The biogas potential from municipal waste and agricultural residues in Hazaribagh, Dhaka city, Bangladesh
- a possible strategy to improve the energy system

A S M Monjurul Hasan

Supervisor, Assistant Professor Dr. Jonas Ammenberg
Examiner, Professor Mats Eklund
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Abstract

Energy is considered as the foremost significant factor towards socio-economic growth. Due to the rapid growth of industrialization in Bangladesh, the need of energy is increasing day by day. Considering the environmental issues, sustainable solutions are needed to address the energy crisis. Energy generation from waste through biogas can be a good solution that can address both the energy demand as well as the waste management issue.

The overall aim of this master thesis is to analyze Hazaribagh’s biogas potential from municipal waste and agricultural residues and estimate how much electricity that can be generated from the produced biogas. The feasible sources of Hazaribagh were considered in order to get the information that would be later on analyzed to estimate possible biogas production. The potential sources include wastes from two markets, six slaughterhouses, domestic wastes, three large-scale tanneries and two small scale tanneries, one poultry farm and three crop lands.

The calculations made in this thesis to roughly estimate the amount of biogas and electricity from the described sources are done in a simple way, just to illustrate the potential. The result shows that the tannery waste has the highest potential followed by slaughterhouse waste. Furthermore, the calculations show that the tannery waste contributes most for electricity generation also followed by slaughterhouse waste. In order to implement biogas solutions, several actors should be involved like government, future owners, local people etc. Different tools like legislation, financial support etc. are also important for implementing the biogas solutions.

In summary, there is a good potentiality of biogas production and electricity generation from municipal wastes and agricultural residues of Hazaribagh. Biogas solutions from waste and agricultural residues can be beneficial from both the energy and the waste management perspective.

Keywords: energy, biogas, environment, municipal waste, agricultural residue, electricity, substrate, raw materials, Bangladesh.
Acknowledgement

At first, my deepest gratitude belongs to almighty ALLAH for his blessings without which I could not make this thesis work complete.

I would like to thank my parents, Md Abdul Mannan Sarker and Mrs Momtaj Begum, who has been taking very good care of me since my childhood. They did their best to fulfil all of my demands throughout this life. I am grateful to my wife Sazia Alam, who always amazes me with her capacity for loving. The journey was not very smooth and she supported me the whole period of my graduate study. I would like to thank each and every family member specially my younger brother, grand-father and grand-mother.

I would like to express my gratitude to my supervisor Assistant Professor Jonas Ammenberg for his kind support, wise direction and invaluable advice to carry out this thesis. I would like to thank my examiner Professor Mats Eklund for his kind consent to be my examiner and giving me the opportunity to complete the work in time. I am really grateful to both of you.

Infinite thanks to Swedish Institute (SI) for giving me the scholarship for studying in Sweden. Last but not the least, I would like to thank Åforsk for their financial support during this thesis work.

June 2016
Linköping, Sweden
A S M Monjurul Hasan
## Abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>BCF</td>
<td>Billion Cubic Feet</td>
</tr>
<tr>
<td>BDT</td>
<td>Bangladesh Taka</td>
</tr>
<tr>
<td>BRAC</td>
<td>Bangladesh Rural Advancement Committee</td>
</tr>
<tr>
<td>BPDB</td>
<td>Bangladesh Power Development Board</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>Dhaka South City Corporation</td>
<td>Municipal corporation of Dhaka (south part)</td>
</tr>
<tr>
<td>GOB</td>
<td>Government of People's Republic of Bangladesh</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>IDCOL</td>
<td>Infrastructure Development Company Limited</td>
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<tr>
<td>LGED</td>
<td>Local Government Engineering Department</td>
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<tr>
<td>NGOs</td>
<td>Non-Government Organizations</td>
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<tr>
<td>TCF</td>
<td>Trillion Cubic Feet</td>
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<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
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<td>JICA</td>
<td>Japan International Cooperation Agency</td>
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## Nomenclature

<table>
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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>EJ</td>
<td>exajoule</td>
</tr>
<tr>
<td>Mtoe</td>
<td>million tonnes oil equivalent</td>
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<tr>
<td>MWh</td>
<td>mega watt hour</td>
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<tr>
<td>kWh/m²</td>
<td>kilo watt hour per meter square per year</td>
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<tr>
<td>kcal/kg</td>
<td>kilo calorie per kilogram</td>
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<td>km²</td>
<td>kilometer square</td>
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<td>MW</td>
<td>mega watt</td>
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<td>MT</td>
<td>metric tonne</td>
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<td>TWh</td>
<td>tera watt hours</td>
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<td>GWh</td>
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<tr>
<td>MWp</td>
<td>mega watt peak</td>
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<tr>
<td>TWh/yr</td>
<td>tera watt per year</td>
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<tr>
<td>kW/m²</td>
<td>kilo watt per meter square</td>
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<tr>
<td>M</td>
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<tr>
<td>kW</td>
<td>kilo watt</td>
</tr>
<tr>
<td>Wp</td>
<td>watt power</td>
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1 Introduction

1.1 Background

In this era of modern civilization, economic growth and energy demand is co-related. Energy is considered as the foremost significant factor towards socio-economic growth (Barnes, Khandker, & Samad, 2011). In many developed parts of the world, there are plans for economic development and increasing demands for energy, but also a wish to improve the energy supply and security and reduce the environmental (mainly climate) impact (F. Ahmed, Al Amin, Hasanuzzaman, & Saidur, 2013).

The recent picture of economic growth in Bangladesh is upwards (Razzaque, Ali, & Mather, 2015). Due to rapid growth of industrialization, the need of energy is increasing day by day (Hossain, 2015). The power generation situation is not moving forward at the same speed with industrialization. As a result, the difference between energy demand and generation has been increased day by day. The country is facing an energy crisis due to old and insufficient power generation capacity (M. M. Rahman, Paatero, Lahdelma, & A. Wahid, 2016). Only 59.6% of the people are having access to electricity in Bangladesh (The World Bank, 2016).

Dhaka is one of the fastest growing mega-cities in the world. This city has become the center of economic growth in Bangladesh (M. Z. Rahman, Siddiqua, & Kamal, 2015). Due to a large number of people, large amount of wastes are generated daily in Dhaka city and it has become one of the major concerns for the municipal corporations as well as the people of the city. Household waste, vegetable and fruit market waste, slaughterhouse waste, sewage, and tannery wastes are the main wastes that are generated daily in this city. Hazaribagh, an area of Dhaka city, is well known for the tannery and leather industry in Bangladesh. 90% of Bangladesh's tanneries, where animal skins are processed for making leather, are located in Hazaribagh. This area is densely populated as other parts of Dhaka city. Due to the un-treated wastes that are generated from the tanneries, the environmental condition of this area is very bad. Generally, the tannery waste and the slaughterhouse waste are considered as the industrial waste. But, these wastes are landfilled without the proper treatment along with the other municipal wastes. Considering the waste management system for tannery and slaughterhouse waste, these have been considered as municipal waste in this study.

In practical, the waste management system of Bangladesh is neither well managed nor environmental friendly (Mohit, 2012). It is a very common picture in Dhaka city that people are throwing the waste here and there and thus polluting the environment. The municipal city corporations of Dhaka city do not deal with the municipal wastes in a sustainable way. Landfilling seems the only trend, practiced by the people. Municipal corporations collect the wastes from the municipal dustbins that are kept on the roadside and later on these wastes are landfilled at the adjacent areas of Dhaka city. There are future plans for dealing with these wastes in an environmentally friendly way (Bangladesh Power Development Board, 2016). Unfortunately, no visible governmental activities are observed till now related to a further use of these wastes. Some private companies and NGOs are working on a small scale to use the wastes for further usages like biogas and bio-fertilizer.

Along with municipal waste, agricultural residues are also a big concern for this country. As an agricultural-based country, Bangladesh has abundant sources of agricultural residues (Huda, Mekhilef, & Ahsan, 2014). Every year, local administrative authorities and other governmental
institutions face the challenge to deal with these wastes and agricultural residues. Though, people have started to use their agricultural and food wastes to produce biogas in many villages at a very small scale. In Dhaka, especially at Hazaribagh, not too many agricultural activities are carried out. Poultry farms have been the main source for agricultural residues in the Hazaribagh area.

The waste problem can be transformed into a resource if the waste streams are used for biofuels and nutrients are recycled (Elango, Pulikesi, Baskaralingam, Ramamurthi, & Sivanesan, 2007). The biogas can be further used in the power generation to mitigate the energy crisis (M. Roungu Ahmmad & Dr. Saiful Haque, 2014). Apart from electricity generation and waste management issues, biogas based energy solutions can pave the way in nutrient management also. Bio-fertilizer from the bio-degradable waste can reduce the soil fertility crisis in the agricultural sector (Hossen, Rahman, Afsana Sara Kabir, Hasan, & Ahmed, 2015). Thus it might be possible in Bangladesh to transform a waste management problem into valuable resources.

1.2 Aim

The overall aim of this thesis is to analyze Hazaribagh’s biogas potential from municipal waste and agricultural residues and estimate how much electricity that can be generated from this biogas.

Specific objectives are defined as follows:

1. To briefly describe the energy and power generation sector of Bangladesh.
2. Provide an overview of relevant municipal wastes and agricultural residues of Hazaribagh.
3. Select some types of such waste/residues and estimate the amounts.
4. Discuss how these potentials could be utilized for biogas.
5. Study pre-requisites/conditions for biogas solutions and discuss how this could be integrated into the energy road map.

1.3 Limitations

One challenge for this research work was access to data from institutions, companies, and governmental agencies. Moreover, lack of co-operation has also been experienced during the data collection phase. Data and information used in the report are from different journal papers, newspapers, official websites, articles and specific data from different stakeholders like Bangladesh governmental organizations, NGOs and local private companies related to the energy and environmental sector via interviews. The author has found some data reliability issues while reviewing the literature.

