in land GEM

Parameter	Valu
k	0,04 year-1
L0	100 m³/Mg
NMOC (non methane organic compound concentration	600 ppmv
Methane content	50% Methane 50 % Carbon dioxide

7.9.3.2 Technical Parameters Related To Waste

Some technical parameters related to waste production should be mentioned in the software Land Gem :

- Landfill Open Year
- Landfill Closure Year
- Waste dumped into the landfill(s) per year

Landfill open and closure year

First, data concerning opening and estimated closure years will be collected to official authorities through the Local Partner.

When the estimated closure years is not known, it will be assumed that the landfill will be in operation until 2030, period on which the simulation and the Study have been performed.

Waste dumped into the landfill (S) per year

The estimation of waste dumped per year into the landfill will be defined as follows:

7.9.3.3 Definition of the scenarios

The comparison is based on three scenarios explained below. The objective is to present three possible situation evolutions (without changes in waste management, with changes only in waste collection and with changes in waste management) and to compare the trends in terms of GHG emission from one to another scenario.

Table 81 : Default values used in LandGEM

<table>
<tr><td>STEP 1</td><td colspan="3">Evaluation of the population from "Opening Year" to "Closure Year" through the data from Census 2001 and 2011 (Population + Population Growth Rate)</td></tr>
<tr><td>STEP 2</td><td colspan="3">• Estimation of the waste produced per year from "Opening Year" to "Closure
• Year" via the Figures related to the Population and the Waste Generation Rate (WGR). The difference between wet and dry season will be taken into consideration.
• From 2001 to 2019 : it will be assumed that the WGR for dry and wet season are those mentioned in the Study of Waste Concern 2013 -2014 on the Waste estimation in the different Paurashavas (e.g Mymensingh : Dry season 0.29 kg/d/cap./Wet season 0.41 kg/d/cap.)
• From 2020 to 2030 : a corrected factor will be applied to the WGR mentioned above. This corrected factor, that reflects the increase of waste generation, is the ratio between the WGR evaluated by the WB in the National Level by 2030 (0.6) and the WGR evaluated by Waste concern at the National Level by 2013</td></tr>
<tr><td rowspan="3">STEP 3</td><td colspan="3">• Estimation of the waste dumped into the landfill(s) per year
• Waste dumped into the landfill corresponds to waste effecti vely collected by the waste collection system. As such, a waste collection ratio will be used; assumptions will be made from the data of Waste Concern estimating that the
• Waste Collection Rate of Paurashava by 2005 was about 55%.</td></tr>
<tr><td>Scenarios 1</td><td>no significate improvement in the waste collection rate through the years</td><td>From "Opening Year to 2020 : WCR = 55% From 2020 to 2030 : WCR = 60%</td></tr>
<tr><td>Scenarios 2 and 3</td><td>Significate impro vement in waste collection system</td><td>From "Opening Year to 2020 : WCR = 55% From 2020 to 2024: WCR = 75% From 2025 to 2029: WCR = 90% 2030 : WCR = 98%</td></tr>
</table>

7.9.3.3 Definition of The Scenarios

The comparison is based on three scenarios explained below. The objective is to present three possible situation evolutions (without changes in waste management, with changes only in waste collection and with changes in waste management) and to compare the trends in terms of GHG emission from one to another scenario.

Table 56: Financial analysis for the installation of Modular Design 1 in Mymensingh for the basis scenario inclusive indirect revenues

	Scenario	Scenario	Scenario
Description of each scenario			
Description	No major improvement in Waste management system : - the waste collection rate is still low (evolution from 50% to 60%) - the open dumpsite has(ve) not been upgraded - Waste are still stored in the dumpsite(s) and no other infrastructure has been developed	No major improvement in Waste treatment system but improvement in waste collection system : - Evolution of the waste collection rate from 50% to 98% [1] - the open dumpsite has(ve) not been upgraded - Waste are still stored in the dumpsite(s) and no oth er infrastructure has been developed	Major improvement in Waste management system : - Evolution of the waste collection rate from 50% to 98% [1] - Development of new infrastructure for waste treatment leading to stopping the storage of waste in the dumpsite(s) - No gas management system set up in the former dumpsite
Technical parameters and assumptions			
Period of simulation	Opening date – Closure date* *closure date arbit rarily set by 2030 if no other information provided at Local	Opening date – Closure date* *closure date arbitrarily set by 2030 if no other information provided at Local	Opening date – 2019* *Assumption : development of new infrastructure of
Collection	Until 2013 : WC [2] = 50% WG [3] 2013 – 2025 : WC = 55% WG 2025 -2030 : WC = 60% WG	Until 2013 : WC = 50% WG 2013 – 2020 : WC = 55% WG 2020 -2025 : WC = 75% WG 2025 -2029 : WC = 90% WG	Until 2013 : WC = 50% WG 2013 – 2020 : WC = 55% WG 2020 -2025 : WC = 75% WG 2025 -2029 : WC = 90% WG
Gas gener.	See LandGEM parameters		
Dumpsite charact.	Characteristics that depend of each dumpsite - See details below		

1 : See Section 7.2 Technical parameters and concepts – Waste Generation
2 : WC : Waste collected
3 : WG : Waste generated

7.9.4 Results

7.9.4.1 Mymensingh

Technical Parameters

Waste production and storage

Table 81 : Default values used in LandGEM

Year	Pop.	Waste Generation			Waste collected and dumped					
		Waste Dry	Waste Wet	Total	S1		S2		S2	
	Inhab.	t/wet season	t/dry season	t/year	% coll.	t/year	% coll.	t/year	% coll.	t/year
2004	236	12 690	17 668	30	55	16 697	55	16	55	16
2005	239	12 852	17 895	30	55	16 911	55	16	55	16
2006	242	13 017	18 124	31	55	17 127	55	17	55	17
2007	245	13 183	18 356	31	55	17 347	55	17	55	17
2008	248	13 352	18 591	31	55	17 569	55	17	55	17
2009	251	13 523	18 829	32	55	17 794	55	17	55	17
2010	254	13 697	19 070	32	55	18 022	55	18	55	18
2011	258	13 872	19 315	33	55	18 253	55	18	55	18
2012	261	14 050	19 562	33	55	18 486	55	18	55	18
2013	264	14 230	19 812	34	55	18 723	55	18	55	18
2014	268	14 412	20 066	34	55	18 963	55	18	55	18
2015	271	14 596	20 323	34	55	19 206	55	19	55	19
2016	274	14 783	20 583	35	55	19 452	55	19	55	19
2017	278	14 973	20 847	35	55	19 701	55	19	55	19
2018	282	15 164	21 114	36	55	19 953	55	19	55	19
2019	285	15 359	21 385	36	55	20 209	55	20	55	20
2020	289	18 666	25 990	44	60	26 794	75	33	75	0
2021	293	18 906	26 323	45	60	27 137	75	33	75	0
2022	296	19 148	26 660	45	60	27 485	75	34	75	0
2023	300	19 393	27 002	46	60	27 837	75	34	75	0
2024	304	19 641	27 347	46	60	28 193	75	35	75	0
2025	308	19 893	27 698	47	60	28 554	90	42	90	0
2026	312	20 148	28 052	48	60	28 920	90	43	90	0
2027	316	20 406	28 412	48	60	29 291	90	43	90	0
2028	320	20 667	28 776	49	60	29 666	90	44	90	0
2029	324	20 932	29 144	50	60	30 046	90	45	90	0
2030	328	21	29 518	50	60	30 430	98%	49	98%	0

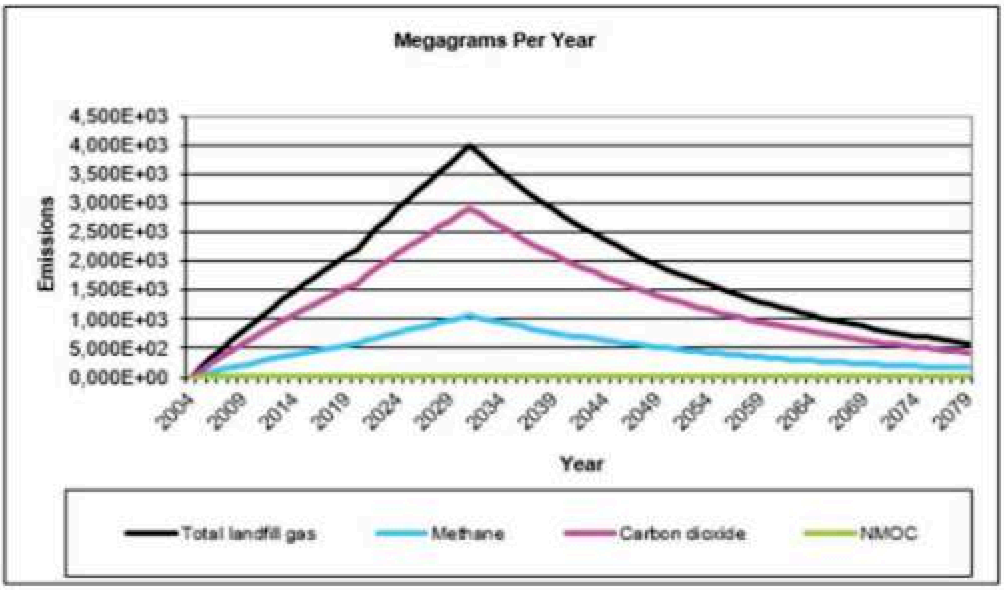
Dumpsite

There is one, official' dumpsite at Mymsensingh. Its characteristics are given below :

Table 82 : Mymensingh dumpsite features - Source (A.K.M. Tarik Alom, Chief Executive officer)

Place	Mymensingh – Shombhugonj Bridge
Surface	7.3 Acres (3 ha)
Ope ning date	2004
Closure Year	Not known – assumed to be at 2030

