LIFE CYCLE ASSESSMENT OF DOMESTIC BIOGAS SYSTEMS

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Degree of Master of Science in Sustainable Process Development

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Thesis submitted in partial fulfilment of the requirements for the degree Master of Science in Sustainable Process Development

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Abstract

Different sizes of biogas systems were analysed using Life Cycle Assessment (LCA) in order to find the effectiveness of biogas system as a renewable energy source for domestic use. As a pre requisite for the LCA, sample survey was carried out in order to find out the existing situation of biogas units installed in Sri Lanka. This survey covered a total of 167 biogas units in the country. According to the survey 143 (86%) are domestic units with a capacity less or equal than 20 m^3 while 27 (16%) of the above sample was not functioning at the time of this survey. A detailed LCA was carried out in two different phases in order to determine the environmental impacts in life cycle of Chinese fixed dome type biogas systems and to calculate the Energy Pay-Back Time (EPBT). In Life Cycle Energy Assessment, Embedded Energy Values (EEV) have been evaluated from the quantity of building materials used in construction of different sizes of biogas plants and the energy payback period have been evaluated for individual biogas plants using EEV and biogas energy production. Similar to the energy calculation, CO_2 emissions from each capacity of biogas units were also calculated. Although there are negative impacts from CO_2 emissions in the construction stage, there is a reduction of CO_2 emissions in the biogas consumption stage due to the replacement of fossil fuels with biogas. While the LPG / kerosene replacement reduces the CO_2 emissions, firewood replacement reduces the amount of particulate matters emitted to the environment. So this will contribute towards a reduction in climate change impact, giving the plant an overall positive impact on climate change.

Although EEV and CO_2 emission per 1 m^3 capacity of the biogas plant reduces with the increase of the size of the plant, there is no linear relationship between them. Therefore an equation was derived to calculate the EPBT ($y = 0.0006x^2 - 0.008x + 0.590$, where x is the capacity of the biogas plant).So it is obvious that construction of higher capacity plant is more energy efficient than a smaller capacity one and also the environmental effects can be minimized. However due to different reasons always the optimum solution is not the construction of a larger unit. So initially the situation should be carefully studied and then only one should construct the largest unit feasible for that application.

Keywords: Life Cycle Assessment (LCA), Embedded Energy Value (EEV), Energy Pay-Back Time (EPBT), CO_2 emissions, Biogas

Dedication

This thesis is dedicated to my beloved **PARENTS** and **HUSBAND**

Acknowledgement

Firstly I would like to express sincere appreciation to my supervisor Prof. Ajith De Alwis, Professor, Department of Chemical & Process Engineering, University of Moratuwa for all the supervision, guidance and support that he has given me throughout my research. I sincerely thank him for his patience, warm consideration and valuable time spent for assisting me.

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List of Abbreviations

Abbreviation	**Description**
ABR	Anaerobic baffled reactors
ADB	Asian Development Bank
AF	Anaerobic filters
ARTI	Appropriate Rural Technology Institute
BOQ	Bill of Quantities
BORDA	Bremen. Overseas Research and Development Agency
CAMARTEC	Centre for Agriculture Mechanization and Rural Technology
CDM	Clean Development Mechanism
EEV	Embedded Energy Value
EPBT	Energy Pay-Back Time
GHG	Green House Gas
HRT	Hydraulic retention time
ICE	Inventory of Carbon Energy
ISO	International Standard Organization
ITDG	Intermediate Technology Development Group
KVIC	Khadi and Village Industries Commission
LCA	Life Cycle Assessment
LCEA	Life Cycle Energy Assessment
LCI	Life Cycle Inventory
LPG	Liquefied Petroleum Gas
LPG	Liquid petroleum Gas
MSW	Municipal Solid Waste
NCRE	Non-Conventional Renewable Energy
NERDC	National Engineering Research and Development Centre
NGO	Non-Governmental Organization
SLSEA	Sri Lanka Sustainable Energy Authority
SLSI	Sri Lanka Standard Institution
SRT	Sludge Retention Time
UASB	Upflow Anaerobic Sludge Blanket
UNEP	United Nations Environment Programme