This study aims to analyze the prospect of biogas production and electricity generation from biogas. The estimation of bio-fertilizer production from biogas process is not included in this study. The selection of feedstock for biogas production is limited to waste from households, vegetable markets, slaughterhouses and tanneries. Only food is considered as domestic waste whereas solid waste is considered as tannery waste for this study. The study has not included the other possible sources as landfill sites and municipal sewage drain. In the agriculture residue part, feedstock is limited to poultry slurry, poultry manure, and straw.
This study is focused on the physical flows of feedstock, meaning that organizational/management issues are not emphasized. However, some conditions for utilization/implementation are discussed. The calculations presented in the report are done in a simple way, just to illustrate the potential of biogas production. For example, the amounts have been estimated roughly and more specific bio-methane yields are needed. Thus, further and deeper studies are required for a more exact estimation of the biogas production potential and electricity generation potential.
2 Methodology

This chapter describes the methodological approaches used in this study. It includes research framework, data collection method, data analysis, and quality of the research.

2.1 Research framework

The research framework is a stepwise formulation of a set of activities to achieve the objective (Sahu et al., 2013). A research framework has been established to proceed with this thesis work. It starts with defining the background that refers to the theoretical framework. The theoretical framework is developed with regards to the concepts of biogas production through anaerobic digestion and electricity generation from biogas.

Data collection is the next step. It consists of a literature study and field work. Analysis of collected data and calculations are the next steps. Finally, outcome of this thesis work is presented. Figure 1 shows the research framework.

Figure 1: Research framework

2.2 Data collection method

2.2.1 Literature studies

Literature studies have been used to understand the energy system of Bangladesh, Dhaka city’s overall waste management system and to find information about wastes that are generated within the Hazaribagh area.

The electronic library of Linköping University was used to search for relevant papers in the scientific databases (Science Direct and Scopus). The reference software “Zotero” was used to store the relevant literature. At the beginning, a wide search of scientific articles and other relevant sources were done. Later on, literature was categorized and prioritized according to the subject and relevance.

Around 100 research papers were collected in the area of “renewable energy”, “energy system”, “environmental technology”, “bioenergy”, “biogas”, “waste”, “Bangladesh” and “Dhaka”.

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2.2.2 Field study
The author visited Hazaribagh, Dhaka for collecting the data on municipal and agricultural wastes of this area. The study area is one of the densely populated areas of Dhaka city. Hazaribagh is located at 23.734722°N 90.369444°E. The total area is approximately 5.3 km² and has a population of 185639 (Barnes et al., 2011).

The categorization of municipal waste in this study is mainly based on the report published by the “Japan International Cooperation Agency (JICA)” on solid waste management in Dhaka city (JICA, 2005). Reports prepared by the local NGOs also have a similar categorization of municipal waste.

The field work for collecting the data about municipal wastes and agricultural residues was carried out from February’2016 to March’2016. During the data collection phase, the following sources were studied:

- Domestic waste
- Two local markets
- Six slaughterhouses
- Five tanneries

Agricultural activities are practiced mainly in the village areas of Bangladesh (Barun Kumar Das & S. M. Najmul Hoque, 2014). As Hazaribagh is a city area, people are not too much interested in agricultural activities. Poultry farming is the most practiced agricultural activity in this area. Some people are also involved in crop production on a very small scale. Poultry manure and rice straw are considered as agricultural residues in this study. One poultry house and three lands were visited to collect the data about agricultural wastes.

During the visit, important information was collected from different NGOs, governmental agencies and Dhaka South City Corporation. Twenty-five interviews were conducted by the author to collect the data from these stakeholders. While trying to collect the data, the author found that some of the stakeholders do not keep the track record of their activities and in many cases do not have the specific information needed.

A short description of data collection methods for different feedstocks are given below.

**Domestic waste**

Different NGOs and governmental agencies have been contacted to get the information about waste amounts. The information that the author got was not sufficient and thus the author conducted interviews with the waste collectors of this area. Five people were chosen randomly from the waste collection team (consists of ten people) at Hazaribagh. A questionnaire was prepared in this regard. A sample questionnaire is attached with this report as Appendix 1.

The interview with waste collectors helped the author to get a better understanding about the waste management system of Hazaribagh and Dhaka city. The collected information via interviews was also very helpful to cross-check with the collected data from NGOs and governmental agencies regarding waste amounts. Figure 2 shows a typical picture of domestic wastes thrown on the roadside at Hazaribagh.
Market waste

There are mainly two markets in the Hazaribagh area. These two markets have been considered for this thesis work. The author collected the information about the physical flows of market waste during the interview with municipal waste collectors. Some local NGOs also provided the information regarding the physical flows of the wastes that refer to the chronological flow of wastes from waste generation phase to the last phase of waste.

Five shop owners among twenty have been chosen randomly for the interview to know about the details about waste that are generated from the shops. A sample questionnaire was prepared in this regard and attached as Appendix 1 to this report.

Slaughterhouse waste

There are six slaughterhouses in the Hazaribagh area. The author visited all of the six slaughterhouses for collecting the quantitative data about waste that are generated by slaughtering activities. Unfortunately, the slaughterhouses normally do not keep the record for the waste that they produce. Though the interview with slaughterhouse owners helped the author to get the clear understanding about various types slaughterhouse wastes. The slaughterhouse owners also helped the author to get a rough idea about the approximate amount of wastes that might be generated from the slaughterhouses.

The author collected the information about the approximate amount of wastes and their physical flows during the interview with municipal waste collectors. In this report, the physical flows of slaughterhouse wastes refer to the chronological flow of wastes from waste generation phase to the last phase of waste.
Tannery waste

Five tanneries have been selected randomly for the field data collection. Two tanneries were large scale and the other three were medium size among these tanneries. There are other 150 medium size and 50 large scale tanneries at this area. The categorization of tannery was based on the size. The tannery that has an area of 20,000 square feet or more is considered as large scale tannery whereas medium size tannery has an area range of 10,000-19,000 square feet.

The quantitative information about wastes from these tanneries was collected with the help of “Bangladesh Bureau of Statistics”. The information was not sufficient and thus to solve this, interviews were conducted with the employees of the studied tanneries. The interviewees were randomly selected. The interviewee’s list is attached with this report as Appendix 2.

The interviewees helped the author to have a better understanding of flows of the waste that are generated at these tanneries. The interviewees provided some updated information also about the tannery waste amounts. After getting all the information from the respondents, the author did the estimation of the waste amount for five tanneries that were visited. Later on, the author roughly estimated the amount of waste from the rest 200 tanneries by extrapolation technique.

Agricultural residues

There are very few small scale poultry farms available at Hazaribagh area. Only one poultry farm is operating on a large scale and only this farm is considered for this thesis work. A questionnaire was prepared to know about the physical flows and approximate amount of poultry manure. The poultry farm owner provided the necessary information regarding physical flows of poultry manure and it’s amount during the interview with the author.

There is no typical agricultural farm for crop production in Hazaribagh area. Very few people use their land for cultivation on a small scale as their hobby. Three people were considered for interview out of the six land-owners. The information related to crop residue amount and flows were collected during the interviews.

2.2.3 Sample questionnaire

In this thesis work, personal interviews were used to collect the data about the amount of waste, waste flow, biogas feasibility and the waste management. Collecting the information about wastes are crucial for this thesis work. Total 25 interviews were conducted in this study to get the data. The interview was face to face and telephone interview as per the convenience of the interviewees. A common questionnaire has been prepared in this regard and has been attached to this report as Appendix 1.

There are mainly three methods for conducting an interview. The methods are “structured”, “semi-structured” and “open-ended” (Barnes et al., 2011). In this thesis work, all the questions were open-ended of the interviews. An open-ended interview gives the freedom and flexibility to discuss and argue between the interviewee and the interviewer.

A general discussion took place at the beginning of the interview about this thesis work. A deeper discussion took place later phase of the interview based on the responses of the interviewees. Interviews were scheduled for maximum thirty minutes. The target respondents were waste collectors, slaughterhouse owners, employees of tanneries, shop owners at the vegetable and fruit markets, poultry farm owner and crop land owners. Some of the interviews
were recorded with prior permission from the interviewees whereas some interviews were not recorded as the interviewees did not allow to do so. Special care was given to maintain the authenticity of the data during the interview.

2.3 Certainty
Certainty factor has been considered in this thesis work while assessing the biogas production from each substrate. The certainty factor in this thesis work consists of two parts that are “Relevance” and “Reliability”. The “Relevance” refers to what extent the information is useful whereas the “Reliability” refers to the trustworthiness of the collected information. Table 1 shows the scale and remarks about the certainty assessment for this thesis work. Three types of scales are considered in this study. The remark for each category is presented at the table.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Remark</th>
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<tr>
<td>Good</td>
<td>Low uncertainty; sufficient relevant information; trustworthy information</td>
</tr>
<tr>
<td>Moderate</td>
<td>Some uncertainty; sufficient relevant information though there are question marks regarding the trustworthiness</td>
</tr>
<tr>
<td>Poor</td>
<td>High uncertainty; not sufficient information; low level of trustworthy information</td>
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</table>

2.4 Data analysis
For the data analysis phase, at first waste generation and disposal data has been compiled from the selected sources. Once the information was compiled from all the planned sources, screening the data was done. Screening refers to the inspection of data for errors or mismatch. There was some mismatch at the collected data. So, the author had to be very careful while screening the data.

The calculation has been done to estimate the potential amount of biogas. The calculation was done in a simple way just to know about the potentiality of biogas production. Related reference papers and reports were used to estimate the amount of biogas derivable from each type of feedstock. Later on, the estimation of electricity was done accordance with the feedstock amount. The results were analyzed and discussed. Some minor changes were made in the final figures of biogas production and electricity generation as this thesis work is mainly representing the estimated result.