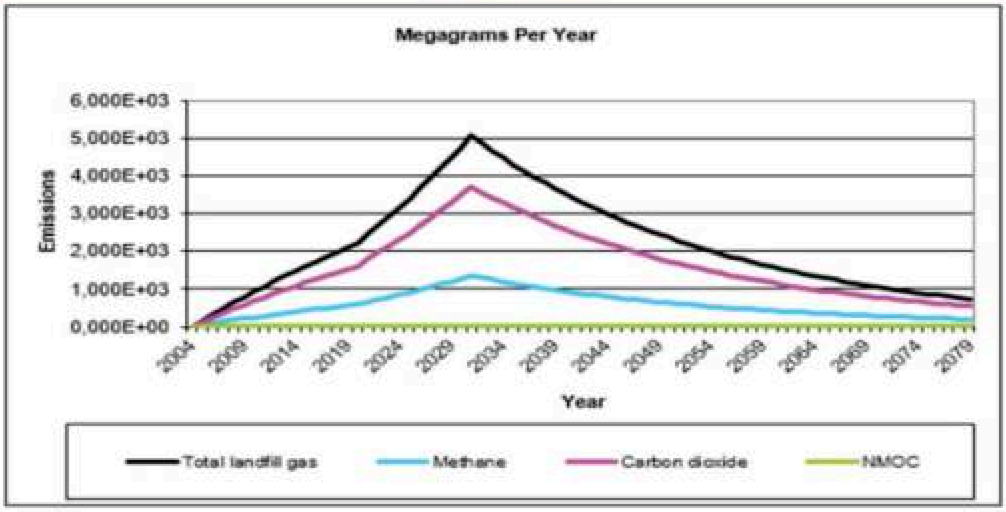
GHG Emission



Scenario 0

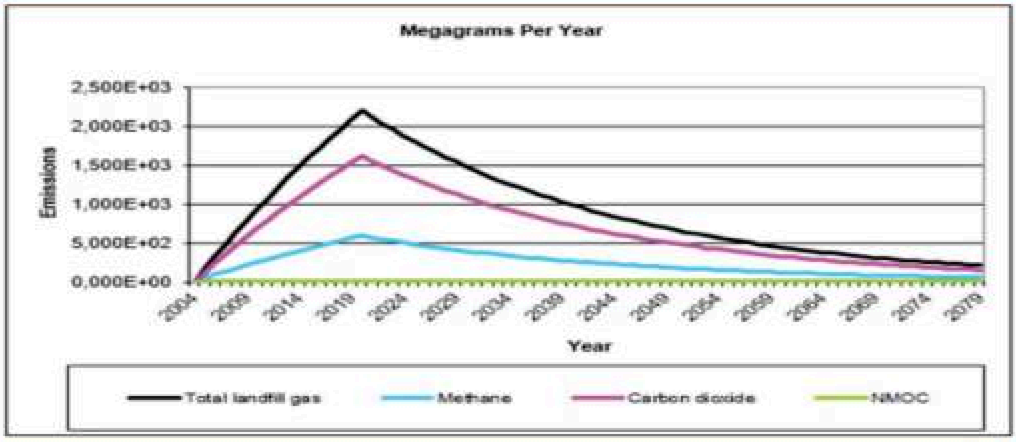
According to S0, Total Gas Emission at Mymensingh dumpsite reaches a peak value in 2031 of 3,184,000 m^3/year. Note that according to this simulation, about 13,600 tons of CH_4 and 37,300 tons of CO_2 will be generated from 2004 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2060.

GHG Emission



Scenario 1

According to S1, Total Gas Emission at Mymensingh dumpsite reaches a peak value in 2031 of 4,043,000 m^3/year. Note that according to this simulation, about 14,700 tons of CH_4 and 40,500 tons of CO_2 will begenerated from 2004 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2066.



Scenario 2

According to S2, Total Gas Emission at Mymensingh dumpsite reaches a peak value in 2020 of 1,792,000 m^3/year. Note that according to this simulation, about 10,000 tons of CH_4 and 27,500 tons of CO_2 will be generated from 2004 to 2030. Because of the theoretical closure of the dumpsite by 2020, gas emissions will thus progressively decrease and fall until the threshold of 1,000,000 m^3/year by 2035.

Conclusion
From these preliminary results, it can be observed that the development of an efficient Waste Management and Treatment System (S2) not only allow to reduce by a factor of 1.5 (S0) to 2.3 (S1) the peak emission but also allow to reduce drastically and on a long term basis the quantity of GHG released into the atmosphere. Over the period of landfill opening and 2030, it can be estimated that the development of efficient infrastructure for waste treatment and management (S2) will reduce CH_4 and CO_2 emission by about 25% compared to the situation S0 (current situation). In order to have a better estimation and evaluate the relevance of developing a flaring or storage systems on the current landfill, field surveys and measurements will be necessary.

7.9.4.2 Cox's Bazar
Technical Parameters

Waste production and storage

Year	Pop.	Waste Generation			Waste collected and dumped					
		Waste Dry Season	Waste Wet Season	Total	S1		S2		S2	
	Inhab.	t/wet season	t/dry season	t/year	% col.	t/year	% col.	t/year	% col.	t/year
2009	132 504	8 030	11 180	19 210	55%	10 565	55%	10 565	55%	10
2010	148 967	9 027	12 569	21 597	55%	11 878	55%	11 878	55%	11
2011	167 477	10 149	14 131	24 280	55%	13 354	55%	13 354	55%	13
2012	188 286	11 410	15 887	27 297	55%	15 013	55%	15 013	55%	15
2013	211 681	12 828	17 861	30 689	55%	16 879	55%	16 879	55%	16
2014	237 983	14 422	20 080	34 502	55%	18 976	55%	18 976	55%	18
2015	267 553	16 214	22 575	38 789	55%	21 334	55%	21 334	55%	21
2016	300 797	18 228	25 380	43 608	55%	23 985	55%	23 985	55%	23
2017	338 172	20 493	28 534	49 027	55%	26 965	55%	26 965	55%	26
2018	380 190	23 039	32 079	55 118	55%	30 315	55%	30 315	55%	30
2019	427 430	25 902	36 065	61 967	55%	34 082	55%	34 082	55%	34
2020	480 539	34 945	48 655	83 600	55%	45 980	75%	62 700	75%	0
2021	540 247	39 287	54 701	93 987	55%	51 693	75%	70 490	75%	0
2022	607 374	44 168	61 497	105	55%	58 116	75%	79 249	75%	0
2023	682 841	49 656	69 139	118	55%	65 337	75%	89 096	75%	0
2024	767 686	55 826	77 729	133	55%	73 455	75%	100	75%	0
2025	863 073	62 762	87 387	150	60%	90 090	90%	135	90%	0
2026	970 311	70 561	98 245	168	60%	101	90%	151	90%	0
2027	1 090	79 328	110	189	60%	113	90%	170	90%	0
2028	1 226	89 185	124	213	60%	128	90%	192	90%	0
2029	1 378	100	139	239	60%	143	90%	215	90%	0
2030	1 550	112	156	269	60%	161	98%	264	98%	0

Dumpsite features

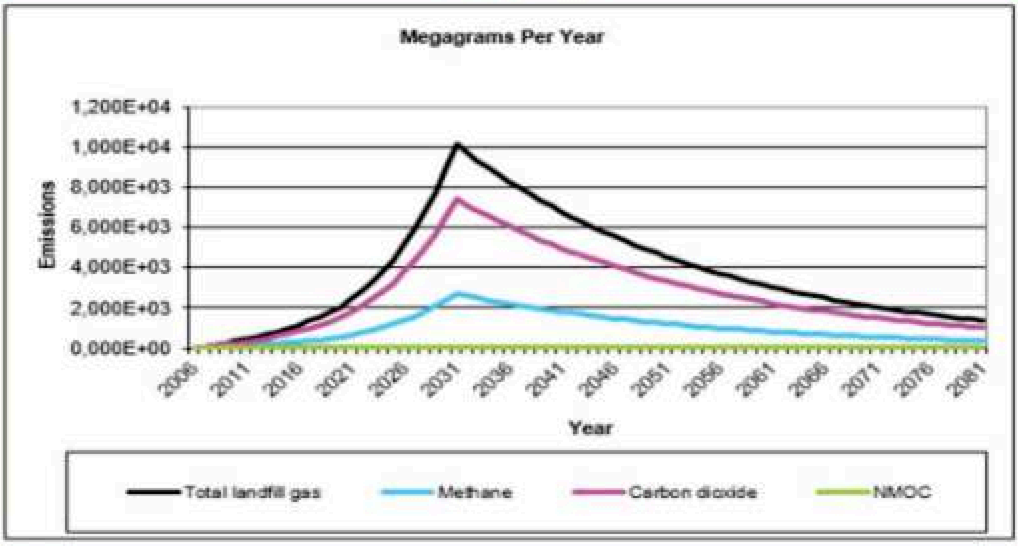
There are three current dumpsites in Cox's Bazar. Their features are given below:

Table 83 : Cox's Bazar dumpsite features - Source (Eng. Nurul Alom – Executive Engineer)

Place	Pona Market	S.M. Para	Mithachari
Surface	2.5 Acres (1 ha)	2.03 Acres (0.8ha)	3.72 Acres (1.5ha)
Opening date	200	Not mentioned	Not
Closure Ye ar	Not known – assumed in service by 2030		

For this simulation, gas emission from one big landfill or from 3 small landfills can be considered as being quite similar. In order to perform the simulation, one theoretical "super-landfill" will therefore be considered, whose theoretical opening year will be the one of the oldest dumpsite. In the case of Cox's Bazar, it will be assumed that 2006 will be the theoretical opening year.

GHG Emission

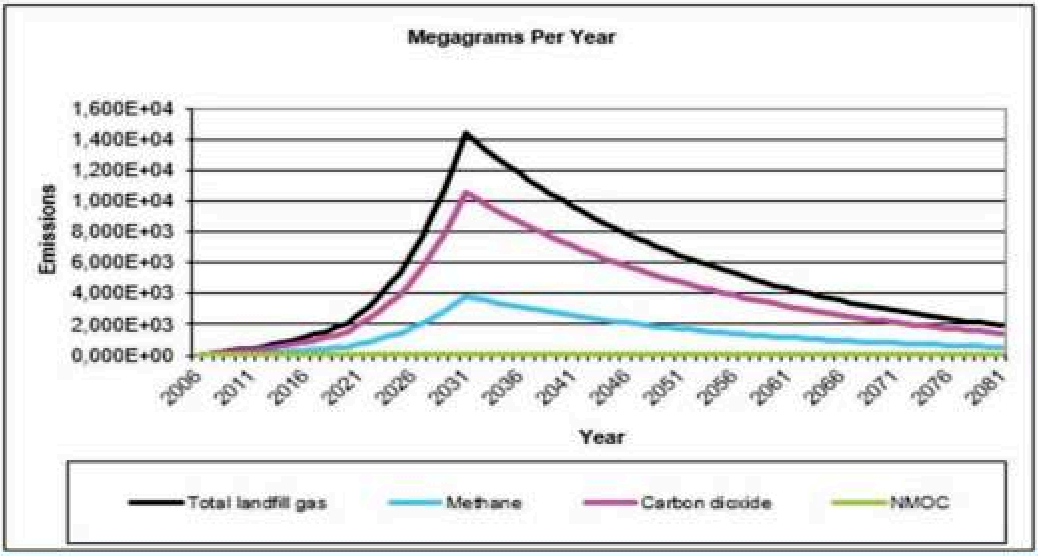


Scenario 0

According to S0, Total Gas Emission at Cox's Bazar dumpsite reaches a peak value in 2031 of 8,092,000 m^3/year.

Note that according to this simulation, about 16,900 tons of CH_4 and 46,3000 tons of CO_2 will be generated from 2006 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2084.

GHG Emission

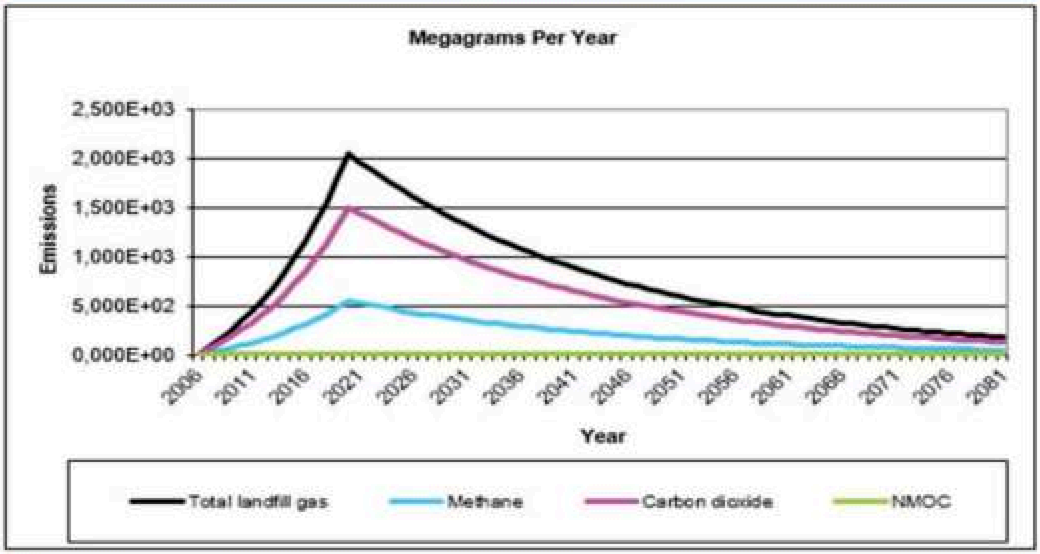


Scenario 1

According to S1, Total Gas Emission at Cox's Bazar dumpsite reaches a peak value in 2031 of 11,100,000 m3/year.