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1. INTRODUCTION

1.1. Background

One of the major factors for the current economic hardship is the growing energy crisis in Sri Lanka. There is a renewed interest from the present government and private sector organizations to explore the potential of renewable energy sources for domestic and industrial consumption. The Ministry of Power and Energy has formulated the National Energy Policies and Strategies of Sri Lanka (2008) which envisages the gradual increase of non-conventional renewable energy (NCRE) resources. According to the Long Term Generation Expansion Plan (2015) of Ceylon Electricity Board NCRE energy share in generating electricity will reaches 20% in 2020 (CEB, 2015). The Government has also recognised the need to elevate bio fuels as an important constituent of the transport energy to achieve this target. Biogas was one such renewable energy technology that is being promoted by many key national institutions since 70s. Biogas systems have been promoted for their capability to provide lighting and as a cooking gas, and then as a way to produce bio-fertilizer from solid waste streams for agricultural needs. The process of installing biogas systems has still moved ahead and currently Asian Development Bank (ADB) is executing a major installation drive of small biogas systems in Asia. Under this program one million domestic biogas plants in about 15 Asian countries will be constructed by 2016, providing access to clean energy and organic fertilizer to about 5 million people (Energy for all, ADB).

Biogas systems can serve Sri Lanka in many ways, as this technology provides triple benefits namely sustainable environmental protection, energy generation and agricultural & farming support. Energy derived from anaerobic digestion is an alternative to fossil fuels and it reduces greenhouse gas emissions which will lead to global warming. However, like any other kind of energy generation, the biogas process has an effect on the environment. Although the biogas is considered as a renewable energy source the construction of the plant is through the use of non-renewables. In order to permit further development of energy technologies, it is important to be aware of the quality and quantity of effects caused. Effects on the environment can be measured by various methods. The most developed method for this purpose is the Life Cycle Assessment (LCA). This includes the collection and transportation of waste, construction of reactors, upgrading of the biogas produced and the end of life of the system.

1.2. Objectives of the research

The main objectives of the research are,

- To identify the environmental impacts of biogas systems
- To calculate the Embedded Energy Values (EEV) and Energy Pay-Back Time (EPBT) of biogas systems (small scale)
- To calculate CO_2 emissions in construction phase of biogas systems

1.3 Outline of the thesis

This thesis consists of five chapters. In the first chapter, research objectives are mentioned and justified with the introduction to the research area. A literature review on biogas systems in Sri Lanka, Life Cycle Assessment and standard methodology has been presented in the second chapter. In the third chapter, details of the biogas survey carried out and Life Cycle Assessment methodology followed to fulfil the research objectives are described. The results obtained during the present study are presented and discussed in the fourth chapter. The fifth chapter contains the conclusion of the study.

2. LITERATURE REVIEW

2.1 Biogas

2.1.1 What is biogas?

Biogas is a gas generated from the anaerobic digestion of organic waste. It consists of CH_4 (50-70%), CO_2 (30-50%) with the remaining gases being: H_2S and water vapour. The characteristic properties of biogas are depended on pressure, temperature and moisture content. The general anaerobic transformation of organic waste can be described by means of the equation 1.1.

$$\boldsymbol{organic\ matter} + \mathbf{H_2O} + \boldsymbol{nutrients} \rightarrow \boldsymbol{new\ cells} + \mathbf{CO_2} + \mathbf{CH_4} + \mathbf{NH_3} + \mathbf{H_2S} + \boldsymbol{heat} \quad \text{Equation 1.1}$$

Main raw materials used for biogas generation are household waste and agricultural waste like cow dung, paddy straw. Although some household biogas units use sewage as a raw material, most of the people in Sri Lanka are reluctant to use it due to the poor understanding of the process.