2.5 Quality of the research
The reliability of a research represents whether the result of the research can be replicated with the same tools or measurement procedure. This thesis work is reliable from a short-term perspective. If anyone wants to replicate this thesis work’s outcome from a long-term perspective, the reliability might be changed and has a possibility of reduction. Because the study phenomenon and conditions are changing and it is difficult to get the exact same result.
3 Theoretical background

Biogas is one of the renewable energy carriers that can provide an environment-friendly solution to the energy demand. The comparison with other renewable energy carriers, the share of biogas production is not too much globally (Huda et al., 2014). Though now-a-days, people are being motivated to produce biogas from waste and this trend is increasing globally. The highest energy consumer countries like the USA, China are expanding their biogas production rapidly for the recent few years (American Biogas Council, 2016). The world’s biogas production has an increase of factor 3.5 from the year 2000 to 2011 which is one of the fastest growing renewable energy resources (World Bioenergy Association, 2016).

3.1 Biogas production process

Biogas is produced via anaerobic digestion of organic materials, where microorganisms are very essential. Different types of organic substrates can be used as raw materials like sludge from wastewater treatment plants, manure, food waste, plant material, process waters from food industries (Lastella et al., 2002). Biogas production is more flexible compared to other biofuels, because it can be produced from hydrocarbons, proteins and fats, including wet and secondary material (Akinbomi et al., 2014).

Pre-treatment is commonly needed in biogas production processes for reducing contamination, storage systems, stirring, pumping and microbial decomposition (Li et al., 2015). Highly liquid substrates like wastewater and sludge from sewage treatment plants, must be de-watered to reduce volume and dry materials need to be diluted to be pump-able. In the biogas production process, substrates which are difficult to decompose, need chemical or thermal pre-treatment to increase their availability to the microorganisms (Akinbomi et al., 2014).

In the digester, biogas produced by anaerobic process. There are four steps in anaerobic process for biogas production (Huda et al., 2014). The steps are:

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

In the hydrolysis phase, complex organic compounds are decomposed into simple compounds with the active presence of microorganism aided by enzymes. Number of intermediate products are normally formed in the next step including fatty acids, alcohols etc. In the “Methanogenesis” phase, the last stage of anaerobic digestion, raw biogas is produced (Li et al., 2015).

The chemical reactions of this phase are:

- Hydrogenotrophic Methanogenesis with carbon dioxide: \( \text{CO}_2 + \text{H}_2 \Rightarrow \text{CH}_4 + \text{H}_2\text{O} \) (Akinbomi et al., 2014)
- Acetoclastic Methanogenesis with acetic acid: \( \text{CH}_3\text{COOH} \Rightarrow \text{CH}_4 + \text{CO}_2 \) (Akinbomi et al., 2014)
Raw biogas contains 50-70% CH₄, 50-30% CO₂ and H₂S (Elango et al., 2007). The steps of anaerobic digestion are shown at Figure 3.

- **Hydrolysis**: Complex organic matter, carbohydrates, fats and proteins are broken down into glucose molecules, fatty acids and amino acids.
- **Acidogenesis**: Bacteria break downs into the glucose molecules, fatty acids and amino acids into volatile fatty acids and alcohols.
- **Acetogenesis**: Volatile fatty acids and alcohols are converted into hydrocarbons, CO₂ and ammonia.
- **Methanogenesis**: Arcahea conversion, methane is produced.

Figure 3: Anaerobic process for biogas production in the digester (based on Anaerobic digestion and bio resources association, 2016)

In order to use the biogas for electricity and heat generation, it is not needed to upgrade the biogas. But there are certain prerequisites for appropriate gas quality. The methane content is significant and it should be high. The amount of water vapor should be low. Generally, Sulphur remains in a form of H₂S in the produced biogas. Sulphur must be removed as much as possible from the produced biogas. However, it is needed to upgrade the biogas if anyone wants to use that as the transportation fuel. The common technologies for upgrading the biogas are “water scrubber technology” and the “pressure swing adsorption (PSA)” technology (Zhang, Yan, Li, Chekani, & Liu, 2015).

A biogas plant not only delivers biogas but also fertilizer as the by-product of the anaerobic digestion process. The digestate of the biogas plant can be used as fertilizer (Elango et al., 2007). It is called as the bio-fertilizer. The nutrient content of this bio-fertilizer is high and can be used for agricultural farming. Quality of bio-fertilizer from anaerobic digestion process is dependent on the quality of digestate (Lastella et al., 2002). A good quality digestate to be used as
biofertilizer is the result of controlling all aspects of biogas production process which starts from feedstock selection for biogas production. The biofertilizer provides fast acting nutrients and enters easily into soil due to the decomposition and breakdown of its organic content (Akinbomi et al., 2014).

### 3.2 Electrical power generation

There are several technologies available to generate electricity from biogas. Electricity can be directly generated from biogas by using the fuel cell, though this system requires very clean gas. This process is very expensive and not economically feasible for developing countries like Bangladesh (Barun Kumar Das & S. M. Najmul Hoque, 2014). Even this is not a common trend in electricity generation from biogas in the developed countries also (Ishikawa, Iwabuchi, Komiya, Hara, & Takano, 2015).

The use of generator is the convenient way to generate electricity from biogas. In principle, chemical energy of the combustible gases is converted to mechanical energy in a controlled combustion system by heat engine. This mechanical energy empowers the electric generator to produce electricity (Akinbomi et al., 2014).

Appropriate electric generators/alternators are available in virtually at all sizes. The technology is well known and maintenance is simple. Biogas can be used in many types of combustion engines, like gas engines, diesel engines, stirling engines and gas turbines, though, gas turbines and combustion engines are the most common heat engines used for biogas energy (Yasar, Ali, Tabinda, & Tahir, 2015).

Appropriate combustions engines are as follows:

- Internal combustion engines (diesel engine, gas motor, gas turbine etc.)
- External combustion engine (stirling engine)

Now a days, most of the commercial biogas power plants are run by internal combustion engines. In contrast with the internal combustion engines, the working fluid is contained internally in the external combustion engine and heated by combustion in an external source, through the heat exchanger or engine wall.

The stirling engine is an example of external combustion engine. This type of engine has the advantage for being tolerant of fuel quality and composition. Normally, stirling engines are relatively expensive and not too much efficient (M. Roungu Ahmmad & Dr. Saiful Haque, 2014). Figure 4 shows the flows of biogas production to electricity generation.
Electricity production using biogas can be a very efficient way of generating electricity in developing countries like Bangladesh where there are abundant biodegradable waste and other bioenergy sources. The calorific value of biogas is variable and dependent on methane content of the gas. Average calorific value of biogas is 21-23.5 MJ/m³, the heating oil equivalent for 1m³ biogas corresponds to 0.5 to 0.6 liter diesel fuel or 6 kWh. Bigger biogas plants are relatively more cost-efficient to smaller biogas plants. However, power generation from biogas is appropriate even for relatively small applications in the range of 10-100kW (Ishikawa et al., 2015).

3.3 Linköping – a good example

Linköping is Sweden's fifth largest city and home for 150,000 people. This city is growing, both geographically and in terms of population number. Linköping began industrializing in the latter half of the 19th century. Modernization of this city gained speed from the 1930s and 1940s. Many industries moved to this city and in the past 40-50 years, Linköping has become a center of high-tech and research that has a focus on the manufacture of aircraft and computers (Mejia Dugand, 2010).

Linköping, Sweden is renowned for biogas production and implementation. Though there are many differences between Linköping and Dhaka, like the socio-economic conditions, population and city infrastructure, the author has decided to consider Linköping due to its large scale biogas production. Biogas has been used in the transportation sector mainly in Linköping. Figure 5 shows the biogas production process in Linköping. The first phase is the pretreatment where the unwanted materials are removed. The next phase is digestion in the digester. Upgraded biogas and bio-fertilizers are produced after this phase. Biogas is used for transportation whereas bio-fertilizers are collected for further usage in the agricultural farming (Mejia Dugand, 2010).
Table 2 shows the substrates for Linköping’s biogas plant. Food waste and slaughterhouse waste are the major raw materials that are used for biogas production in Linköping. The other raw materials are glycerol from biodiesel industry, residues from the food industry and many non-specified materials. In 2012, Tekniska Verken started to treat the food waste of local inhabitants. The waste management system in Linköping is integrated with the biogas production system. People separate their organic and inorganic household waste and keep the organic waste in a green bag. Figure 6 shows the household organic waste separation in Linköping. Later on, these green bags are collected by Tekniska Verken which is the local energy provider company.

Figure 5: Biogas production system in Linköping (Source: Tekniska Verken, Sweden)

Figure 6: The household waste (organic waste part) separation at green bag in Linköping
Table 2: Substrates in Linköping biogas plant (Source: Tekniska Verken, Sweden)

<table>
<thead>
<tr>
<th>Type</th>
<th>Proportion (% weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food waste</td>
<td>48</td>
</tr>
<tr>
<td>Food Industry</td>
<td>28</td>
</tr>
<tr>
<td>Slaughterhouse waste</td>
<td>20</td>
</tr>
<tr>
<td>Other substrates (e.g. Fat, Alcohol, Glycerol)</td>
<td>4</td>
</tr>
</tbody>
</table>

In 2014, the total produced biogas amount in Linköping is around 16 Milj Nm$^3$ raw biogas, according to data provided by Sören Nilsson Påledal (Process engineer, Tekniska verken R&D Biogas).
4 Bangladesh and Dhaka city

This chapter describes about the Dhaka city and its context. The pollution situation and some projects are included for better understanding in this chapter. The overall view of energy situation in Bangladesh is also discussed here.

4.1 Geographical location of Bangladesh

Bangladesh is located at the north eastern part of south-Asia, latitude 23.7000° N and longitude is 90.3500° E. The total land area of Bangladesh is 147,570 km². There are eight divisions namely Dhaka, Rajshahi, Khulna, Barisal, Sylhet, Chittagong, Mymensingh, Rangpur. Bangladesh is surrounded by India on the north, west, and northeast while by Myanmar on the south-east and the Bay of Bengal on the south side. Among the major landscapes, floodplains occupy nearly 80% of land whereas hilly areas occupy near about 12%, and terraces occupy about 8%. The flat part of this country is delta shaped (Barnes et al., 2011). Cultivation and settlement are the major reasons for usage of flat lands in Bangladesh. The hilly areas are mainly occupied by aboriginal people. Figure 7 shows the geographical map of Bangladesh.