Note that according to this simulation, about 20,800 tons of CH_4 and 57,000 tons of CO_2 will be generated from 2006 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2093.

GHG Emission



Scenario 2

According to S2, Total Gas Emission at Cox's Bazar dumpsite reaches a peak value in 2020 of 1,638,000 m^3/year.

Note that according to this simulation, about 7,500 tons of CH_4 and 21,000 tons of CO_2 will be generated from 2006 to 2030. Because of the theoretical closure of the dumpsite by 2020, gas emissions will thus progressively decrease and fall until the threshold of 1,000,000 m^3/year by 2032.

Conclusion

From these preliminary results, it can be observed that the development of an efficient Waste Management and Treatment System (S2) not only allow to reduce by a factor of 4.9 (S0) to 6.7(S1) the peak emission but also allow to reduce drastically and on a long term basis the quantity of GHG released into the atmosphere. Over the period of landfill opening and 2030, it can be estimated that the development of efficient infrastructure for waste treatment and management (S2) will reduce CH_4 and CO_2 emission by about 55% compared to the situation S0 (current situation).

Note that these Figures show such an impressive evolution because of the assumption on the population growth over the next decades; indeed, it has been considered a rapid and significant population growth rate (13%).

This simulation is therefore given as an indication and should be adapted depending on the real evolution of the population.

Moreover, in order to have a better estimation and evaluate the relevance of developing a flaring or storage systems on the current landfill, field surveys and measurements will be necessary.

7.9.4.3 Dinajpur

Technical Parameters

Waste production and storage

Year	Pop.	Waste Generation			Waste collected and dumped					
		Waste Dry	Waste Wet Season	Total	S1		S2		S2	
	Inhab.	t/wet season	t/dry season	t/year	% coll.	t/year	% coll.	t/year	% coll.	t/year
2001	157	10 582	14 734	25 316	55%	13	55	13 924	55%	13 924
2002	160	10 761	14 983	25 744	55%	14	55	14 159	55%	14 159
2003	163	10 943	15 236	26 179	55%	14	55	14 399	55%	14 399
2004	166	11 128	15 494	26 6 22	55%	14	55	14 642	55%	14 642
2005	168	11 316	15 756	27 072	55%	14	55	14 889	55%	14 889
2006	171	11 507	16 022	27 529	55%	15	55	15 141	55%	15 141
2007	174	11 702	16 293	27 995	55%	15	55	15 397	55%	15 397
2008	177	11 899	16 568	28 468	55%	15	55	15 657	55%	15 657
2009	180	12 101	16 848	28 949	55%	15	55	15 922	55%	15 922
2010	183	12 305	17 133	29 438	55%	16	55	16 191	55%	16 191
2011	186	12 513	17 423	29 936	55%	16	55	16 465	55%	16 465
2012	192	12 901	17 962	30 863	55%	16	55	16 974	55%	16 974
2013	198	13 300	18 518	31 818	55%	17	55	17 500	55%	17 500
2014	204	13 712	19 092	32 804	55%	18	55	18 042	55%	18 042
2015	210	14 137	19 683	33 819	55%	18	55	18 601	55%	18 601
2016	217	14 574	20 292	34 867	55%	19	55	19 177	55%	19 177
2017	224	15 026	20 921	35 946	55%	19	55	19 771	55%	19 771
2018	231	15 491	21 569	37 060	55%	20	55	20 383	55%	20 383
2019	238	15 971	22 237	38 207	55%	21	55	21 014	55%	21 014
2020	245	19 758	27 510	47 268	55%	25	75	35 451	75%	0
2021	253	20 370	28 362	48 732	55%	26	75	36 549	75%	0
2022	261	21 001	29 240	50 241	55%	27	75	37 681	75%	0
2023	269	21 651	30 146	51 797	55%	28	75	38 848	75%	0
2024	277	22 322	31 079	53 401	55%	29	75	40 051	75%	0
2025	286	23 013	32 042	55 055	60%	33	90	49 549	90%	0
2026	295	23 725	33 034	56 760	60%	34	90	51 084	90%	0
2027	304	24 460	34 057	58 517	60%	35	90	52 666	90%	0
2028	313	25 218	35 112	60 329	60%	36	90	54 296	90%	0
2029	323	25 999	36 199	62 198	60%	37	90	55 978	90%	0
2030	333	26 804	37 320	64 124	60%	38	98%	62 841	98%	0

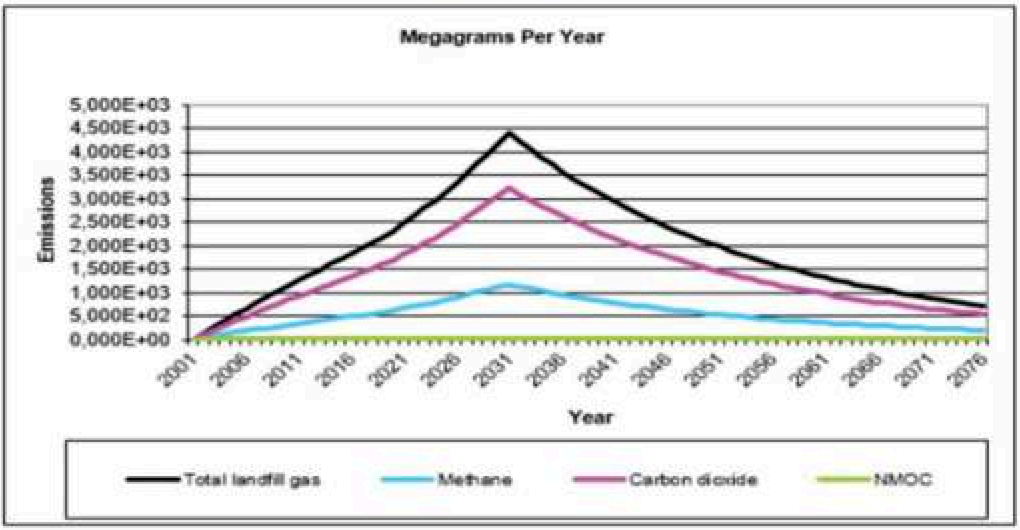
Dumpsite features

There is one "official" dumpsite at Dinajpur. Its characteristics are given below:

Table 84 : Dinajpur dumpsite features - Source (Mr. Md. Golam Nabi, Conservancy Officer)

Place	Moila Goffa
Surface	6.5 Acres (ha)
Opening date	2001
Closure Year	Not known – assumed in service by

GHG Emission



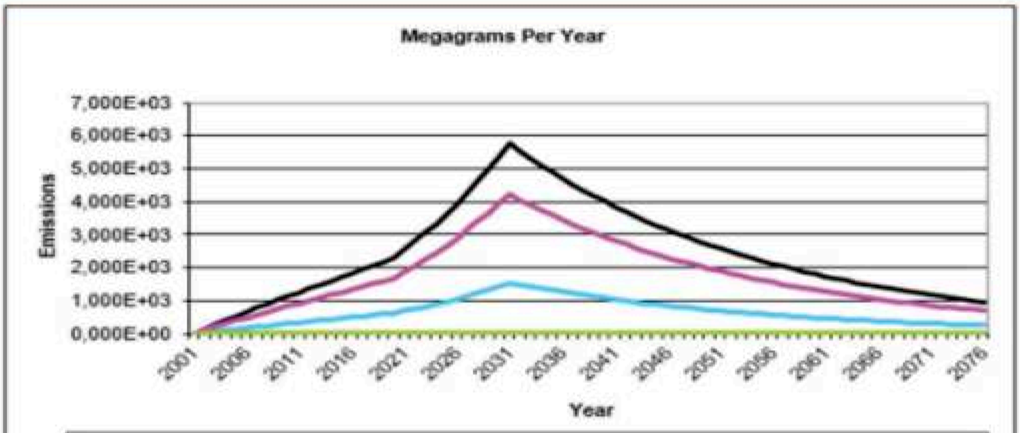
Scenario 0

According to S0, Total Gas Emission at Dinajpur dumpsite reaches a peak value in 2031 of 3,507,000 m^3/year.

Note that according to this simulation, about 15,000 tons of CH_4 and 41,200 tons of CO_2 will be generated from 2001 to 2030.

Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2063.

GHG Emission



7.9.4.4 Sirajganj
Technical Parameters

Waste production and storage

Year	Pop.	Waste Generation			Waste collected and dumped					
		Waste Dry	Waste Wet Season	Total	S1		S2		S2	
	Inhab.	t/wet season	t/dry season	t/year	% coll.	t/year	% coll.	t/year	% coll.	t/year
2007	145 806	5 260	7 324	12	55%	6 921	55%	6 921	55	6 921
2008	148 978	5 374	7 483	12	55%	7 072	55%	7 072	55	7 072
2009	152 218	5 491	7 646	13	55%	7 225	55%	7 225	55	7 225
2010	155 530	5 611	7 812	13	55%	7 383	55%	7 383	55	7 383
2011	158 913	5 733	7 982	13	55%	7 543	55%	7 543	55	7 543
2012	162 370	5 858	8 156	14	55%	7 707	55%	7 707	55	7 707
2013	165 902	5 985	8 333	14	55%	7 875	55%	7 875	55	7 875
2014	169 511	6 115	8 514	14	55%	8 046	55%	8 046	55	8 046
2015	173 198	6 248	8 700	14	55%	8 221	55%	8 221	55	8 221
2016	176 966	6 384	8 889	15	55%	8 400	55%	8 400	55	8 400
2017	180 816	6 523	9 082	15	55%	8 583	55%	8 583	55	8 583
2018	184 749	6 665	9 280	15	55%	8 770	55%	8 770	55	8 770
2019	188 768	6 810	9 482	16	55%	8 960	55%	8 960	55	8 960
2020	192 874	8 350	11 626	19	55%	10 986	75%	14 981	75	0
2021	197 070	8 531	11 878	20	55%	11 225	75%	15 307	75	0
2022	201 357	8 717	12 137	20	55%	11 469	75%	15 640	75	0
2023	205 737	8 906	12 401	21	55%	11 719	75%	15 980	75	0
2024	210 213	9 100	12 671	21	55%	11 974	75%	16 328	75	0
2025	214 786	9 298	12 946	22	60%	13 347	90%	20 020	90	0
2026	219 458	9 500	13 228	22	60%	13 637	90%	20 455	90	0
2027	224 232	9 707	13 516	23	60%	13 934	90%	20 900	90	0
2028	229 110	9 918	13 810	23	60%	14 237	90%	21 355	90	0
2029	234 094	10 134	14 110	24	60%	14 546	90%	21 820	90	0
2030	239 186	10 354	14 417	24	60%	14 863	98%	24 276	98%	0