2.1.2 Benefits of biogas

Biogas systems can serve Sri Lanka in many ways, as this technology provides triple benefits namely energy generation, sustainable environmental protection and agricultural & farming support. Traditionally in early days the biogas technology was looked at only as a source of energy for the rural population mainly for lighting and cooking. However with the development of technology, biogas can be used for electricity generation and powering farm equipment using micro turbines or reciprocating gas engines. Biogas can also be used as a fuel for vehicles after been compressed. It is considered as a renewable energy source because it is produced from sewage and waste products, the only time it will be depleted is when we stop producing any waste. Another major advantage for the environment is the mitigation of deforestation and soil erosion through the substitution of firewood as an energy source.

A study done by Munasinghe (2000) for Practical Action South Asia showed that 75% of the energy requirements for cooking in the households which have biogas unit are supplied by their household biogas units. Therefore women and girl children in average save 2-2½ hours per day when cooking with gas. Most of these females (79%) use this time for some income earning activities in which they earn the equivalent of 24% of their monthly income.

In addition to the energy generation biogas system can be considered as a sustainable waste management tool especially for the organic portion of the waste. By producing biogas using the waste in dump sites across the country, soil and water pollution can be decreased. At the same time air pollution is also minimized which is a huge problem for the people living around the waste dump sites.

The slurry produced as a by-product of the biogas generation is a nutritious fertilizer which contains high amount of N, P & K. As revealed by the experiments, 10 tons of digested straw can replace the entire fertilizer demand of one hectare of paddy field. (Munasinghe, 2000)

2.1.3. Classification of biogas units

Biogas plants can be classified in several ways depending upon the plant design and mode of working.

eg: classified according to whether they are:

- Mesophilic (25-45 °C) or thermophilic (50-60°C)
- Wet (5-15% dry matter in the digester) or dry (over 15% dry matter in the digester)
- Continuous, semi continuous or batch
- Single, double or multiple digesters
- Vertical tank or horizontal plug flow
- High rate & low rate

Biogas systems can be divided into “high-rate” systems, involving biomass retention and “low-rate” systems without biomass retention. High rate systems also incorporate internal mixing.

High-rate systems are characterised by a relatively short hydraulic retention time (HRT), but long sludge retention time (SRT). eg: biogas settlers, anaerobic baffled reactors (ABRs), anaerobic filters (AFs) and up flow anaerobic sludge blanket (UASB) reactors, etc.

Low-rate systems are characterised by a relatively long HRT, which is equal to the SRT as the sludge and liquid enter and leave the tank in more or less as homogeneously mixed slurry. eg: batch reactors, fed-batch reactors (accumulation systems), plug-flow reactors (PFR) or continuously stirred tank reactors (CSTR), etc. Figure 2.1 shows a general classification of Low-rate biogas units.