Figure 7: Geographical map of Bangladesh (Source: Nations online project, 2016)
4.2 Dhaka in context

Dhaka is the capital city of Bangladesh. This mega city is located in central Bangladesh, on the eastern banks of the Buriganga River. Dhaka lies on the lower reaches of the Ganges Delta. This city has an area of 1,463.60 square kilometers. The total population is around 11 million people in this city (A. Islam et al., 2014). Dhaka city is divided into two parts administratively. Two separate municipal corporations are working at Dhaka city which are “Dhaka South City Corporation” and “Dhaka North City Corporation”.

Figure 8: Dhaka city geographical map (Source: Maps of Bangladesh, 2016)

Dhaka has been always the focus for financial and administrative activities of Bangladesh since its liberation at 1971. This city holds a glorious history from British reign (1757-1947) at Indian subcontinent area till now (Begum, Biswas, & Hopke, 2011). The situation started to deteriorate for the last couple of decades due to unplanned infrastructure (Begum et al., 2011). Most of the infrastructures are being built without proper planning.

The energy crisis is another major problem for Dhaka city as well as for Bangladesh. As there are deficits in the generation of electricity in Bangladesh, load shedding is a very common phenomena in this city.
The large number of population is one of the major problems for Dhaka city and many other problems are linked with this problem (Fatemi & Rahman, 2015). Figure 9 shows the densified cities in the world. It can be seen from the figure that Dhaka has the highest number of people living at per square kilometer.

![Population (per square kilometer)](image)

**Figure 9:** The most densified cities in the world (Source: New Geography, 2016)

Lots of people are deprived of fundamental human rights in this city (Mohit, 2012). Currently, many NGOs are working to improve the living standards of people. The government is also engaged in different social beneficial activities. Some parts of Dhaka city are introducing waste management systems in small scale and it has been a success story (M. Z. Rahman et al., 2015). Government has taken some initiatives to mitigate the energy crisis of this city by encouraging to install solar panels at the houses (Jabeen & Guy, 2015).

**Pollution scenario in Dhaka city**

Bangladesh has ranked the fourth among 91 countries with the worst urban air quality in the latest air pollution monitoring report published by the World Health Organization. Basically, there are two major sources of air pollution in Dhaka city which are industries and transportation vehicles. Industrial sources include fertilizer factories, textile factories, brick kilns, spinning mills, tanneries, chemical, pharmaceuticals industries, etc. (Nahar, Zhang, Ueda, & Yoshihisa, 2014).

Tanneries at Hazaribagh in Dhaka City, emit hydrogen sulphide, ammonia, chlorine, and some other odorous chemicals which are poisonous. The average ambient concentrations of suspended particulate matter (SPM) and airborne lead in Hazaribagh are higher than the national ambient air quality standards of Bangladesh (Fatemi & Rahman, 2015).

The waste management system of this city is not well organized. Landfilling is mainly practiced for waste handling in Dhaka city (Ahsan et al., 2014). People throw their waste here and there
and thus pollute the surrounding areas. Figure 10 shows such an example of pollution at Dhaka city.

Figure 10: One typical picture of Dhaka city’s pollution

In the transportation sector, most vehicles are fossil fuel based and have significant environmental impacts. The water pollution situation is also severe along with air pollution. The Buriganga river of Dhaka is dead and polluted badly due to industrial waste, tannery waste and municipal waste (Begum et al., 2011).
5 Energy context of Bangladesh

This section describes different energy sources which includes fossil fuel and renewable energy sources. Sector wise use, the reserves of primary fossil fuels like natural gas, coal and oil are discussed along with renewable energy sources.

5.1 Fossil fuel

Fossil fuels are formed from different organic materials and considered as the major energy sources in the world. This includes mainly natural gas, oil and coal. In Bangladesh, the major portion of energy comes from fossil fuel.

Natural gas

Natural gas is the most valuable natural resource of Bangladesh and plays a significant role in the economy. Figure 11 shows the sector wise natural gas consumptions in Bangladesh. It can be seen from the figure that natural gas has been used mostly for the power generation (41%) followed by the industry (17%) and the captive power generation (17%). The other sectors for gas consumption are fertilizer (6%), transportation (6%) and household use (12%).

![Pie chart showing gas consumption categories](image)

Figure 11: Category wise gas consumption in Bangladesh (Source: Bangladesh Petroleum Corporation, 2016)

Twenty six gas fields have been discovered by April, 2015 with a proven reserve of 27.12TCF. Currently, twenty gas fields are being operated now and total 12.03TCF of natural gas has been produced as of April, 2015 (M. T. Islam et al., 2014).
Oil

There is no significant oil reserve in Bangladesh. The Haripur oil reserve is the only mentionable in this regard which is discovered in 1989 at northwest of the Sylhet district. The estimated oil reserve is 1.4 Mtoe, out of which 0.84 Mtoe was supposed to be recovered as of year 2004 (A. Islam et al., 2014). Later on, due to poor oil quality and water presence at oil zone, exploitation from this oil field was abandoned. Bangladesh heavily dependent on imported crude oil and refined petroleum products for various sectors like industrial use, transportation and small scale power generation (Khatun & Ahamad, 2015). Currently, the total demand of refined oil is 4.87 million metric ton and annual growth rate is 5% (Debnath, Moursheed, & Chew, 2015).

Coal

Coal is considered as the most abundant and cheap source of energy not only in Bangladesh but also all over the world. Coal fired power plants contribute to 41% of the global electricity generation (M. T. Islam et al., 2014). In Bangladesh, coal contributes 2.07% of total power generation. Five coal deposits have been discovered at the north-west part of Bangladesh till now (Khatun & Ahamad, 2015). According to Bangladesh Petroleum Corporation, the estimated reserve in the coal deposits are approximately 3300 million MT which is equivalent to 45–50 TCF of natural gas. Most of the coal deposits contain bituminous type of coal and it has a high calorific value compared to the other types of coal (S. Rahman & Rahman, 2013).
5.2 Renewable Energy

This section describes the renewable energy sources of Bangladesh. Bangladesh has enormous sources of renewable energy, especially bioenergy, solar, hydro and wind energy. Among all renewable sources, bioenergy and solar are the most promising in the country (A. K. M. S. Islam, Islam, & Rahman, 2015).

Bioenergy

It was not too many years ago when biomass was used for heating and cooking in many parts of Bangladesh. This situation has been changed with the advent of fossil fuel based technology. However, Bangladesh is still struggling to fulfill the energy demand of its people. The rural people of this country still relies on biomass for fulfilling their energy demand. Biomass is still being used for heating, cooking and other household activities. Biomass refers to agricultural residues, rice husk, wood, animal waste, municipal waste, etc.

Bangladesh is an agricultural based country and has abundant sources of agricultural residues. Table 3 shows the amount of agriculture crops and residues for 2011. It can be seen from the table that rice has the highest share. The total residues amount in 2011 is 41.66 million tons (Barun Kumar Das & S. M. Najmul Hoque, 2014).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Production (million tons)</th>
<th>Residues</th>
<th>Crop residues (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>50.63</td>
<td>Straw</td>
<td>25.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Husk</td>
<td>10.13</td>
</tr>
<tr>
<td>Maize</td>
<td>1.02</td>
<td>Stalks</td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cobs</td>
<td>0.31</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.97</td>
<td>Straw</td>
<td>0.63</td>
</tr>
<tr>
<td>Jute</td>
<td>1.52</td>
<td>Stalks</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leaves</td>
<td>0.21</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>4.67</td>
<td>Bagasse</td>
<td>1.68</td>
</tr>
<tr>
<td>Mustard</td>
<td>0.23</td>
<td>Straw</td>
<td>0.17</td>
</tr>
<tr>
<td>Coconut</td>
<td>0.08</td>
<td>Husk</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shell</td>
<td>0.019</td>
</tr>
<tr>
<td>Lentil</td>
<td>0.081</td>
<td>Straw</td>
<td>0.058</td>
</tr>
</tbody>
</table>

Animal manure is also considered as agricultural residues. Animal manure is the mixture of organic material, moisture, and ash (Duong, 2014). Cattle, buffaloes, goats and sheep are the sources of animal manure in Bangladesh. It is a common practice in Bangladesh to use the manure as fertilizer in agricultural crop production (Yasar et al., 2015).
Table 4 shows the animal manure generation ratio, waste generation and waste recovery in Bangladesh. It can be seen from the table that cattle have the highest share of manure followed by goat.

<table>
<thead>
<tr>
<th>Animal manure type</th>
<th>Generation ratio (kg dry matter/capita/day)</th>
<th>Waste generation (kton/year)</th>
<th>Waste recovery (kton/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>2.86</td>
<td>23,978.38</td>
<td>14,387.03</td>
</tr>
<tr>
<td>Buffalo</td>
<td>2.52</td>
<td>1195.74</td>
<td>717.44</td>
</tr>
<tr>
<td>Goat</td>
<td>0.55</td>
<td>4496.8</td>
<td>2698.08</td>
</tr>
<tr>
<td>Sheep</td>
<td>0.33</td>
<td>345.69</td>
<td>207.41</td>
</tr>
<tr>
<td>Poultry dropping</td>
<td>0.02</td>
<td>1917.12</td>
<td>958</td>
</tr>
</tbody>
</table>

Table 4: Animal manure production in Bangladesh (Source: Huda et al., 2014)

There is a potential for electricity generation of 160.93 TWh from agricultural crop residues, 121.768 TWh from waste and 29.91 TWh from fuel wood, saw dust and forest residues in Bangladesh (M. T. Islam et al., 2014). IDCOL (a company established by the Government of Bangladesh), have invested 238.65 million Bangladesh Taka (BDT) in biomass based technologies which include biogas based power plants, biomass power plants and biomass gasification plants. IDCOL also aims to install 100,000 domestic biogas plants in Bangladesh by 2018 (Infrastructure Development Company Limited, 2016). 40,000 domestic biogas plants have been established till now by governmental and different non-governmental organizations. It should be noted that the planned biogas plants are small scale where food waste, poultry manure and cow manure could be used as feedstock.