Dumpsite features

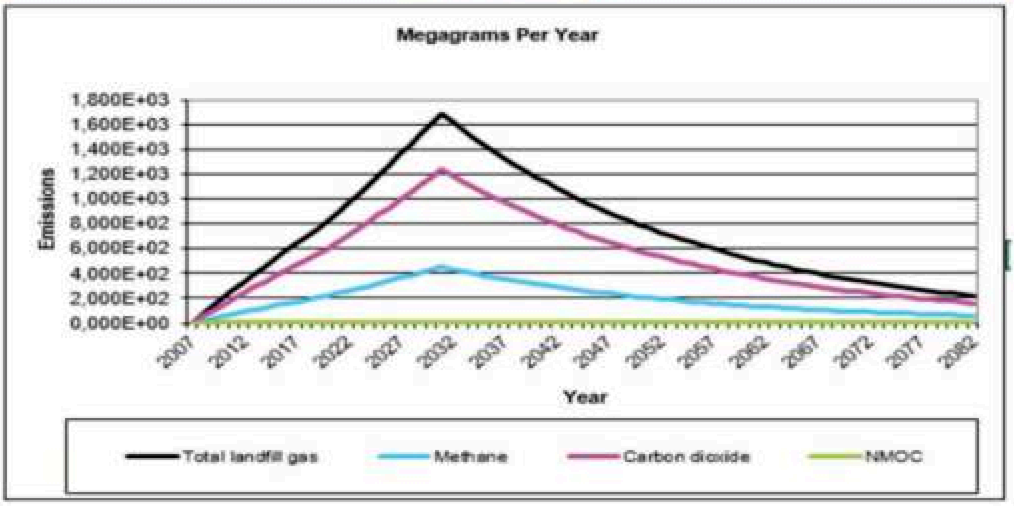
There is two "official" dumpsite at Sirajganj. Their features are given below :

Table 85 : Sirajganj dumpsite features - Source (Md. Kahan Billala, Conservancy Officer)

Place	Bombaria	Shailkot
Surface	6.2 Acres (ha)	2 Acres (ha)
Opening date	2007	2007
Closure Year	Not known – assumed in service by 2030	

For this simulation, gas emission from one big landfill or from 2 small landfills can be considered as being quite similar. In order to perform the simulation, one theoretical "super-landfill" will therefore be considered, whose theoretical opening year will be the one of the oldest dumpsite. In the case of Cox's Bazar and Sirajganj, both landfills have been opened the same year; therefore, it will be assumed that 2007 will be the theoretical opening year.

GHG Emission

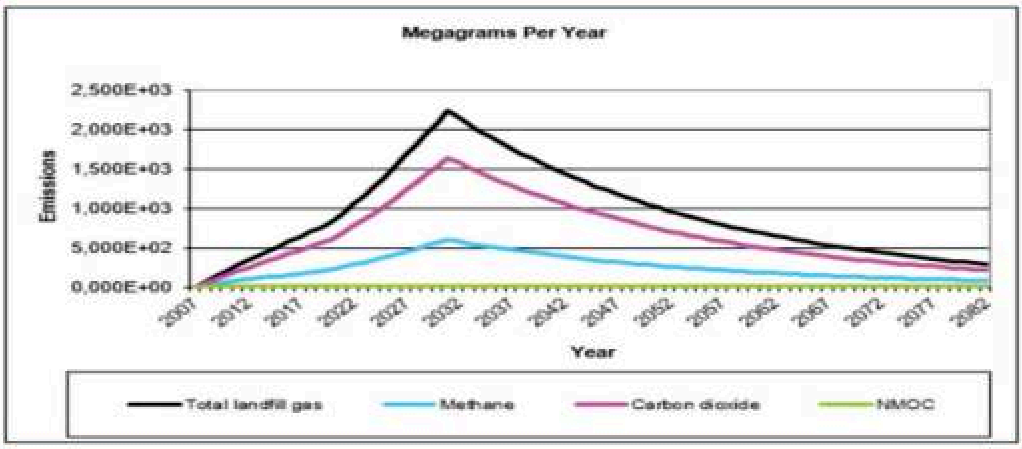


Scenario 0

According to S0, Total Gas Emission at Sirajganj dumpsite reaches a peak value in 2031 of 1,351,000 m^3/year.

Note that according to this simulation, about 4,900 tons of CH_4 and 13,300 tons of CO_2 will be generated from 2007 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2039.

GHG Emission

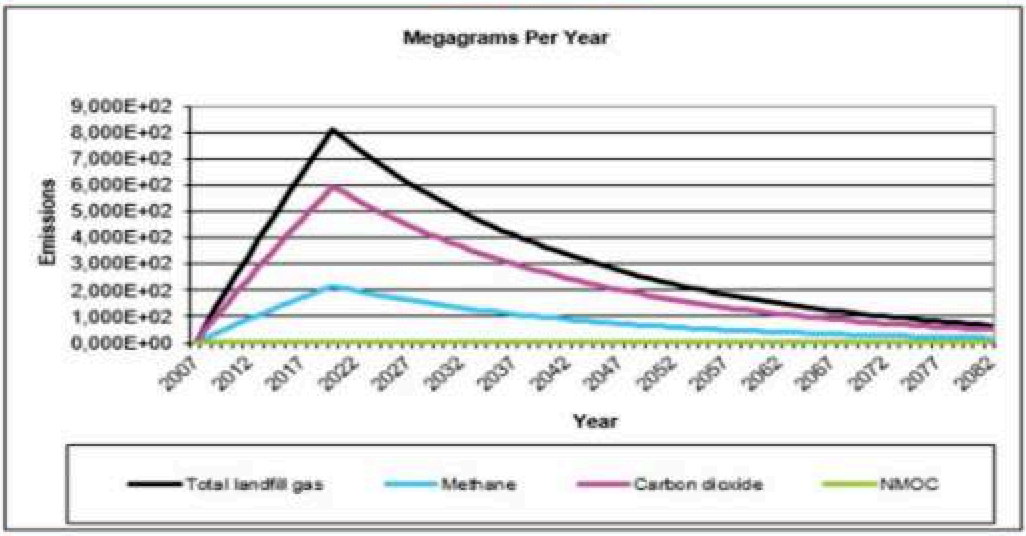


Scenario 1

According to S1, Total Gas Emission at Sirajganj dumpsite reaches a peak value in 2031 of 1,788,000 m^3/year.

Note that according to this simulation, about 5,500 tons of CH_4 and 15,000 tons of CO_2 will be generated from 2007 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m3/year by 2046.

GHG Emission



Scenario 2

According to S2, Total Gas Emission at Sirajganj dumpsite reaches a peak value in 2020 of 649,000 m^3/year.

Note that according to this simulation, about 3,300 tons of CH_4 and 9,100 tons of CO_2 will be generated from 2007 to 2030. Because of the theoretical closure of the dumpsite by 2020, gas emissions will thus progressively decrease.

Conclusion

From these preliminary results, it can be observed that the development of an efficient Waste Management and Treatment System (S2) not only allow to reduce by a factor of 2.1 (S0) to 2.8(S1) the peak emission but also allow to reduce drastically and on a long term basis the quantity of GHG released into the atmosphere. Over the period of landfill opening and 2030, it can be estimated that the development of efficient infrastructure for waste treatment and management (S2) will reduce CH_4 and CO_2 emission by about 33% compared to the situation S0 (current situation). In order to have a better estimation and evaluate the relevance of developing a flaring or storage systems on the current landfill, field surveys and measurements will be necessary.

7.9.4.5 Habiganj

Technical Parameters

Waste Production And Storage

Year	Pop.	Waste Generation			Waste collected and dumped					
		Waste Dry	Waste Wet Season	Total	S1		S2		S2	
	Inhab.	t/wet season	t/dry season	t/year	% coll.	t/year	% coll.	t/year	% coll.	t/year
2007	145 806	5 260	7 324	12	55%	6 921	55%	6 921	55	6 921
2008	148 978	5 374	7 483	12	55%	7 072	55%	7 072	55	7 072
2009	152 218	5 491	7 646	13	55%	7 225	55%	7 225	55	7 225
2010	155 530	5 611	7 812	13	55%	7 383	55%	7 383	55	7 383
2011	158 913	5 733	7 982	13	55%	7 543	55%	7 543	55	7 543
2012	162 370	5 858	8 156	14	55%	7 707	55%	7 707	55	7 707
2013	165 902	5 985	8 333	14	55%	7 875	55%	7 875	55	7 875
2014	169 511	6 115	8 514	14	55%	8 046	55%	8 046	55	8 046
2015	173 198	6 248	8 700	14	55%	8 221	55%	8 221	55	8 221
2016	176 966	6 384	8 889	15	55%	8 400	55%	8 400	55	8 400
2017	180 816	6 523	9 082	15	55%	8 583	55%	8 583	55	8 583
2018	184 749	6 665	9 280	15	55%	8 770	55%	8 770	55	8 770
2019	188 768	6 810	9 482	16	55%	8 960	55%	8 960	55	8 960
2020	192 874	8 350	11 626	19	55%	10 986	75%	14 981	75	0
2021	197 070	8 531	11 878	20	55%	11 225	75%	15 307	75	0
2022	201 357	8 717	12 137	20	55%	11 469	75%	15 640	75	0
2023	205 737	8 906	12 401	21	55%	11 719	75%	15 980	75	0
2024	210 213	9 100	12 671	21	55%	11 974	75%	16 328	75	0
2025	214 786	9 298	12 946	22	60%	13 347	90%	20 020	90	0
2026	219 458	9 500	13 228	22	60%	13 637	90%	20 455	90	0
2027	224 232	9 707	13 516	23	60%	13 934	90%	20 900	90	0
2028	229 110	9 918	13 810	23	60%	14 237	90%	21 355	90	0
2029	234 094	10 134	14 110	24	60%	14 546	90%	21 820	90	0
2030	239 186	10 354	14 417	24	60%	14 863	98%	24 276	98%	0

Dumpsite features

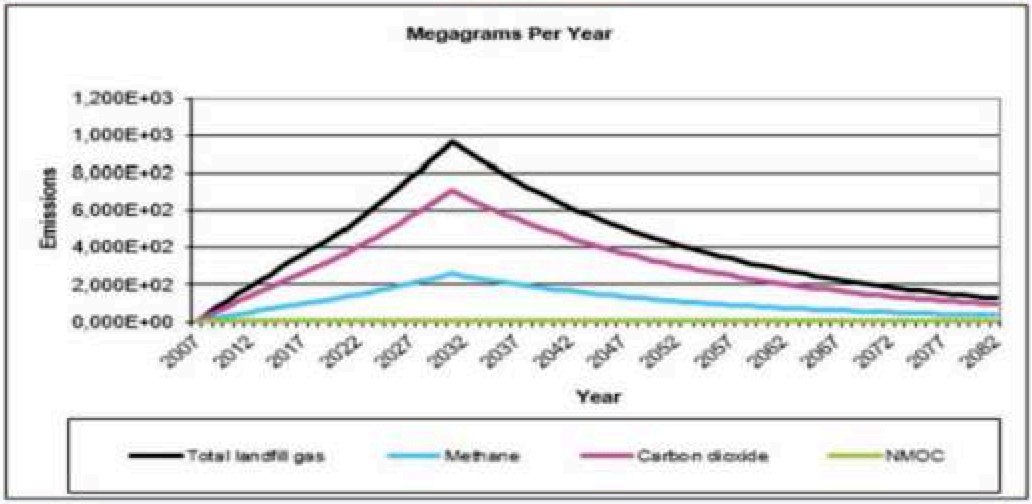
There is two "official" dumpsite at Sirajganj. Their features are given below:

Table 86 : Habiganj dumpsite features - Source (Shahadat Hossain, Conservancy Officer)

Place	Shilpo	Koladoba	Goshaipur
Surface	5.5 Acres (ha)	4.5 Acres (ha)	2 Acre s
Opening date	2007	2009	2010
Closure Year	Not known – assumed in service by 2030		

For this simulation, gas emission from one big landfill or from 3 small landfills can be considered as being quite similar. In order to perform the simulation, one theoretical "super-landfill" will therefore be considered, whose theoretical opening year will be the one of the oldest dumpsite. In the case of Habiganj, it will be assumed that 2007 will be the theoretical opening year.