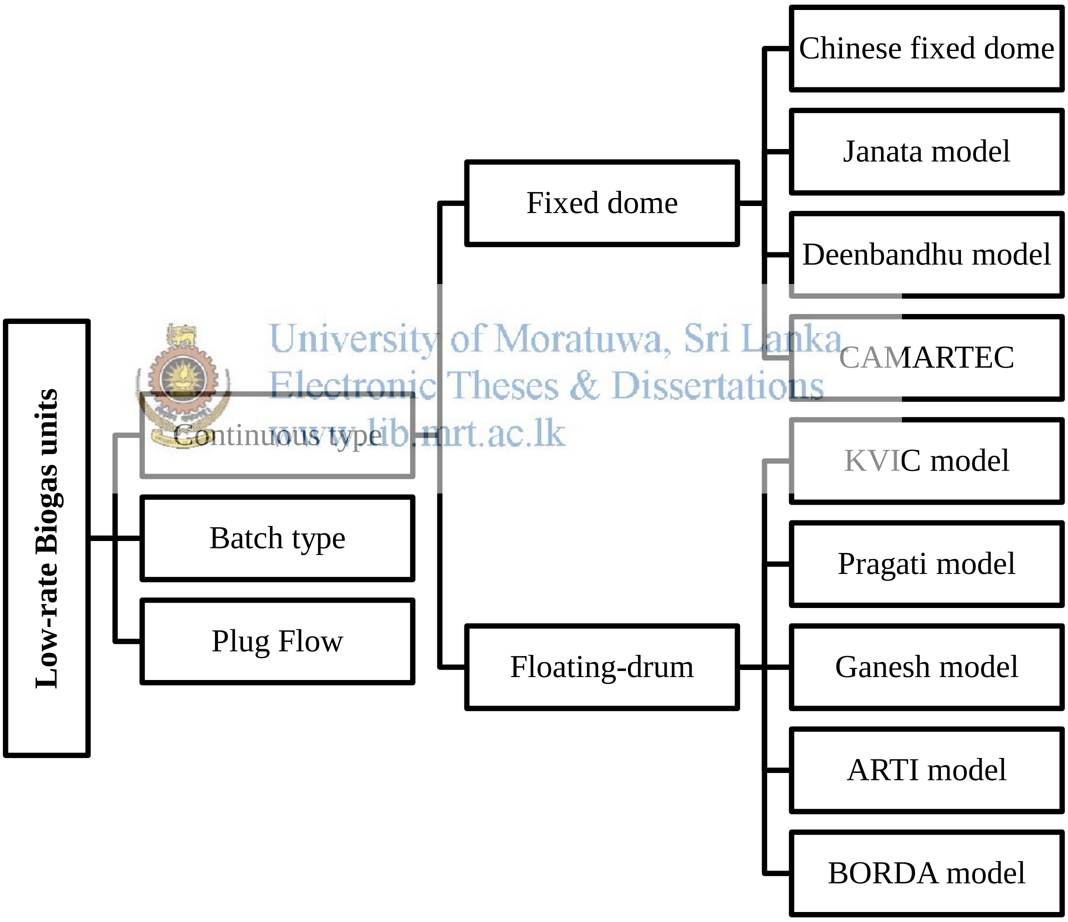

Figure 2-1: General classification of biogas units (Types of Biogas Digesters and Plants, 2014)

Biogas plants can be also classified according to the size of the digester i.e. Domestic biogas plants (4-20 m^3 capacity), industrial (20-50 m^3) and centralized/community units (above 50 m^3).

Continuous type plants

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. The most widespread designs of continuous type digesters are the fixed dome digester and the floating cover biogas digester (shown in figures 2.2 & 2.3). The digestion process is the same in each digester but the gas collection method is different. In the floating cover type, the water sealed cover of the digester is capable of rising as gas is produced, where it acts as a storage chamber, whereas the fixed dome type has a lower gas storage capacity and requires good sealing if gas leakage is to be prevented.

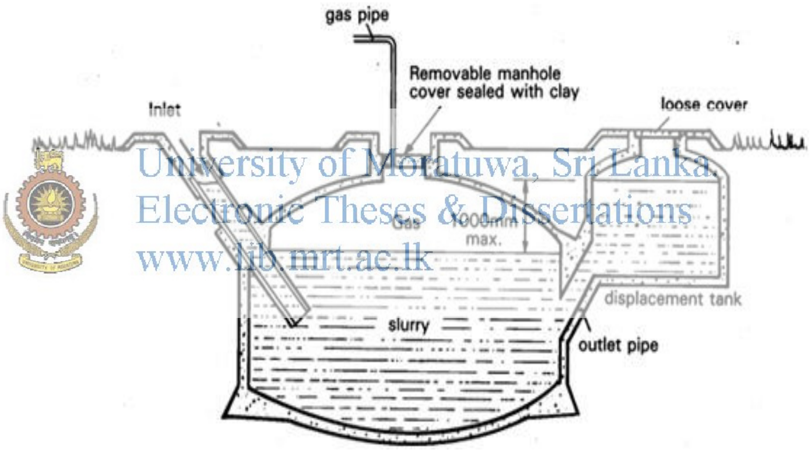

Figure 2-2**:** Fixed-dome Biogas Plant (Ewings, 2014)