Table 5 shows the biomass energy situation in Bangladesh. Domestic waste and manure are considered as major feedstock for the domestic biogas plant. It can be seen from the Table 5 that domestic biogas potential in Bangladesh has been estimated to 8.6 million m$^3$. Though there are potential for both biomass gasification power plant and biogas power plant, achievements in these sectors are few compared to the potentiality. Biomass and biogas power plants are generating about 2 MW electricity.

Table 5: Biomass energy situation in Bangladesh (Source: M. T. Islam et al., 2014)
Solar energy

Due to the geographical location of Bangladesh, there is an enormous potentiality of solar energy and the solar energy technology is becoming popular day by day. Bangladesh receives an average solar radiation of 4–6.5 kWh/m². The primary energy consumption of Bangladesh is 26.7 Mtoe (1.12*10¹⁸ J) which is only 0.11 % of the total solar irradiance of the country (Halder, Paul, Joardder, & Sarker, 2015).

Bangladesh does not have large-scale commercial solar power plants. However, recently small scale commercial solar power plants are being established (M. U. Ahmed, Nurul Hossain, & Hasanuzzaman, 2015). The country is mainly focusing on solar home system for diffusion of solar energy in village areas where still no national grid line is available.

Many organizations like IDCOL, “Grameen Shakti” etc. are working along with different governmental organization like BREB, BPDB etc. for diffusion of this technology. More than 65,000 solar home systems are being installed every month in the village areas with an average year to year installation growth of 58% (Bangladesh Power Development Board, 2016). This program of solar energy diffusion is being acclaimed as one of the largest and fastest growing off-grid renewable energy programs in the world (Infrastructure Development Company Limited, 2016).

Wind energy

The wind power plants are not very common in Bangladesh (A. K. M. S. Islam et al., 2014). This country has a costal belt of around 724 km along the Bay of Bengal consisting of several islands and only these areas are suitable for wind power plants (Mondal & Denich, 2010). A commercial wind power plant requires adequate economic and technical evaluation, which is not yet readily available for Bangladesh. A well-constructed wind map and data is also required to establish an integrated wind energy network (Khan, Iqbal, & Mahboob, n.d.)

Normally, the wind travels a long way from Indian Ocean and enters Bangladesh. In between, March to September wind blows at an average speed of 3–6 m/s over Bangladesh (Islam S, 2002). According to research data, it shows that wind speed less than 7 m/s is not viable for large scale grid connected wind power plants. The wind speed in Bangladesh varies from 2.96 m/s to 4.54 m/s at the height of 25 to 50 meter (Rofiqul Islam, Rabiul Islam, & Rafiqul Alam Beg, 2008).

Bangladesh has started small projects in this sector. Bangladesh Power Development Board installed 4x225 KW = 900 KW capacity grid connected wind plants at Muhuri Dam area (Sonagazi, Feni). There is another project of 1000 KW Wind Battery Hybrid Power Plant at Kutubdia Island, that consists of 50 Wind Turbines of 20 kW capacity each. Bangladesh government is planning to install 15 MW wind power plants across the coastal areas and Muhuri Dam areas of Feni (Bangladesh Power Development Board, 2016).

Hydro energy

Geographically Bangladesh has a flat terrain. Mainly the rivers at Chittagong hilly areas have potential for hydro power plants (Halder et al., 2015). In 1962, the first hydro-power plant was installed in the Karnafuli river basin with two units of capacity 40 MW each. Later on 1988, three more units of 50 MW each were installed. This hydro power plant is known as “Kaptai
hydroelectric power plant” and the total installed capacity is now 230 MW (Rofiqul Islam et al., 2008). Bangladesh has near about 1897 MW hydro power potential comprising of 330MW in Karnafuli river basin, 80MW in Matamuhuri river basin, 87 MW in Sangu river basin and 1400 MW in Brahmaputra river basin. In 2005, Bangladesh power development board has installed a 50 kW micro-hydro power plant at Barkal upazila of Rangamati district and financing a 50–70 kW Mohamaya irrigation-cum-hydro power project located at Mirersorai, Chittagong (Halder et al., 2015).
6 Electricity generation in Bangladesh

This chapter describes the power generation status in Bangladesh. Both the fossil fuel based power generation and renewable sources based power generation is discussed.

6.1 Fossil fuel

There are many areas in Bangladesh where people are still deprived from access to electricity. Even there is a deficit between power generation and demand with existing power connections (Hossain, 2015). Present power demand is 6298 MW as of January, 2016 (Bangladesh Power Development Board, 2016). Load-shedding is the only present solution to address this problem (M. M. Rahman et al., 2016).

Bangladesh government turned to high cost oil-based quick rental power plants to alleviate this situation (Hossain, 2015). Many local energy experts are already criticizing this short term initiative for mitigating the energy crisis. According to the Ministry of Power, Energy and Mineral Resources, the forecasted demand in Bangladesh would be 19000 MW in 2021 and 34000 MW by 2030 (Bangladesh Power Development Board, 2016). Table 6 shows some important information about Bangladesh power sector. It can be seen form the table that generation capacity of Bangladesh is 14077 MW whereas the highest generation has been 8177 MW till now.

<table>
<thead>
<tr>
<th>Table 6: Bangladesh power sector at a glance (Source: Bangladesh Power Development Board, 2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation capacity <a href="MW">including captive</a></td>
</tr>
<tr>
<td>Highest generation (MW)</td>
</tr>
<tr>
<td>Transmission line (Ckt. km)</td>
</tr>
<tr>
<td>Distribution line (km)</td>
</tr>
<tr>
<td>Power import (MW)</td>
</tr>
<tr>
<td>Per capita power generation (kWh)</td>
</tr>
<tr>
<td>System loss</td>
</tr>
</tbody>
</table>

Energy supply from primary sources has been increased for the last few years but there is no significant development is visible for substantial alternative energy sources that can address the sustainable solution in Bangladesh (Hossain, 2015). Final energy consumption has been increased over 200 % from 1992 to 2015.

Figure 12 shows the power generation from different sources in Bangladesh. It can be seen from the figure that power generation of Bangladesh predominantly relies on natural gas, which accounts for 63.19%. Other sources include furnace oil (20.77%), diesel (7.92%), coal (2.07%), hydro (1.91%) and power import (4.14%) (Bangladesh Power Development Board, 2016).
As there has not been enough new gas field exploration for the recent days in Bangladesh, experts in energy sectors are concerned with gas consumption at this pace, and resources are estimated to be depleted within a decade (Halder et al., 2015). Due to the deficit of supply and demand in energy, people are suffering from interrupted power and load shedding specially at rural areas of Bangladesh (Barnes et al., 2011).
6.2 Renewable energy

Renewable energy is considered as clean energy and normally derived from the natural process. It does not have hazardous depletion during utilization time. Bangladesh has enormous potential for increasing the share of renewable energy in the power generation sector and Government of Bangladesh is increasing steadily renewable energy’s contribution with national power generation system. Figure 13 shows the shares of different types of renewable energy in Bangladesh. It can be seen from the figure that hydro power has the largest contribution (58.6%) in the renewable energy field for power generation and followed by solar energy (39.5%). Bioenergy contribution is 1.4% and wind power plant represents 0.5% (Bangladesh Power Development Board, 2016).

![Figure 13: The share of different types of renewable energy in power generation sector of Bangladesh (Source: Bangladesh Power Development Board, 2016)](image)

In rural parts of Bangladesh, there are many local off-grid power generation plants that are available. These power plants play a significant role to mitigate the energy demand in the rural parts (Khatun & Ahamad, 2015). According to Bangladesh power development board, such off-grid total power is 146.1 MW till the year of 2015. Among all the shares, solar photovoltaics contributes 145 MW, wind power plants contribute 1 MW and small scale hydro contribute to 0.1 MW (Bangladesh Power Development Board, 2016).
7 Biogas feedstock potential

This chapter describes the raw material and potential sources for biogas production in Hazaribagh, where the author has made the visit. It includes the sources, flows and other important characteristics of the various sources.

7.1 Municipal waste

Municipal waste is the heterogeneous composition of wastes that are organic and inorganic, biodegradable, hazardous and non-hazardous and generated from various activities in the city areas. The main components of municipal solid waste are food waste, paper, textile, plastic, leather, rubber, wood and various combustible materials. It has been stated earlier that considering the waste management system, tannery waste and slaughterhouse waste are also considered as municipal waste in this thesis work. Per capita waste generation is dependent on socio-economic conditions like economic status of people, food habits, age, gender and seasons (Waste concern, 2016). Organic materials are the sources for biogas production by anaerobic digestion. In Hazaribagh area, the sources for organic wastes are the domestic waste, vegetable market waste, tannery waste, slaughterhouses, sewage and drain of municipalities and landfills.

According to the JICA’s report (mentioned at “methodology” chapter), the categorization of municipal waste is presented in Figure 14. This figure shows that organic materials have the highest volume (80%) in the composition of municipal solid waste in Hazaribagh. The others significant compositions are paper (9.4%), plastics (3.0%) etc. Textile, wood, leather, metal and glass are having less significant shares in the waste composition.

![Figure 14: This figure shows the municipal waste composition of Hazaribagh area, Dhaka](Source: JICA, 2005)
7.1.1 Domestic waste

Domestic waste consists of various organic and inorganic substrates. Landfilling is the regular practice to deal with domestic waste in Dhaka city. Dhaka South City Corporation has placed some dustbins in different places. People are supposed to use those dustbins for the wastes. Unfortunately, the author found that people are throwing their household wastes here and there.