GHG Emission

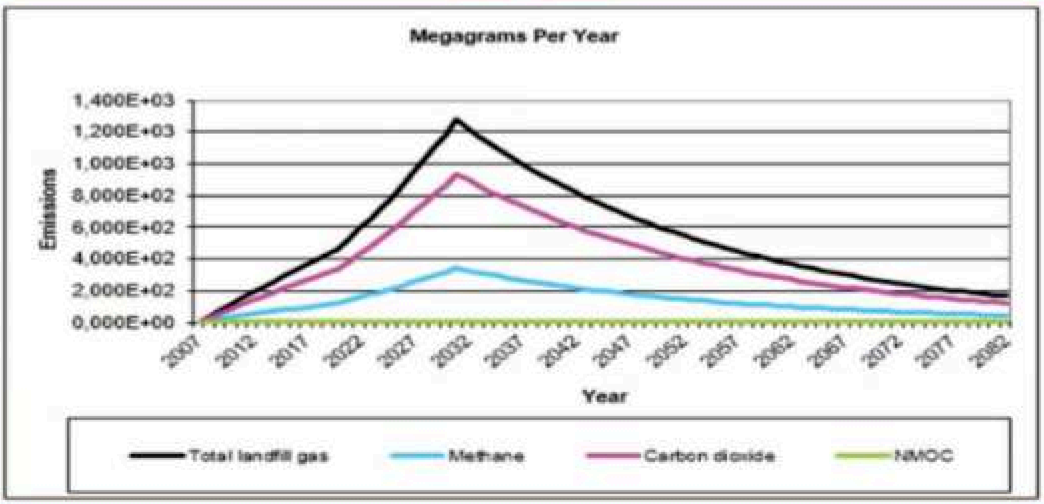


Scenario 0

According to S0, Total Gas Emission at Mymensingh dumpsite reaches a peak value in 2031 of 771,000 m^3/year.

Note that according to this simulation, about 2,800 tons of CH_4 and 7,600 tons of CO_2 will be generated from 2007 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease.

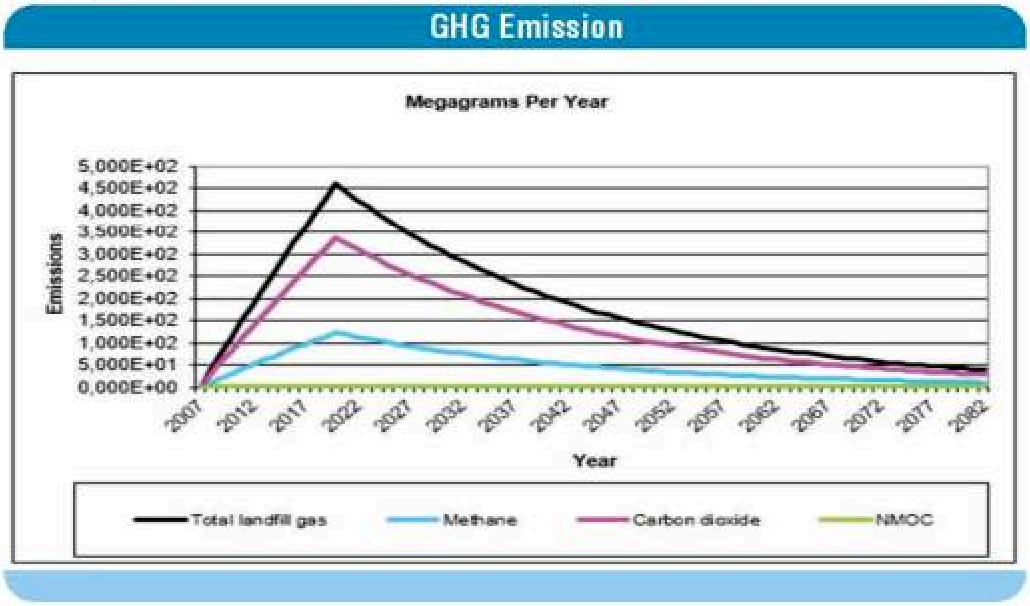
GHG Emission



Scenario 1

According to S1, Total Gas Emission at Mymensingh dumpsite reaches a peak value in 2031 of 1,021,000 m³/year.

Note that according to this simulation, about 3,100 tons of CH_4 and 8,600 tons of CO_2 will be generated from 2007 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease.



Scenario 2

According to S2, Total Gas Emission at Mymensingh dumpsite reaches a peak value in 2020 of 377,000 m³/year.

Note that according to this simulation, about 1,900 tons of CH_4 and 5,100 tons of CO_2 will be generated from 2007 to 2030. Because of the theoretical closure of the dumpsite by 2020, gas emissions will thus progressively decrease.

Conclusion

From these preliminary results, it can be observed that the development of an efficient Waste Management and Treatment System (S2) not only allow to reduce by a factor of 2.1 (S0) to 2.8 (S1) the peak emission but also allow to reduce drastically and on a long term basis the quantity of GHG released into the atmosphere. Over the period of landfill opening and 2030, it can be estimated that the development of efficient infrastructure for waste treatment and management (S2) will reduce CH_4 and CO_2 emission by about 32% compared to the situation S0 (current situation). In order to have a better estimation and evaluate the relevance of developing a flaring or storage systems on the current landfill, field surveys and measurements will be necessary.

7.9.4.6 Jessore

Technical Parameters

Waste production and storage

Year	Pop.	Waste Generation			Waste collected and dumped					
		Waste Dry	Waste Wet Season	Total	S1		S2		S2	
	Inhab.	t/wet season	t/dry season	t/year	% coll.	t/year	% coll.	t/year	% coll.	t/year
2008	193	6 881	9 588	16 469	55%	9 058	55%	9 058	55%	9 058
2009	196	6 973	9 716	16 690	55%	9 179	55%	9 179	55%	9 179
2010	199	7 067	9 846	16 913	55%	9 302	55%	9 302	55%	9 302
2011	201	7 161	9 978	17 140	55%	9 427	55%	9 427	55%	9 427
2012	204	7 257	10 112	17 369	55%	9 553	55%	9 553	55%	9 553
2013	207	7 355	10 247	17 602	55%	9 681	55%	9 681	55%	9 681
2014	210	7 453	10 385	17 838	55%	9 811	55%	9 811	55%	9 811
2015	212	7 553	10 524	18 077	55%	9 942	55%	9 942	55%	9 942
2016	215	7 654	10 665	18 319	55%	10 075	55%	10 075	55%	10
2017	218	7 757	10 808	18 564	55%	10 210	55%	10 210	55%	10
2018	221	7 861	10 952	18 813	55%	10 347	55%	10 347	55%	10
2019	224	7 966	11 099	19 065	55%	10 486	55%	10 486	55%	10
2020	227	9 687	13 497	23 184	55%	12 751	75%	17 388	75%	0
2021	230	9 817	13 678	23 495	55%	12 922	75%	17 621	75%	0
2022	233	9 948	13 861	23 810	55%	13 095	75%	17 857	75%	0
2023	236	10 082	14 047	24 129	55%	13 271	75%	18 096	75%	0
2024	239	10 217	14 235	24 452	55%	13 448	75%	18 339	75%	0
2025	243	10 353	14 426	24 779	60%	14 868	90%	22 301	90%	0
2026	246	10 492	14 619	25 111	60%	15 067	90%	22 600	90%	0
2027	249	10 633	14 815	25 447	60%	15 268	90%	22 903	90%	0
2028	253	10 775	15 013	25 788	60%	15 473	90%	23 210	90%	0
2029	256	10 919	15 214	26 134	60%	15 680	90%	23 520	90%	0
2030	259	11 066	15 418	26 484	60%	15 890	98%	25 954	98%	0

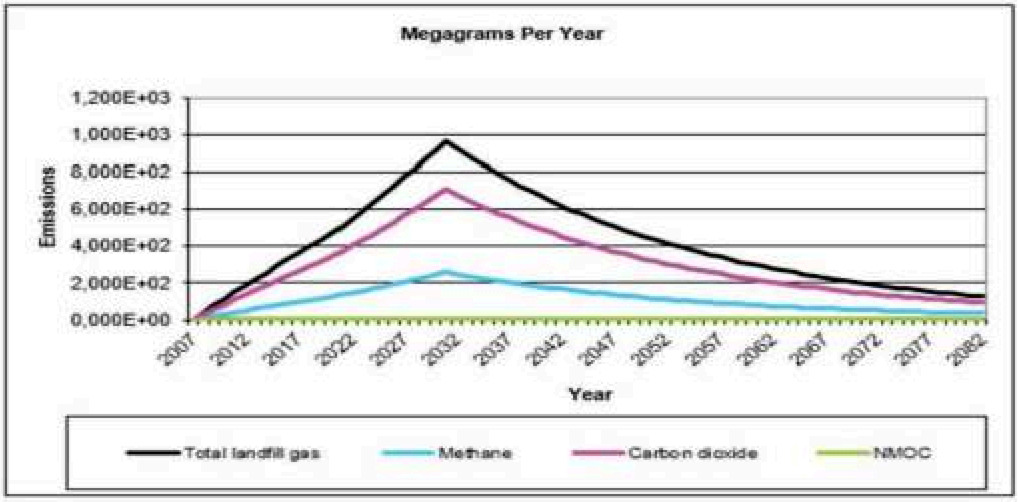
Dumpsite Features

There is one "official" dumpsite at Jessore. Its characteristics are given below:

Table 87 : Jessore dumpsite features - Source (Faruq Rahaman, Conservancy Officer)

Place	Hamidpur
Surface	3 Acres (ha)
Opening date	2008
Closure Year	Not known – assumed in service by 2030

GHG Emission

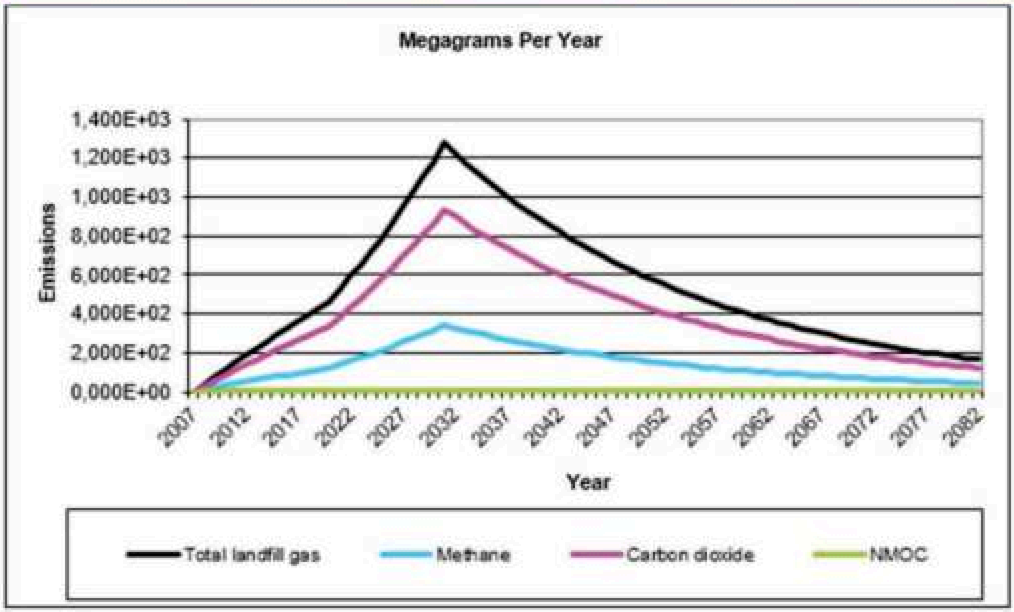


Scenario 0

According to S0, Total Gas Emission at Jessore dumpsite reaches a peak value in 2031 of 1,516,000 m^3/year.