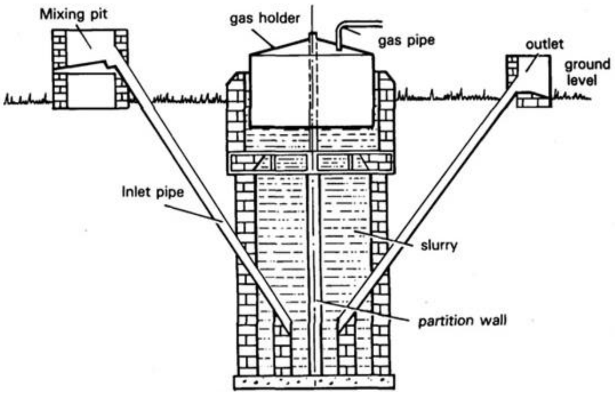

Figure 2-3 : Floating-drum Biogas Plant (Ewings, 2014)

Fixed-dome Biogas Plants

- A fixed-dome biogas plant consists of an enclosed digester with a fixed, non-movable gas space. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Minimum size of a fixed-dome plant is 5 m^3 while there are digesters with volumes up to 200 m^3. There are different types of fixed dome biogas plants as follows. (Types of Biogas Digesters and Plants, 2014)
- **Chinese fixed dome**: This is the original biogas unit.
- **Janata model**: An Indian-built fixed-dome digester
- **Deenbandhu model**: Successor to the Janata model, simplifies the silo-shape of the Chinese fixed dome fermentation chamber/gas collector down to a hemispherical dome.
- **CAMARTEC**: Simplest design of the fixed-dome digesters. Floating-drum Biogas Plants

Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored.

They are used most frequently by small to middle sized farms (digester size: 5-15m^3) or in institutions and larger agro-industrial estates (digester size: 20-100m^3).

- KVIC model.
- Pragati model
- Ganesh model
- floating-drum plant made of pre-fabricated reinforced concrete compound units
- floating-drum plant made of fibre-glass reinforced polyester
- low cost floating-drum plants made of plastic water containers or fiber glass drums: ARTI Biogas plants
- BORDA model

Batch plants

Batch plants are filled and then emptied completely after a fixed retention time. Batch type biogas plants introduced by the National Engineering Research and Development (NERD) centre are being used for bio-gasification of rice straw for household energy needs in rural areas in Sri Lanka. NERDC has won the Silver Award in 1996 at the International Inventors Competition in Switzerland, as one of the environmentally friendly system of Biogas generation, and patented this biogas system. Batch type biogas plant constructed in University of Moratuwa is shown in the figure 2.4

Figure 2-4: Batch type biogas plant (Alwis, 2012)

Sri Lankan Batch type biogas plants

The popularization of this technology among people was very slow in the initial stages due to the construction cost. In 2002 biogas plant was constructed in Muthurajawela for disposing 40 tons of market garbage per week.

Though it was designed to treat vegetable waste it was fed with mixed Municipal Solid Waste (MSW) because there was no supply of the expected amount of vegetable waste. Therefore the expected outcome couldn’t be achieved. However this system can be used to treat cow dung & paddy straw in the agriculture sector.

Plug Flow Type Plants

A plug flow digester is a long narrow (typically a 5:1 ratio; 5 times as long as the width) tank made of reinforced concrete, steel or fiber glass with a gas tight cover to capture the biogas. Figure 2.5 shows a schematic diagram of the plug flow type biogas plant constructed by SLSEA at Narahenpita jathika pola.