There are some social organizations who are working to collect the household wastes from the houses in Hazaribagh. They collect the waste from the house and charge 40 BDT/per month from each family. Later on, these wastes are dumped at city corporation dustbins and further on taken away by city corporation trucks for landfilling. Very small portions of the waste are composted by some local organizations (e.g. waste concern).

Figure 15 shows the waste collection for landfilling by the cleaners at Hazaribagh.

![Figure 15: Typical picture of waste collection at Hazaribagh area for landfilling](image)

Around 8.4 metric tons (8400 kg) of domestic/household waste (e.g. organic and other types of waste) is generated daily in Hazaribagh. It has been found that around 80% of waste is organic (JICA, 2005). Based on rough assumptions done by the author, the daily amount of generated organic waste is estimated to approximately 6 metric tons in Hazaribagh. Figure 16 shows the domestic waste flows.
Figure 16: Schematic flow diagram for household waste in Hazaribagh area
7.1.2 Market waste

Hazaribagh is one of the large areas of Dhaka city. Many people from outside of this area also come here to sell and buy vegetables and other goods. There are mainly two market places in Hazaribagh, namely “Hazaribagh bazar” and “Bou bazar”. “Hazaribagh bazar” is considered as the main vegetable market whereas “Bou bazar” is comparative smaller than “Hazaribagh bazar”.

Hazaribagh Bazar

This market remains opens almost the whole day. Daily activities start at 4 AM and continues to 1 AM. Some shops remain open even for 24 hours. Several various commercial premises sell different types of vegetables and fruits. The market has approximate 20 shops for vegetables and fruits that are authorized from Dhaka South City Corporation. The water sewage system is not well planned and the whole area becomes flooded during the heavy rainfall season. This is to be noted that there are some businessmen who do not have the license for doing business and does not have commercial space in the market area, but still they come with their agricultural goods and do their business on the street of the market. The poor people are the main customers of these street shops. Figure 17 shows a typical picture of vegetable shops of the “Hazaribagh bazar”.

![Figure 17: Typical picture of the “Hazaribagh bazar”](image)

The vegetables and fruits that are not sold are thrown away into the dustbin. The peels and fruit residues are also thrown away at the dustbins. Based on rough assumptions done by the author the daily amount of generated biodegradable waste is estimated to approximately 0.1 metric ton. The whole wastes are thrown away at city corporation dustbins. The cleaner and waste collectors later pick up the wastes from the local dustbins for landfilling outside of Dhaka city. Very small portions of the waste are composted by some local organizations (e.g. waste concern).
Figure 18: A typical sight of municipal dustbins at Hazaribagh area

A schematic flow diagram is shown in Figure 19.

Vegetables and fruits market (Hazaribagh bazar)

Sold vegetables and fruits

Unsold vegetables and fruits, peels and residues (0.1 ton/day)

Municipal dustbins

Landfill sites

Very small portion used for composting

Figure 19: Schematic flow diagram for market waste
Bou Bazar

This market is comparative smaller but otherwise almost identical to “Hazaribagh bazar”. This market remains open daily for the limited time and serves mainly the residues of Dhaka South city corporation employee residential area. This market has only 7 shops for vegetables and fruits. Based on rough assumptions done by the author the daily generated amount of biodegradable waste is estimated to 0.01 metric ton and the whole wastes are thrown away at the city corporation dustbins.
7.1.3 Slaughterhouse waste

There are mainly six slaughterhouses in Hazaribagh area which are used for slaughtering the cattle, goats, sheep and chicken. All the slaughterhouses are located at “Hazaribagh bazar” and are privately owned. Dhaka South City Corporation does not regulate the slaughtering related activities and there is no proper monitoring and controlling system regarding slaughtering house waste.

The slaughter houses of Hazaribagh slaughter in average total 300 cattle, goats and sheep and about 4000 chickens per month (field visit by author, 2016). The consumed parts by human are meat, liver, tongue and tripe. Rest of the parts from animals are sold to local businessman and remaining are thrown away at dustbin.

The waste is mainly composed of blood, bones, entrails etc. In many countries (e.g. Columbia, Brazil, Spain etc.) animal blood have further usage after the slaughtering related activities. This does not happen in Bangladesh. The blood is washed away to the municipal drains. Approximately 123 tons of blood are washed away to the municipal drains per year as waste water from the slaughter houses. Some parts of entrails are sold to the customers. But major portions are thrown away at municipal dustbin as waste. Figure 20 is showing the slaughterhouse wastes that are kept at slaughterhouses and are thrown away later on at the municipal dustbins.

![Figure 20: Typical picture of slaughterhouse wastes at “Hazaribagh bazar”](image)

Approximately 3 tons of entrails are thrown away at the dustbin per month from these slaughterhouses. Later on, these wastes are being collected by Dhaka South City Corporation for landfilling. There are some private organizations that use very small portions of these landfilled wastes for preparing of compost fertilizers.
Many customers want to buy bone meat from the slaughterhouses. So most of the bones are sold with meat to the customers. A very little portion of bones is kept for further usage. These bones are taken away from slaughter houses by some local businessman who sell those bones later to different pharmaceutical companies and plastic goods manufacturers. This is to be noted here that bones are used to manufacture the outer shell of the capsule in the pharmaceutical industry of Bangladesh. Different plastic goods manufacturer companies use the bones to prepare their products like buttons for shirt and comb (Siddiquee, Islam, & Rahman, 2013). Approximately 1200kg waste bones are sold monthly from slaughter houses of Hazaribagh. Based on rough estimations done by the author the yearly amount of slaughterhouse waste is approximately 1500 ton/year.

A schematic flow diagram is shown in the Figure 21.

![Figure 21: Schematic flow diagram for slaughterhouse waste](image-url)
7.1.4 Tannery waste

Tannery waste is the heterogeneous composition of wastes that are organic and inorganic, biodegradable, hazardous and non-hazardous and generated from various activities at the tanneries. Tannery waste can be both solid type and liquid type. Majority portion of wastes are the mixture of both liquid and solid materials according to respondents’s opinion. The major solid wastes generated by the tanneries are fleshing, chrome shaving, chrome splits, buffing dust, trimmings, etc. Raw material for tanneries are raw hide or skin. About 60000 tons of raw hides and skins are processed in the tanneries of Hazaribagh every year.

Solid and liquid wastes are generated due to use of some chemicals such as chromium oxide, ammonium sulfate, formic acid, sulfuric acid and sodium chloride. There are several steps and these chemicals are used in various steps. The chemicals are washed by water at the end of each process and liquid waste is generated by this washing process. Figure 22 shows the tannery wastes that are washed away at municipal drains.

Figure 22: Typical picture of a tannery waste flow at municipal drains of Hazaribagh area

About 850 kg solid waste is generated out of 1000 kg of raw hide in the leather processing phase. The percentage of different solid wastes are given below in the Table 7. It can be seen from the table that fleshing has the highest share in the solid waste followed by chrome shaving, chrome splits and buffing dust.

Table 7: Solid waste types of tannery waste

<table>
<thead>
<tr>
<th>Solid waste type</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleshing</td>
<td>50%-60%</td>
</tr>
<tr>
<td>Chrome shaving, chrome splits, buffing dust</td>
<td>35%-40%</td>
</tr>
<tr>
<td>Skin trimmings</td>
<td>5%-7%</td>
</tr>
<tr>
<td>Hair</td>
<td>2%-5%</td>
</tr>
</tbody>
</table>

According to the respondents, approximately 62500 tons of solid waste is generated per year from the tanneries. The liquid wastes are washed away at the municipal drains whereas the solid wastes are landfilled.
7.2 Agricultural residues

Agriculture in a country depends on many factors such as rainfall, temperature, solar radiation, atmospheric condition and soil fertilisation (Didar-Ul Islam & Bhuiyan, 2016). All these conditions have made Bangladesh a suitable country for agriculture. The total agricultural land in Bangladesh is about 90,500 km². Approximately 52.54% of the total land in Bangladesh is used for agricultural activities only (Huda et al., 2014).

Agricultural residues are the non-edible plant parts that are left after harvesting or remain as the by-product after the crop process. Animal manure is also considered as agricultural residues. Rice husk, straw, coconut husk and shell, beans, vegetable trees, sugarcane bagasse, animal manure etc. are the main agricultural residues considered in Bangladesh (Barun Kumar Das & S. M. Najmul Hoque, 2014). Normally crop residues are collected at the same time of harvesting or after harvesting. Agricultural residues are not only used for energy generation but also for cooking and raw manufacturing material in Bangladesh (Huda et al., 2014).

7.2.1 Manure

Manure contains important minerals that are appropriate for biogas production. Carbohydrate is the main component followed by proteins and fat in manure. It can work as the base for biogas production (Duong, 2014). Manure emits methane if it left in a place due to self-composition. People complain about the odour that comes from manure. Through biogas production, one can use the manure in a sustainable way (Ishikawa et al., 2015).

![Figure 23: Inside picture of the poultry house at Hazaribagh](image)

In Hazaribagh, the poultry farm is the main source of manure. There is one poultry farm in this area. This poultry farm is privately owned. Eggs and chicken from this farm are sold to the local businessmen of “Hazaribagh bazar”. The farm has 2000 layer chicken raised in two separate commodities. The owner of the farm collects the poultry manure and some portion of poultry slurry. The remaining poultry slurry is washed away with water at municipal drain while cleaning the poultry farm. The total amount of chicken manure (slurry included) produced from this farm is 55 tons/year.
7.2.2 Straw
Straw is the part of the cereal crop without the kernel (Duong, 2014). In Hazaribagh, the only straw is from rice. Cellulose, a smaller portion of hemicellulose and lignin are the main parts of straw. Total solid and C/N varies between different cereals and also for a certain crop (Chandra, Takeuchi, & Hasegawa, 2012). Figure 24 shows a typical picture of rice straw.

![Figure 24: A picture of rice straw](image)

The content of rice straw can be seen in Table 8. The volatile matter has the highest percentage in straw followed by carbon. The other significant contents are oxygen, ash etc.