Note that according to this simulation, about 5,400 tons of CH_4 and 15,000 tons of CO_2 will be generated from 2008 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m3/year by 2042.

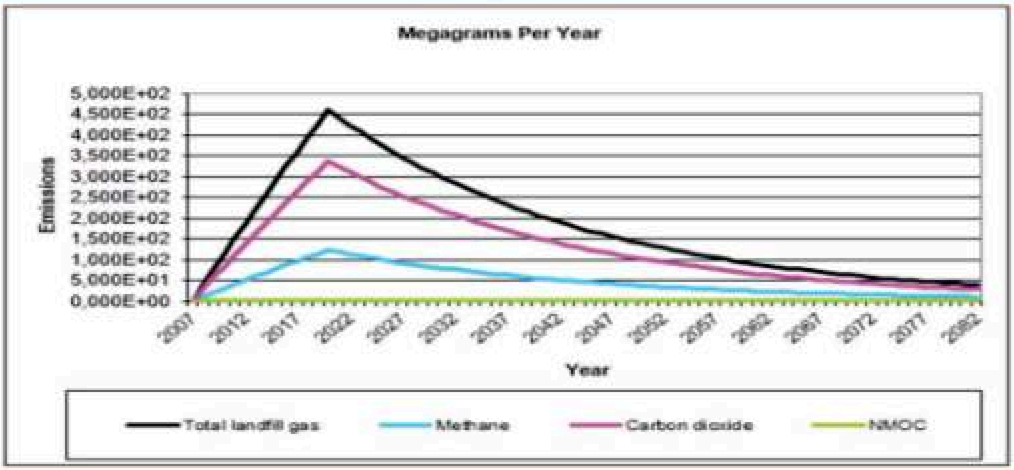
GHG Emission



Scenario 1
According to S1, Total Gas Emission at Jessore dumpsite reaches a peak value in 2031 of 2,495,000 m^3/year.

Note that according to this simulation, about 6,200 tons of CH_4 and 17,000 tons of CO_2 will be generated from 2008 to 2030. Because of the theoretical closure of the dumpsite by 2030, gas emissions will thus progressively decrease and fall under the threshold of 1,000,000 m^3/year by 2054.

GHG Emission



Scenario 2
According to S2, Total Gas Emission at Jessore dumpsite reaches a peak value in 2020 of 750,000 m^3/year.

Note that according to this simulation, about 3,700 tons of CH_4 and 10,200 tons of CO_2 will be generated from 2008 to 2030. Because of the theoretical closure of the dumpsite by 2020, gas emissions will thus progressively decrease.

Conclusion

From these preliminary results, it can be observed that the development of an efficient Waste Management and Treatment System (S2) not only allow to reduce by a factor of 2 (S0) to 3.3 (S1) the peak emission but also allow to reduce drastically and on a long term basis the quantity of GHG released into the atmosphere. Over the period of landfill opening and 2030, it can be estimated that the development of efficient infrastructure for waste treatment and management (S2) will reduce CH_4 and CO_2 emission by about 32% compared to the situation S0 (current situation). In order to have a better estimation and evaluate the relevance of developing a flaring or storage systems on the current landfill, field surveys and measurements will be necessary.

This preliminary estimation has been conducted in order to show the impact of inadequate waste management and treatment system on the emission of GHG and Global Warming.

It is likely that waste management will improve over the next decade via the combined effect of capacity building of local authority and pressure of the population. From these figures, we can observe that the improvement of waste management without taken into account efficient storage and treatment will increase significantly emissions of GHG over the next decades. Bangladesh being one of the most sensitive country in the world to global warming, this issue will have to be addressed without delay.

Developing efficient waste management and treatment options is part of the solution. As shown on the different figures, closing current open dumpsite will allow to reduce drastically GHG emission. Moreover, it may be possible to go a step further by conceiving a system for flaring or collecting biogas from current dumpsite, and then totally avoid GHG emission from these landfills. A detailed analysis, including gas emission measurement from the current site will be necessary to define the best option on both technical and financial point of view.

7.10 Technology Providers

Waste to energy technologies are well known in many Western countries. Specialized companies, including consultants, engineering firms, contractors and operators have developed profitable businesses in this area in the recent years. Considering the fact that markets in Europe and other similar regions show limited growth, these companies are keen to export their experience and know- how to other countries like Bangladesh. A number of these companies already created joint ventures and public private partnerships for anaerobic digestion plants and waste incinerators in South Asia. Specifically these plants are built under EPC contracts following international standards and regulations. Various companies have already shown a major interest in WtE projects in Bangladesh, of which an exemplary list is given here below :

Table 88: List of Technology providers for implementing WtE solutions

Company name	Website
Indaver	http://www. indaver.be/en/home/
Vyncke	http://www.vyncke.com
Seghers Keppel	http://www.keppelseghers.com
OWS	http://www.ows.be/
Suez	https://www.suez.com/en
Veolia	http://www.veolia.com/en

8.1 Financial Summary of Proposed Solutions

The table hereafter shows the results of the detailed financial analysis elaborated in section 7.5.3. The financial analysis focused on two proposed modular designs (modular design 1: anaerobic digestion + composting + recycling and modular design 2: anaerobic digestion + composting + gasification) and this for two different capacities: a basis scenario and large scenario.

It can be remarked that modular design 2 includes a gasification installation right from the start of the project, which results in a relatively high investment costs. Furthermore, it can be clearly observed that the size of the WTE facility greatly impacts on the cost per ton of waste treated. Since Mymensingh generates the most waste of all municipalities, it is not surprising that this municipality results in profitable values in a large scale scenario for modular design 1. If you compare the large scenario with Dinajpur, one can remark that although Dinajpur has a smaller waste volume to treat, the energy production is larger for Dinajpur than for Mymensingh. The reason for this is due to the higher organic content for the waste in Dinajpur than for Mymensingh. However, these data have to be carefully checked in a detailed study.

SREDA Sustainable and Renewable Energy Development Authority

UN DP

SREPGen Project
Feasibility Study on Waste-to-Energy conversion in six Municipalities in Bangladesh

Ecorem

FINANCIAL ANALYSIS SUMMARY

CAPACITY DATA

		unit	Mymensingh				Cox's Bazar				Dinajpur				Habiganj				Jessore				Sirajganj			
			Modular Design 1		Modular Design 2		Modular Design 1		Modular Design 2		Modular Design 1		Modular Design 2		Modular Design 1		Modular Design 2		Modular Design 1		Modular Design 2		Modular Design 1		Modular Design 2	
			Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large
Yearly capacity		ton/yr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Daily capacity		ton/d	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Yearly energy production	Total	KWhr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		kWe	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Local consumption	KWhr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Feed to grid	KWhr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FINANCIAL DATA on a life cycle of 15 years

		unit	Mymensingh				Cox's Bazar				Dinajpur				Habiganj				Jessore				Sirajganj			
			Modular Design 1		Modular Design 2[4]		Modular Design 1		Modular Design 2[4]		Modular Design 1		Modular Design 2[4]		Modular Design 1		Modular Design 2[4]		Modular Design 1		Modular Design 2[4]		Modular Design 1		Modular Design 2[4]	
			Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large	Basis	Large
Investment costs	Machines for treatment	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gas engine	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gasifier and engine	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Rolling machine	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Construction	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Engineering	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Reserve	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total investment costs (1)(2)		$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Process costs	Employment/Management	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Maintenance cost	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Operation costs	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Insurance costs	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total Process costs		$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Revenues	Local energy consumption	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Electricity feed to grid	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Sales recycled material	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Sales compost	$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total Revenues (3)		$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL Profit/loss		$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Profit/loss per ton waste		$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IRR		%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NPV		$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PBP		year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FINANCIAL INPUT DATA

Market price	Local energy consumption	$/KWhr	0,153	Based on local information 2016
	Injection into the grid	$/KWhr	0,36	Based on local information 2016
	Compost for soil improvement	$/ton	38,2	Based on local information 2016
	Sales of metal/ glass/ paper/textile	$/ton	164,1	source: Waste concern, 2013
Operations	Working days per year	days	261	

Remarks

1: Investment costs take into account a loan cost and a depreciation time

	Interest	Depreciation time	
Machines for treatment	3,0%	12	years
Gas engine	3,0%	8	years
Gasifier and engine	3,0%	8	years
Rolling machine	3,0%	8	years
Construction	2,8%	25	years
Engineering	3,0%	25	years
Reserve	3,0%	16	years

2: The investment cost does not take into account the aquisition cost of the land and the sanition costs

3: Indirect revenues from waste collection, reduction of CO2 and saving on health cost are not taken into account

4: The financial analysis of Modular Design 2 assumes the installation of a gasifier and engine starting from the beginning of the Project

8.2 Conclusions

Based on a number of site-specific features of the waste and energy sector of Bangladesh and a thorough study of waste to energy (WtE) technologies, a selection of the most adequate technologies or combination of technologies was made suitable to the framework of six selected municipalities: Mymensingh, Cox's Bazar, Sirajganj, Dinajpur, Habiganj and Jessore.

In the mixed municipal solid waste (MSW), the wet organic fraction is high (approx. 70-91%) which increases the moisture content of the waste stream (approx. 57-67%). This information about the waste composition has significant influence technology selection process. The preliminary selection withheld incineration, gasification and anaerobic digestion to be further be analysed in detail.

The detailed analysis concluded that the mixed MSW may be too wet, associated with a too low calorific value to be incinerated or gasified properly, requiring a pretreatment step involving sorting and drying and auxiliary fuel. Therefore, the anaerobic digestion module is comparatively suitable in terms of a technological point of view. However, financial viability is questionable.

To give a clear direction and to facilitate the initiation of commercial piloting, concepts for possible pilot projects were developed. The applied modular approach of the design allows reconsideration of the installation of each model after a detailed study in correspondence with the local waste context, authority and stakeholders. Another advantage is that the modules can be implemented in phases, so that one can build a second module after the first module has been shown to be successful.