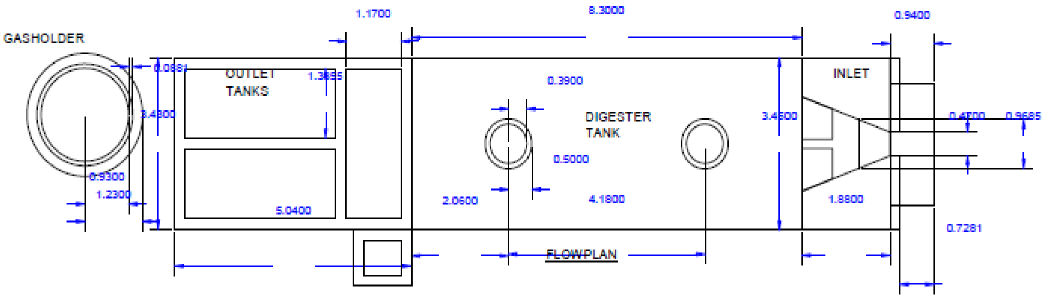

Figure 2-5: Plug Flow Type Plant (Dilhani, 2013)

Taiwan bag digester

In this design, two large plastic bags are used to contain the digestible material and for gas storage as shown in the figure 2.6. It is not built under ground, but just laid on the top of the soil. This means that the temperature varies quite a lot, as the bag gets heated by the sun during the day, and then cools down in the night. It is a very cheap biogas plant since the plastic material often is an industrial waste material; this also limits its use to places, where such waste material is available.

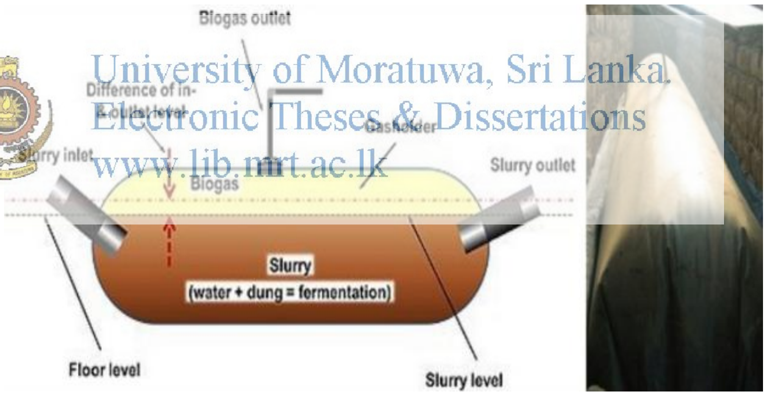

Figure 2-6: Taiwan bag digester (khavi, 2016)

Other technologies

At present biogas units constructed from plastics are been used in Sri Lanka and prefabricated units are available in the sizes of 0.5 m^3, 1 m^3& 5 m^3. Household waste like vegetable residues, waste food, fruit peelings, rotten fruit, etc. can be used as the raw material to this unit and there is an opening to put waste manually to the unit. Such prefabricated biogas unit available in Sri Lanka is shown in figure 2.7

Figure 2-7: Prefabricated biogas unit (Arpico green gas unit, 2013)

Community versus family size plants

Biogas plants can be constructed either as individual family units or as community plants. Individual plants are appropriate for families, whereas the community plants are set up to meet fuel and fertilizer needs of groups, institutions and village. Community plants are suitable where individuals do not have adequate raw materials and finance to set up family units. Many energy planners argue that individual plants should be constructed only when setting up a community plant is infeasible.

2.2 Standards available in Sri Lanka for Biogas units

“Sri Lanka standard code of practise for design and construction of standalone domestic biogas systems” was approved by the technical advisory committee on biogas standard appointed by Sri Lanka Standard Institution (SLSI) in collaboration with Practical Action (formerly ITDG) and was authorized for adoption and publication as a Sri Lanka standard by the Council of the SLSI on 24.08.2006. This code of practice is aimed at standardization of stand-alone domestic biogas systems for Sri Lanka in order to suit the needs of biogas generation, manure production, hygiene effects, operational and maintenance aspects. This code prescribes up to 2 metric tons dry batch digester and 6-12 m^3 continuous flow biogas digesters. This would act as a guide for any person to access to necessary information and setup biogas systems while getting the confidence among the communities and decision makers. (SLSI, 2006)

2.3 Stake holders of biogas in Sri Lanka

Many governmental institutes, private organizations and non-governmental organizations are involved in promoting biogas in Sri Lanka. Following are the major stakeholders of biogas.