<table>
<thead>
<tr>
<th>Content</th>
<th>Rice straw (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed carbon</td>
<td>14.01</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>61.2</td>
</tr>
<tr>
<td>Ash</td>
<td>20.49</td>
</tr>
<tr>
<td>Carbon</td>
<td>39.99</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3.94</td>
</tr>
<tr>
<td>Oxygen</td>
<td>30.26</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.79</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The author made an estimation by talking to land owners. The estimation shows that one can get approximately 0.05 ton straw per year from this area.
7.3 Estimated biogas and electricity generation

The calculations made in this thesis to roughly estimate the amount of biogas and electricity from the described sources will be done in a simple way, just to illustrate the potential. It means that the actual production might be different if implemented. The calculations of biogas production and electricity generation are attached as Appendix 4 to this report.

Figure 25 shows the feedstock amount ratio in terms of weight. It can be seen from this figure that tannery waste has the highest share followed by slaughterhouse waste among all the considered feedstock. The amount of straw is very less in Hazaribagh area compared to the other biomass and thus, straw’s ratio (0.0014%) is not presented in the following chart.

The estimated amount of municipal waste and agricultural waste are presented for biogas production along with the electricity generation from each substrate in Table 9. It will be possible to understand how each type of feedstock contributes to the total amount of theoretically produced biogas. Biogas production from few different types of substrates are attached to this report as Appendix 3. However, as mentioned before, calculations presented in the report are approximate and it is required to have further studies, with a deeper technical look.
Table 9: This table shows the estimated feedstock amount, approximate biogas production from each substrate and theoretically electricity generation from each substrate for Hazaribagh area

<table>
<thead>
<tr>
<th>Feedstock sources</th>
<th>Substrate</th>
<th>Estimated amount (ton/year)</th>
<th>Data collection method</th>
<th>Approximate biogas production (m³/year)</th>
<th>Certainty</th>
<th>Comment</th>
<th>Theoretical generation of Electricity (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic waste</td>
<td>Food waste</td>
<td>6</td>
<td>Interview, report</td>
<td>440</td>
<td>Moderate</td>
<td>Most data are reliable</td>
<td>2600</td>
</tr>
<tr>
<td>Market waste</td>
<td>Vegetable and fruit waste</td>
<td>40</td>
<td>Interview, report</td>
<td>2650</td>
<td>Moderate</td>
<td>Most data are reliable</td>
<td>15900</td>
</tr>
<tr>
<td>Slaughterhouse waste</td>
<td>Entrails and blood</td>
<td>1500</td>
<td>Interview</td>
<td>79000</td>
<td>Moderate</td>
<td>Second large share among the feedstocks; most data are reliable</td>
<td>474500</td>
</tr>
<tr>
<td>Tannery waste</td>
<td>Fleshing</td>
<td>62500</td>
<td>Interview, report, extrapolation</td>
<td>3125000</td>
<td>Good</td>
<td>Largest share among all the considered feedstocks; reliable data.</td>
<td>18750000</td>
</tr>
<tr>
<td>Poultry house waste</td>
<td>Manure and slurry</td>
<td>55</td>
<td>Interview</td>
<td>4300</td>
<td>Moderate</td>
<td>Most data are reliable</td>
<td>25700</td>
</tr>
<tr>
<td>Straw</td>
<td>Rice straw</td>
<td>0.05</td>
<td>Interview</td>
<td>7</td>
<td>Poor</td>
<td>Amount of straw is very small; have question marks about the data quality.</td>
<td>40</td>
</tr>
</tbody>
</table>
Figure 26 shows the theoretical generation of electricity from each considered substrate in the Hazaribagh area. It can be seen from the following figure that tannery waste contributes most for the electricity generation followed by slaughterhouse waste. Electricity generation from straw is very less in Hazaribagh area compared to the other sources.

![Theoretical generation of Electricity (kWh)](chart.png)

**Figure 26 : The electricity generation (theoretically) from considered substrates in Hazaribagh**

It has been stated earlier in Chapter 6 that the present electrical power demand in Bangladesh is 6298 MW. The amount of estimated electricity generation is not too much compared to the total power demand of Bangladesh. But this amount of generated electricity can help to fulfil a large portion of power demand at an area like Hazaribagh.
8 Conditions for biogas implementation

To diffusion the environmental technology as like biogas it requires several actors to be involved from the beginning which includes government, future owners and people. They are the main actors to implement and maintain the technology (Yaqoot, Diwan, & Kandpal, 2016). Local sufficient knowledge and skills should be available also for implementation, maintenance and future repairing work (Urmee & Md, 2016).

The government is an important actor for diffusion of the environmental technologies in a country (Kanda, Mejía-Dugand, & Hjelm, 2013). The other important actors are public, private organizations, NGOs, media etc. Governmental initiatives has the ability to influence and implement a technology (Urmee & Md, 2016). Figure 27 shows the governmental initiatives what include legislation and policy, financial support, education and training, trade mobility related programs etc.

Figure 27 : The government initiatives for diffusion the environmental technology

Legislation and policy play very important role to diffusion the renewable energy technologies (Kanda et al., 2013). It consists of rules and programs. It is very essential to have a good policy for implementing environmental energy technologies in a country (Yaqoot et al., 2016). Bangladesh published their renewable energy policy in December 2008 and this policy includes modalities and procedures, fiscal and other incentives and tariff regulations (Bangladesh Power Development Board, 2016). This policy is much more focused on power generation for mitigating the energy crisis in Bangladesh (Rofiqul Islam et al., 2008).

Legislation and policy
Trade mobility related programs
Financial support
Education and training related programs

Government initiatives
Bangladesh is an agricultural based country and thus, have abundant sources of biogas feedstock. In the published policy, it has been stated that the biogas share will be increased but it is difficult to get clear guideline about the biogas feedstock supply and use. Municipal waste can be a very good feedstock for biogas and many countries are increasing their biomass share by using the municipal and agricultural wastes to produce biogas (Barnes et al., 2011).

In order to produce biogas from municipal waste in a large scale, it is better to have integration of waste management system with biogas production chain (Mejia Dugand, 2010). Many countries that are focusing on biogas solution, have integrated their waste management system with biogas production. The author has presented the example of Linköping, Sweden in this regard at “Chapter 3” of this report where the waste management system and biogas production system is integrated with each other. The waste management policy of Bangladesh reflects mainly landfilling of waste. Bangladesh government should establish a sustainable waste management system. Furthermore, it is needed to integrate the waste management system with the renewable energy policy.

Financial incentives act as an effective program for implementing environmental technologies (Barnes et al., 2011). The Bangladesh government can give financial support to promote the environmental technologies in many ways to the people and organizations. The financial help can be as a form of subsidy, loan, tax exemption etc. Sometimes, the capital and operational expenditure become high for the environmental technologies. Financial help can solve this issue and motivate the stakeholders to go for environmental technology implementation.

Educating the people is another important part for diffusion the environmental technology (Barnes et al., 2011). The people should be informed and educated about the various benefits of biogas solutions. Many people in Bangladesh are not aware of the bio-fertilizer which is a by-product of the biogas production process. The bio-fertilizer is a good source of the plant’s nutrients. The government should involve local NGOs and media to inform the people about the multiple benefits of the biogas solutions and thus to motivate the people to use it. Public interest and co-operation are also very significant to diffuse the environmental technology in a community (Urmee & Md, 2016). It has been observed that without the public support and co-operation, several environmental diffusion projects have been failed in many countries.

Creating a market is another important part for diffusion of environmental technologies (Kanda et al., 2013). It is very essential for the companies to have a favourable market situation so that companies can sustain their business in the energy and environmental sector (Kanda et al., 2013). Trade mobility plays a significant role in this regard. The government should create an environment for the companies so that they can bring the new ideas and technologies in the market and continue their business. It is a challenging task for a government to diffuse the environmental technology like biogas without engaging and encouraging the commercial companies to involve at this sector (Yaqoot et al., 2016).
9 Conclusion

The overall aim of this thesis was to analyze Hazaribagh’s biogas potential from municipal waste and agricultural residues and to estimate how much electricity that can be generated from biogas. With this goal, five objectives have been selected and can be answered as follows:

1. **To briefly describe the energy and power generation sector of Bangladesh.**

   In Bangladesh, the major portion of energy comes from fossil fuels. Natural gas is the most valuable natural resource of Bangladesh. The other fossil fuels like oil and coals also have significant contributions in the energy sector. This country has enormous sources of renewable energy, especially bioenergy, solar, small scale hydro and wind energy. Among all renewable sources, bioenergy and solar are most promising in the context of Bangladesh.

   In the power sector of Bangladesh, there is a gap between power generation and demand. Bangladesh government turned to high cost oil-based quick rental power plants to alleviate this situation. Energy supply from primary sources has been increased for the last few years but there is no significant development is visible that can address the sustainable solution in energy and power sector of Bangladesh.

2. **Provide an overview of relevant municipal wastes and agricultural residues of Hazaribagh.**

   Hazaribagh is a crowded area and thus generates a lot of municipal wastes. The main components of municipal solid waste are food waste, paper, textile, plastic, leather, rubber, wood and various combustible materials. Organic materials have the highest volume (80%) in the composition of municipal solid waste in Hazaribagh. Few agricultural activities are also visible in this area which mainly includes poultry farming. Rice straw is also produced due to crop farming. The amount of municipal waste is high compared to the agricultural residues in Hazaribagh.

3. **Select some types of such waste/residues and estimate the amounts.**

   Domestic waste, market waste, tannery waste, and slaughterhouse waste are considered as municipal waste in this thesis work whereas poultry manure and rice straw are considered as agricultural residues. The step was taken in order to identify and describe up-to some extent of the amounts and composition of the municipal wastes and agricultural residues for this area. The estimation was done in a simple way just to illustrate the potential of biogas production.