Two modular designs were proposed, involving both an anaerobic digestion unit: modular design 1, maximizing the revenues out of the sales of recyclable materials and the energy production through anaerobic digestion, and modular design 2, maximizing the energy production through both a anaerobic digestion and gasification module. The application of gasification to treat Bangladeshi waste streams is considered as an option to be further looked into, but the detailed financial analysis showed that the extra area requirement and investment for the drying facility and gasifier unit, greatly impacts the profitability of the plant, even when the energy produced by the anaerobic digestion is reused for drying the feedstock and serving as auxiliary fuel for arriving at the required temperatures for gasification reaction. Furthermore, it can be observed that when the size of the installation increases the project becomes more economically viable. If the indirect revenues are not taken into account, only the large scale scenario from modular design 1 for Mymensingh succeeds to arrive at a positive internal rate of return: a revenue of 0.2 $/ton, corresponding with a IRR of 2.33% and a PBP of 12.5 years.

Therefore, it is recommended to start with modular design 1 and to upgrade to modular design 2 once WTE plant has proven its sustainable performance, and after a detailed study in correspondence with the local waste context, authority and stakeholders are executed. Alternatively, a separate small size pilot project

with gasification technology can be implemented as proposition of modular design 2. Furthermore, it is recommended to at least include a collection tax as an income for the waste treatment facility, because it is a world-wide recognized and important income for the profitability of a waste treatment facility.

Finally, not only financial figures are arguments to install an integrated waste management system but also a functioning waste treatment plant has an important influence on the environment and health of the municipality. These social and

environmental benefits can also be expressed in economic value and can be considered as indirect revenues and were shown to have a large impact on the total cost for treatment of the municipality. Indeed, the overall objective of the project was the reduction of GHG emissions. It has been shown in this study that an efficient waste management and treatment system not only allows to reduce the peak emission by a factor of 1.5 to 6.7, but also allows to reduce drastically and on a long term basis the quantity of GHG released into the atmosphere. Over the period of landfill opening and 2030, it can be estimated that the development of efficient infrastructure for waste treatment and management will reduce CH_4 and CO_2 emission by about 25- 55%, as compared to the current situation in the municipalities.

8.3 Recommendations

It is recommended to start with the development of a pilot plant. Indeed, from the consultant's perspective, the pilot plant will have a major demonstration potential. Detailed, efficient monitoring and professional management of such site will create experiences, which are most useful for the adjustment of the various parameters according to the entrance data, especially for those linked to Waste-to-Energy conversion (biogas production, power generation, etc.). As such, the concept developed in this study can be tested with the field experience, so that it can be adapted (technically, economically, and environmentally) and disseminated in other municipalities.

In order to make concrete progress on this Project, the following consultancy services are proposed:

1. Organization of a field mission to a host municipality (i.e. Mymensingh) with officials of SREDA, UNDP and ECOREM, in order to meet the local stakeholders (local authorities, representatives of the civil society, NGOs or companies with waste-related activities, members of university involved in waste management, a.o.), and discuss in detail about their vision of the proposed pilot / demonstration site, taking into account the local constraints and opportunities. In particular, the necessary territory should be made available for the plant; this can be done by providing a concession for the operation during specific period. This visit would allow for collecting additional, site-specific and most relevant information.
2. Preparation of a detailed study targeted on the selected pilot project, that will be based on primary data and updated data and that will include a detailed business plan according to the discussions with the local authorities and the relevant stakeholders, and a site specific environmental and social assessment.
3. Conclusion of such a study would be presented in the municipality during a workshop in order to unite the stakeholders around the project; the support of the local actors being the fundamental way to achieve its development. Indeed, an efficient and integrated waste management system must be implemented step by step by each municipality, in order to guarantee its success and the involvement of the population, as the main beneficiary.

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Annexes - 1

Workshop on Inception Report Feasibility Study on Waste To Energy Conversion in six municipalities in Bangladesh
Dhaka, 31 August, 2016

During and after the Workshop of 31 August many issues on Waste-to-Energy (WTE) were discussed. A number of valuable remarks and suggestions were communicated for consideration in the present study. An overview is given below. It is the purpose to incorporate as much as possible the ideas in the future Intermediate Report and Final Report.

Toxicity aspects, environmental and health standards should be considered when designing the WTE technology (i.e. heavy metals pollution).

Small municipalities may not produce sufficient waste. It may be better to consider larger municipalities, with a constant waste production, sufficient to deliver 0,4 MW of electricity at least.

It is expected that good data sets will arise from this study and the detailed analysis. Since such information does not really exist at the moment, these data sets could be most useful for other climate change projects as well.

A list of unpublished primary (recently collected) data is available for all the 330+ municipalities (World Bank). This info should be considered to assume the municipality's daily waste production, waste characterization, etc. The local partner of the Consultant should provide the experts with this information within the shortest period of time.

Incineration technology as such may be less interesting for the municipalities in Bangladesh, since most of the caloric-rich waste fraction is already recovered and recycled by informal waste pickers on the dump sites. Further, the Bangladeshi household waste fraction is generally very wet for which fermentation processes and biogas production is preferred. It is thus important to elaborate these solutions in much detail.

It is recommended to consider a combination/ more combination of technologies in this study that could also treat the "side" streams (e.g. composting of residues, RDF from plastics, etc.). In particular, the compost is considered as an important side-product for enriching the soils depleted in organic matter (use as fertilizer, see also activities of Waste Concern). In some municipalities a multiple solution could be proposed.

The industry produced wastes are mostly recycled on the plant's site, or sold to the local markets. Examples of recycled industrial bio-wastes are from rice husk (sold for 7 BDT/kg), wood chips, saw dust, etc. The relevance of the industry as a major contributor to bio-waste production for this WtE project should therefore be reconsidered. However, the industry remains a major energy consumer, for which they will be further considered in the study.

Public awareness at municipality level is foreseen only indirectly via the implementation of pilot WTE projects. Pre-treatment separation is considered as highly important for the good functioning of the WtE plants. There should be much attention to this aspect.

Social issues, such as informal waste picking or resettlement, will be also subject of the analysis subject to this study, once the 6 municipalities have been selected.

The concerned municipalities should be invited along with additional government officials during the second workshop, and should also consulted at the appropriate times.

Comparison will be made to other related studies on waste and WTE, sponsored by GIZ, ADB, UNDP and WB. Lessons should be learnt from previously failed projects as well (e.g. private investments for WTE plants).

Although this might take more time, the national institutional framework on waste and WtE should be further elaborated and implemented as well. It is most important to any potential international investor.

Final recommendations to the Inception Report based on the discussions during and after the Workshop.

To develop in detail the municipality analysis, more weight should be given to the Interim Rpt. As such, it is proposed to change the internal deadline for this second report from 5 to 31 October, and to foresee in a second workshop on Tuesday 8 November, 2016.

It is also recommended to replace the smaller municipalities from the shortlist of 12, and to look for at least medium-sized towns that can produce sufficient household waste for a production of 0,4 or more MW.

Minutes of Interim Report Validation Workshop on

Feasibility Study on Waste to Energy Conversion in Six Municipalities in Bangladesh
IEB, Dhaka, 8 November 2016

In the frame of the Consultancy Assignment of Ecorem for the preparation of the Feasibility Study on Waste-to-Energy solutions for six selected municipalities a Workshop was organized to present the intermediate report, focusing on the data analysis and the proposed technologies for waste treatment.

This interim report validation workshop was successfully completed with participation of distinguished experts from the concerned departments, Ministries, Professors, scientists, development partners, Ngos', private investors, Power grid companies , civil society and 6 Pouroshava representatives under SREPGen Waste to Energy Feasibility study viz, Dinajpur, Shirajgonj, Jessore, Mymensingh, Habigonj, and Cox's Bazar Pouroshava (list of participants attached).

The Program of the Workshop is shown below.

In the welcome words of the Chair Mr Siddique Zobair the importance of this Project was again emphasized, not only for the selected municipalities, but also for the whole of Bangladesh.

Mr Walter Mondt, Chairman of Ecorem, put forward the importance of translating the western technology into the local context of Bangladesh. He also stressed the need of training and capacity building at various levels when implementing technologies in pilot and demonstration projects. He also acknowledged the good cooperation with the local partner, the Client SREDA, the UNDP and the various local administrations.

The Chief Guest: Mr. Anwarul Islam Sikder ndc, Chairman of SREDA, NPD, SREPGen project.

Special Guests: Mr. Arif Mohammed Faisal, Program Specialist, UNDP Bangladesh.

Joint Secretary **Mohammed Alauddin** , Power Division, Ministry of Power, Energy and Mineral Resources (MPEMR).

After the tea and coffee break the Technical Session was chaired by **Prof. Ijaz Hossain** and moderated.

The first speaker was **Mr. Stefan Helsen** of Ecorem, who gave an overview of the activities performed under the consultancy assignment up to the Interim Report. He commented on the secondary and primary data collection related to the waste production and local issues of all of the six municipalities. Next he analyzed the figures, allowing to make the bridge to the possible technologies for Waste-to-Energy. Basically, the anaerobic digestion appears the most suitable technique to treat the waste. Possibly, incineration could be considered for some selected waste streams. Mr Helsen also showed examples of similar projects and commented on the costing and revenues and final products, including gas or electricity, compost and other waste materials that can be sold on the local markets.

Local Partner **MPower**, represented by **Prof. Mahbub Hasan** spoke about the data collection, as performed in the six municipalities. He explained how the data were collected through direct field visits to MSW dumping sites, observation, and participation of the Conservancy officers of 6 municipalities followed by Focus Group Discussion (FGD) at the office of District Commissioners' Office.

Ultimately, the participants made recommendations for comprehensive future studies and analysis of primary information based on typical questionnaires. His presentation was very accurate and revealed many good ideas for later projects.

The subsequent **Questions and Answers** session allowed for further discussions with the representatives of the municipalities, who agreed that accurate data are not always available for the purpose of Feasibility Studies. Also, they mentioned the weaknesses of their current waste collection/ management system; however, they were all interested in and charmed to be part of the Project, and ready to collaborate.

The representative from 6 municipalities, Ministries of **MPEMR, PDB, LGRD, REB, SREDA, GIZ, Doe,** Dhaka North City Corporation (DNCC), BUET , NGOs, Private business, and civil society were invited in this workshop (List of participants attached).

A number of questions, remarks and recommendations were noted as positive inputs towards implementation of WTE projects as soon as possible, and all possible cooperation were assured.

Details of the deliverable and recommendations are compiled in the Interim report. More technical discussions followed with questions from the interested public, until the Chairman closed the Workshop around 2 pm.

It can be concluded that the Workshop was very successful for the Client SREDA, the Consultant Ecorem and the stakeholders present. The Consultant will incorporate the various ideas that were discussed during the event when preparing the Final Report, due December 2016. This deliverable will show a waste management model, applicable to all the six selected municipalities. It will not only look into the Waste-to-Energy potential of the waste, but will also provide insight in efficient waste collection and separation. The model will be presented in a modular format, allowing expanding according to the specific needs of the municipalities and the available budgets. Point of attention for the Consultant is the social dimension and the seasonal variation in the waste, as referred to in the Terms of Reference.