National Engineering Research and Development Centre (NERDC)

National Engineering Research and Development Centre (NERDC) is a research organisation which developed the dry batch biogas unit. NERDC is not only involved in dry batch system but also conducting research on other types including the plug flow anaerobic digesters.

Department of Animal Production and Health (Dept. AP&H)

This department is actively involved in biogas because farmers with cattle shed can construct biogas unit as a solution to waste problem as well as to provide clean energy for cooking. Therefore livestock development officers were trained on construction and maintenance of biogas units.

Sri Lanka Sustainable Energy Authority (SLSEA)

Sri Lanka Sustainable Energy Authority was established in 1997 with the objectives of ensuring energy security, increasing indigenous energy and improving energy efficiency. According to those objectives biogas is promoted by SLSEA, as a method of renewable energy generation. In 2009 a demonstration biogas plant was constructed at ‘Jathikapola’, Narahenpita as a solution for the market garbage problem.In addition to that SLSEA has started a national biogas programme in 2014 with the objectives of Developing utilization of biogas systems in Sri Lanka, Establishing a soft loan facility and Identification, development & implementation of Economic model.

Lanka Biogas Association

The Lanka Biogas Association was launched in 2008 with the vision of positioning biogas in the centre of energy, environment and agro systems in Sri Lanka. Main objective of formulating this was to promote the use of biogas in Sri Lanka to realize its triple benefits in energy, agriculture and environmental management.

Delivery mechanisms are established a Secretariat for the promotion of the objects of the Association and the conduct of its business and activities, promote and foster a high code of professional conduct amongst all persons engaged in the promotion of use of biogas, establish and promote representational links with Regional and International bodies promoting use of biogas, undertake activities that will provide fellowship and a sense of identity and community among the members of the association. (Lanka Biogas Association, 2008)

Energy Forum

The Energy Forum of Sri Lanka is a non-profit organization working to create an environment that enables the promotion and adoption of renewable and distributed energy, energy efficiency and integrated sustainable resource management mechanisms to alleviate poverty, to address energy capacity deficiencies and to protect the environment. One of the main concerns of them is introduction and implementation of sustainable waste management practices by means of producing biogas.

Other institutes

Engineering & agricultural faculties of universities are involved in researches on biogas and Non-Governmental Organizations like Practical Action are actively involved in promoting biogas in Sri Lanka.

2.4 Current situation in Sri Lanka

Although the biogas systems were introduced to Sri Lanka in 1970s it was mainly on research basis. In the initial stage only state sector institutions and schools implemented biogas units within their premises. Several government and non-governmental institutions in Sri Lanka have started to promote biogas as a fuel and have set up an extension programme for biogas technology. United Nations Environment Programme (UNEP)'s Sri Lanka Renewable Energy demonstration Project was constructed and operated at Pattiyapola in Hambanthota district until 1988. The 1989 disturbances in the country led to the termination of this project completely and now it has been sold for scrap. There were two other community projects at Jayanthipura in Polonnaruwa district and at Suriyawewa in Hamabanthota district. Due to the lack of a policy framework and poor community participation all of them ended up as failures. (de Alwis, 2002)

A detail study on biogas was conducted by S Wijesinghe & JA Chandrasiri (1986). They have inspected 303 biogas plants, representing a majority of the units installed in Sri Lanka up to 1984. According to the findings of this study 280 of these had been put into commission at some time prior to the study. Of the 280 commissioned plants, 170 (61%) was functioning satisfactorily providing biogas for cooking and/ or lighting. The remaining 110 (39%) were either not functioning or were supplying very little gas owing to gas leaks, inadequate input of dung, or poor plant management. The most common plant was the $6m^{3,}$ fixed dome, household plant, and the most common raw material used was cattle dung. And also the majority of household plants the cost of construction was partly or wholly subsidized. Excluding the plants that had not commenced operation up to the time of the inspection, there was a total of 280 units, and of these, 200 were actually functioning. 27 were not functioning for a period of up to 6 months and 53 for over 6 months.