   The result of this thesis work shows that the tannery waste has the highest potential followed by slaughterhouse waste. In terms of agricultural residues, the amount of poultry manure is much compared to the amount of rice straw.
4. **Discuss how these potentials could be utilized for biogas.**

Biogas can be produced from the described raw materials/feedstocks. This research shows that there is a good potentiality of biogas production from the municipal wastes and agricultural residues. Electricity generation from biogas is a common trend for utilizing the biogas. The amount of biogas production and electricity generation from biogas can be estimated theoretically. Such type of estimation gives an initial insight and a ground for further analysis. Normally, there will be differences between theoretical production and practical production. Biogas production and electricity generation should be accompanied by other activities as well as the process must be optimized to reach a certain level that is close to the theoretical production.

Bio-fertilizer can also be produced as a by-product from the described feedstocks. The usages of chemical fertilizers in the agricultural fields are increasing for the recent years in Bangladesh. The over usages of chemical fertilizers decrease the fertility of the lands. The bio-fertilizers can be used in the agricultural fields that not only helps to fulfill plant’s nutrient demand but also to increase the fertility of the lands.

The estimated amount of produced biogas and electricity are not too large compared to the total energy demand in Bangladesh. However, this thesis work can provide a food for thought to the government as well as the policy makers to think about the biogas solutions in a large scale that can address the energy, the waste management and the nutrient management of agricultural lands.

5. **Study pre-requisite/conditions for biogas solutions and discuss how the biogas solutions could be integrated into the energy road.**

Availability of suitable feedstock is necessary for large-scale biogas production and proper waste management system eases the continuous supply of appropriate feedstock for biogas production. Along with the feedstock availability, it requires several actors to be involved from the beginning which includes government, future owners, and people for diffusion the environmental technology like biogas. Local sufficient knowledge and skills should be available for implementation, maintenance, and future repairing work. The government is the most significant actor for integrating the environmental technology like biogas with the energy road map as they have the ability to influence people with the help of different tools like legislation, financial support etc. Moreover, other actors like media, NGOs should be involved also for a successful integration of biogas solutions with the energy road-map.

The “Government of Bangladesh” can think about the biogas solutions in a large scale as a pilot project in Hazaribagh. If the project becomes successful, the government can move forward in a massive scale at other parts of the city and country.
Reference list


Duong, S. (2014). Systematic Assessment of Straw as Potential Biogas Substrate in Co-digestion with Manure; Systematisk utvärdering av halm som potentiellt biogassubstrat i samrötning med gödsel.


(2016). Field visit by author at Hazaribagh on March, 2016


Appendix 1

*Interview Guide*

Date: ____/____/____ (dd/mm/yyyy)
Interview duration: 30 minutes (max)

Topic: The biogas potential from municipal waste and agricultural residues in Hazaribagh, Dhaka city, Bangladesh - a possible strategy to improve the energy system.

Name of the interviewee:

Working place type of interviewee:

Occupation/designation:

Name of the Interviewer: A S M Monjurul Hasan

Interview structure: Semi-structured.

*Questions*

Q1. Please give me a brief idea about waste management system of your working place.

Q2. Please give me an approximate idea of waste generated in your working place.

Q3. Are you currently using your waste or by-product?

Q4. What is your opinion about the existing waste management system in Hazaribagh?

Q5. Do you think that is it possible to use the waste for further usage? Please share your idea with me.

Q5. Is it feasible to produce biogas from the waste that is generated from your farm/tannery/shop/slaughterhouse? Please share your idea with me.

Q6. Are you interested to use the waste for biogas production?

Note:
- All information will be handled with strict confidentiality.
- Supplementary questions may be asked based on interviewee’s response.

Appendix 2

*Appendix 2 contains information about the interviews regarding this thesis work.*
<table>
<thead>
<tr>
<th>Interviewee’s Occupation</th>
<th>Interviewee’s working place type</th>
<th>Number of interviewees</th>
<th>Mode of Communication</th>
<th>Date</th>
<th>Duration per interviewer</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managerial position</td>
<td>Large tannery</td>
<td>2</td>
<td>Telephone conversation</td>
<td>March 28, 2016</td>
<td>Approx. 30min; not allowed to record</td>
<td>Covered two large size tanneries</td>
</tr>
<tr>
<td>Executive level position</td>
<td>Medium size tannery</td>
<td>3</td>
<td>Personal interview and telephone conversation</td>
<td>March 29, 2016</td>
<td>Approx. 40min; not allowed to record</td>
<td>Covered three medium size tanneries</td>
</tr>
<tr>
<td>Waste collector</td>
<td>Large area</td>
<td>5</td>
<td>Personal interview</td>
<td>February 25, 2016 and February 26, 2016</td>
<td>Approx. 40min; recorded</td>
<td>The waste collectors are responsible for collecting all types of wastes in Hazaribagh.</td>
</tr>
<tr>
<td>Crop land owner</td>
<td>Small size land</td>
<td>3</td>
<td>Personal interview</td>
<td>February 27, 2016</td>
<td>Approx. 30min; not recorded</td>
<td>n/a</td>
</tr>
<tr>
<td>Shop owner at Hazaribagh market</td>
<td>Medium size shop</td>
<td>4</td>
<td>Personal interview</td>
<td>March 2, 2016</td>
<td>Approx. 30min; recorded</td>
<td>n/a</td>
</tr>
<tr>
<td>Shop owner at Boubazar market</td>
<td>Medium size shop</td>
<td>1</td>
<td>Personal interview</td>
<td>March 3, 2016</td>
<td>Approx. 30min; not recorded</td>
<td>n/a</td>
</tr>
<tr>
<td>Slaughterhouse owner</td>
<td>Medium size</td>
<td>6</td>
<td>Personal interview and telephone conversation</td>
<td>March 4, 2016 and March 5, 2016</td>
<td>Approx. 30min; not recorded</td>
<td>n/a</td>
</tr>
<tr>
<td>Poultry farm owner</td>
<td>Large size</td>
<td>1</td>
<td>Personal interview</td>
<td>March 10, 2016</td>
<td>Approx. 30min; not recorded</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Appendix 3

Specific biogas production for various potential substrates. The values given are approximate in the table.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Volatile Solids VS (%)</th>
<th>Methane yield (m$^3$/ton VS)</th>
<th>Approximate biogas (m$^3$/ton)</th>
<th>Considered value for biogas production (m$^3$/ton)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic waste</td>
<td>85-95</td>
<td>400-420</td>
<td>60-70</td>
<td>66</td>
<td>(Rao et al., 2000)</td>
</tr>
<tr>
<td>Slaughterhouse waste</td>
<td>90-95</td>
<td>650-670</td>
<td>50-60</td>
<td>52</td>
<td>(Mejia Dugand, 2010)</td>
</tr>
<tr>
<td>Fruit and vegetable waste</td>
<td>85-95</td>
<td>400-420</td>
<td>60-70</td>
<td>66</td>
<td>(Chima Ngumah et al., 2013)</td>
</tr>
<tr>
<td>Straw</td>
<td>80-90</td>
<td>180-200</td>
<td>130-150</td>
<td>140</td>
<td>(Chima Ngumah et al., 2013)</td>
</tr>
<tr>
<td>Tannery waste (fleshing)</td>
<td>75-85</td>
<td>60-70</td>
<td>45-55</td>
<td>50</td>
<td>(Basak, Rouf, Hossain, Islam, &amp; Rabeya, 2015)</td>
</tr>
<tr>
<td>Poultry house waste</td>
<td>70-80</td>
<td>70-80</td>
<td>60-70</td>
<td>65</td>
<td>(Rao et al., 2000)</td>
</tr>
</tbody>
</table>
Appendix 4

*Biogas production calculations*

**Domestic waste:**

1 ton domestic organic waste produce approximately 66 m³ biogas. 
6.7 ton of domestic waste produce = \(66 \times 6.7\) m³ biogas = 442 m³ biogas.

**Market waste:**

1 ton market waste (organic) produce approximately 66 m³ biogas. 
40.15 ton of market waste produce = \(66 \times 40.15\) m³ biogas = 2649 m³ biogas.

**Slaughterhouse waste:**

1 ton of blood produce approximately 52 m³ biogas. In Hazaribagh, blood amount is 123.73 ton/month. 
Yearly biogas production from blood = \((123.73 \times 52 \times 12)\) m³ biogas = 77207.52 m³ biogas

1 ton of entrails produce approximately 58 m³ biogas. In Hazaribagh, entrail amount is 2.7 ton/month. 
Yearly biogas production from entrails = \((2.7 \times 58 \times 12)\) m³ biogas = 1879.2 m³ biogas

Total biogas production = \((77207.52 + 1879.2)\) m³ biogas = 79086 m³ biogas

**Tannery waste:**

1 ton tannery waste produce approximately 50 m³ biogas. 
62500 ton of tannery waste produce = \((62500 \times 50)\) m³ biogas = 3125000 m³ biogas.

**Poultry house waste:**

1 ton poultry house waste produce approximately 65 m³ biogas. 
55 ton of poultry house waste produce = \((55 \times 65)\) m³ biogas = 3575 m³ biogas.

**Straw:**

1 ton poultry house waste produce approximately 140 m³ biogas. 
0.05 ton of straw produce = \((0.5 \times 78)\) m³ biogas = 7 m³ biogas.
Electricity generation calculations

1 m³ biogas corresponds 6 kWh.

**Domestic waste:**

442 m³ biogas corresponds to (6×442) kWh = 2652 kWh

**Market waste:**

2649 m³ biogas corresponds to (6×2649) kWh = 15894 kWh

**Slaughterhouse waste:**

79086 m³ biogas corresponds to (6×79086) kWh = 474516 kWh

**Tannery waste:**

3125000 m³ biogas corresponds to (6×3125000) kWh = 18750000 kWh.

**Poultry house waste:**

3575 m³ biogas corresponds to (6×4290) kWh = 21450 kWh.

**Straw:**

7 m³ biogas corresponds to (6×7) kWh = 42 kWh.