Recommendations Main recommendations from stakeholders and experts are as follows:

1. Ministry of Local Government, and Rural Development (LGRD) should enact national policy framework for collecting and recycling MSW of each Municipality under a scientific system in all municipalities.
2. Conduct regular MSW dumping survey, assessment and monitoring system in all municipalities and enforce new laws to implementation of waste to energy plants
3. Initiate Community based partnership to promote awareness and reduce climate change impacts from GHG emissions, and values worth in WTE transformation for a clean and healthy city environment
4. Invite educations Institutes to impart HR training, and R&D in innovative MSWM system and in compliance with UNFCCC guidance, and sustainable development
5. Introduce pre-sorting, and proper waste collection, and delivery system to recycling plants and charge extra levy from violators, and unlawful garbage dumping
6. Integrate private Public partnership (PPP) next five year development plan and minimize knowledge gap between grass root people, and municipal waste management in collaboration with UNDP & INGOs), and minimize shortage of Power and fertilizers.
7. Take positive steps towards pilot demonstration WTE plant to avoid fear and skepticism with innovative technology transfer from the west.
8. Allow private and foreign investment as a commercial enterprise, and disseminate across the country on soft loan, and grants with application of innovative technology.
9. Customize loan and grant disbursement policy easily and fast accessible by private partners, and NGO's without hassle and disparity with marketing support, and incentives.
10. Help promote 3R policy to turn waste into commercial secondary raw material, and share the cost and benefits with the private parties, reduce poverty and contribute to create employment in clean urban environment.

Acknowledgement

In successful accomplishment of Interim validation Workshop of SREPGen project, Ecorem- Abo group (Belgium) Consultant, and MPower (local Partner) gratefully acknowledge the efficient guidance and contributions of Mr. Anwarul Islam Sikder ndc, former Chairman, and current Chairman Md. Helal Uddin, SREDA, Mr. Siddique Zobair, Member (EE & C), SREDA, Mr. Md. Alauddin, Joint Secretary, Power Division, Mr. Arif Mohammed Faisal, Program Specialist, Climate Change Division, UNDP, Md. Taibur Rahman, Project Manager, SREPGen Project, UNDP, Mohammad Nurul Alam, Miss Mahsin Hamuda (UNDP), Ms. Nusrat Jahan Imu, Mrs. Rowshon Ara, Joint Secretary, LGRD, Prof. Dr. Ijaz Hossain, Department of Chemical Engineering, BUET. Mr. Commodore Razzak, Md. Nurul Alam, Ex-Engr of Cox's Bazaar and Dr. Khalequzzaman, Engr. Dev (GIZ), I am also thankful to Dr. Walter Mondt, Chairman and Dr. Stefan Helsen, International WTE Specialist, Ecorem-Abo group for dynamic leadership, presentation, and continued commitment in systematic WTE feasibility studies and long term vision of demonstration projects in future. Mpower Staff Md. Nazmul Hosson, and Engr. Md. Jwel, and S.M. Shahin for hard work in the workshops.

Dr. Walter Mondt
Chairman Ecorem-Abo Group (Belgium)-Consultant
Prof. Mahbub Hasan
Chairman, M Power Bangladesh (Local partner-Ecorem-Abo group)

Short list of Workshop participants from SREDA

(8 November, 2016,Time : 9:30 AM, -1 : 00PM)
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Annex 2 : Selection Process

Qualitative Analysis

Name of Paurashava	Region	District	Cat	Population	Flooding risks	Road infrastructure	Pop Density inh./km²	Electrical features HV	Electrical features PP	Industry	Climatic region	Rainfall	Proposed 12 Paurashavas
	SELECTION OF 12 MUNICIPALITIES												
	Administrative features		Elimination Criteria		Qualitative								
Mymensingh	Dhaka	Mymensingh	A	258,040		N	2,969	VS	Ed	I	G	W	Mymensingh
Tarabo	Dhaka	Narayanganj	A	150,709		N	9,087	V	Ed	I	G	D	
Faridpur	Dhaka	Faridpur	A	121,632		N	2,331	VS			G	D	
Narsingdi	Dhaka	Narsingdi	A	146,115		N	4,002				G	D	
Savar	Dhaka	Dhaka	A	286,008		N	43,578		Ed	I	G	D	
Kishoreganj	Dhaka	Kishoreganj	A	103,798		R	3,148	VS		I	G	W	
Bhairab	Dhaka	Kishoreganj	A	118,893		N	3,148	VS		I	G	W	
Tangail	Dhaka	Tangail	A	167,412		N	2,290	VS		I	G	D	Tangail
Jamalpur	Dhaka	Jamalpur	A	142,764		N	2,439	VS			G	D	
Kaliakoir	Dhaka	Gazipur	A	157,162		N	5,991			I	G	D	
Tongi	Dhaka	Gazipur	A	406,420		N	5,991	VS		I	G	D	
Sreepur	Dhaka	Gazipur	B	126,249		R	5,991			I	G	D	Sreepur
Chandpur	Chittagong	Chandpur	A	159,021		R	2,714	VS		I	G	W	Chandpur
Noakhali	Chittagong	Noakhali	A	107,854		N	2,451				A	W	
Feni	Chittagong	Feni	A	156,971		N	3,163	VS		I	A	W	
Cox's Bazar	Chittagong	Cox's Bazar	A	167,477		N	3,363	VS			A	W	Cox's Bazar
Brahmanbaria	Chittagong	Brahmanbaria	A	172,017		N	3,636		Ed	I	G	D	
Bogra	Rajshahi	Bogra	A	400,983		N	3,621	VS	Ec	I	D	D	
Pabna	Rajshahi	Pabna	A	144,442		N	3,046	VS		I		D	
Nawabganj	Rajshahi	Nawabganj	A	180,731		R	3,227	VS			D	W	
Sirajganj	Rajshahi	Sirajganj	A	159,812		R	3,477	VS		I		D	Sirajganj
Naogaon	Rajshahi	Naogaon	A	150,549		R	2,643	VS			E		
Dinajpur	Rangpur	Dinajpur	A	186,727		N	2,745		(Ed		D	D	Dinajpur
Saidpur	Rangpur	Nilphamari	A	127,104		N	2,281	VS	Ec		D	W	
Jessore	Khulna	Jessore	A	201,798		N	3,679	VS			F	D	Jessore
Jhenaidaha	Khulna	Jhenaidah	A	107,834		N	1,905	VS		I	F	D	
Satkhira	Khulna	Satkhira	A	113,322		R	2,367	(VS)			F	D	
Kushtia	Khulna	Kushtia	A	102,688		N	3,222		Ed	I	D	D	Kushtia
Pirojpur	Barisal	Pirojpur	A	60,056		R	2,116				A	W	Pirojpur
Patuakhali	Barisal	Patuakhali	A	65,000			1,746	VS			A	W	
Habiganj	Sylhet	Habiganj	A	69,512		R	2,666				D	W	Habiganj
Moulvibazar	Sylhet	Moulvibazar	A	56,537			2,370	V	Ed			W	

LEGEND	Flooding	Road	Density	Electric	Power Plant	Industry	Climat	Rainfall	Proposition
	Nat/Low	National HW	< 2,000	V : HV line	Ed : PP in the	I : Food Industry or waste from agriculture	SE	>200cm	Paurashava selected
	Moderate Risks	Regional HW	2,000 < X ≤ 3,785	(V) : HV line planned	Ec : PP in the City		NE	> 200 cm	
	High Risks		> 3,785	S : Substation existing			NN		
				(S) : Substation			NW		
							W		
							SW		
							S		

Annex 3: Matrix Analysis

Qualitative Analysis

C	Category	Sub-criteria				
C1	Compatibility of waste regarding the requirements	Type of waste	Specific fraction requested	Some fractions should be removed	All fraction of domestic waste	Not relevant
		Pre-processing	Strict pre - processing	Light pre-processing required / processing may be required due to the composition of	No pre - processing required	Not relevant
		Impact of climate/seasonality on the process	High impact (too wet, too cold, etc.), variation in the tonnage	Low or medium impact	No significative impact	Not relevant
		Moisture content	Moisture content out of the operating range		Moisture content consistent with the operating	Not relevant / no information
		C:N Ratio	CN ratio out of the operating		CN ratio consistent with the operating	Not relevant / no information
		pH	pH out of the operating range		pH consistent with the operating range	Not relevant / no information
		LHV	LHV out of the operating range		LHV consistent with the operating range	Not relevant / no information
		Size of facility / Minimal requirements of waste quantity to ensure sustainability of the	Scale of applications limited to small or large plants		Adaptable to small, medium or large scale	Not relevant
C2	Compatibility with the current waste management system	Impact of collection efficiency And frequency of waste supply	Constant supply required	Constant supply required but possibility of temporary storage	Batch supply or no constant supply possible	Not relevant
		Competition with other initiatives (compost plant, etc.)	Competition with some initiative MSW	Partial competition with some initiative MSW	No competition	Not relevant
C3	Complexity of the process and evaluation regarding the local comp. etences	Complexity of the process	Medium or large scale facility with complex equipments and additional complex treatment to convert energy	Medium or large scale facility with complex equipments whitout additional complex treatment to	Small scale facility	Not relevant
		O&M frequency	Daily O&M with technical expertise	Daily O&M with technician and periodic O&M by experts	Periodic O&M	Not relevant
		Local skills available	No relevant competences at local level	Local personnel with few technical skills with po ssibilities of training	Local engineers and technician (waste management, electromechanics, water management, power generation, gas production, etc.)	Not relevant
C4	Compatibility of the possibilities of energy recovery with needs, current uses and existing facilities	Type of valorisation possible		Heat, hot water and/or power	Gas (+ Heat, hot water, power)	Not relevant
		Compatibility with needs (esp. Domestic use)	No compatibility with needs	No compatibility or compatibility limited with other sectors than domestic	Compatibility with the domestic sector but diversification possible	Not relevant
		Competition with other similar facility / local market company	Presence of facilities with similar output in/near the City		Absence of facilities with similar output in/near the City	Not relevant
		Local integration	Expensive and infrastructure work required	Development of a dedicated facility (boiling plant, etc.)	Direct use	Not relevant
C5	Investment C osts	Investments costs	Incineration / Thermal Process	Medium Scale Anaerobic Digestion	Small scale Anaerobic	Not relevant
C6	Environmental, social and economic considerations	Possible impact on water quality	High	Medium	Low or not significative	Not relevant
		Possible impact on air quality	High	Medium	Low or not significative	Not relevant
		Possible impact on soil quality	High	Medium	Low or not significative	Not relevant
		Involvevement of the population	High	Medium	Low or not signi ficative	Not relevant
		Job creation / reconversion	Lost of job / reconversion of dumpsite operators limited		Creation of job limited (quantity, expertise, etc.)	
		By-products (end products, products from sorting, etc.)	Further treatment requested without possibility of valorization / costs for	Further treatment requested	Possibility of recycling directly some material	Not relevant

Thermal					
Incineration					
Mymensingh	Cox's Bazar	Dinajpur	Sirajganj	Jessore	Habiganj
...	...				...
	...				

Bio-chemical											
Anaerobic Digestion											
Mymensingh		Cox's Bazar		Dinajpur		Sirajganj		Jessore		Habiganj	
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale
Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale	Small scale	Large scale

শেখ হাসিনার উদ্যোগ ঘরে ঘরে বিদ্যুৎ

Supported by Development of Sustainable Renewable Energy Power Generation Project (SREPGen)

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