The vast majority of the plants were of fixed dome type - 266 (88%) of the total 303 units inspected. The other 37 were of the floating gas holder type.

Table 2-1: Numbers of functioning and non-functioning biogas plants in households and institutions (LCA de S Wijesinghe, JA Chandrasiri, 1986)

	Functioning	**Not functioning for 6 months or less**	**Not functioning for more than 6 months**
No. of household plants	159	26	25
No. of institution plants	41	1	28
Total	**200**	**27**	**53**

In 1996, a propagation of biogas technology programme among the communities and provinces was led by the Intermediate Technology Development Group (ITDG). This has been implemented by Energy Forum by networking the professionals from the government (Department of agriculture, Provincial Councils, etc.), private sector institutions, development organization and academic institutions (University of Ruhuna, University of Moratuwa, etc.). The project has started its activities with the national survey of existing biogas systems in Sri Lanka in 1996. Summary of data obtained from this study are given in table 2.2

Table 2-2: Summary of the survey in 1996 (de Alwis, 2002)

Total units surveyed	369
Under construction	4
Completed systems surveyed	365
Functioning units	104
Functioning rate	28.5%
Abandoned systems after successful use	16
Success rate	32.9%

Further they have studied about the time savings the men and women get from biogas units. “Women saved their cooking time by 96 minutes/day, which is 31% less than an average household. The time spent on fuel wood collection reduced due to use of biogas units by 2-3 days per month and there was a reduction of 56% of time on cleaning of utensils (33 minutes a day). Where the men were concerned, they too demonstrated a reduction of 1-2 days of fuel wood collection per month while the children too showed the same result on fuel wood collection”. (ITDG, Biogas technology, 2006)

The major project activities at initial stage of the project (1997-2000) were the establishment of biogas units for demonstration purposes in various training institutions, establishment of new private biogas units, capacity building of users and constructors (masons) of biogas nits and dissemination of information using various methods to the public. After year 2000, the project concentrated more on wider dissemination while continuing the construction and rehabilitation of biogas units. From 2003 onwards project has focused more on capacity building. The total household level beneficiaries were around 300 and 180 from newly constructed units and rehabilitation units respectively. In addition to this 40 number of demonstration units were also constructed under this project. Summary of the units constructed and rehabilitated is given in the table 2.3

Table 2-3: No. of biogas units implemented by ITDG (ISB, 2006)

Year	**Rehabilitated units**	**New units**	**Demonstration units**	**Total**
1996-1998	150	50	30	230
1999	26	42	4	72
2000	4	82	5	91
2001	-	128	1	129
Total	**180**	**302**	**40**	**522**

Industrial Service Bureau (ISB) has done a study to evaluate the contribution of ITDG to the mitigation of climate change through the implementation of biogas units carried out during the period from 1996 to 2002. They have identified that there are mainly two usage of biogas as energy source for households, i.e. cooking and lighting purpose. When biogas substitutes conventional domestic fuels that are not carbon neutral, it will contribute to reduce Green House Gas (GHG) emissions. According to the study 482 household units and 40 institutional units contributed to reduce 2,445 ton of CO_2 per year and CDM (Clean Development Mechanism) potential was 2.4 million rupees per year.

Janathakshan; an Non-Governmental Organization (NGO) have started a project on “Up-scaling biogas technology for sustainable development and mitigating climate change in Sri Lanka” in 2014 with collaboration of Sri Lanka Sustainable Energy authority which is funded by SWITCHAsia program of European Union. Ultimate goal of this project is to reduce over 5700 tons of CO_2 equivalent emissions with the installation of biogas units. (Janathakashan, 2015)

2.5 Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle (from cradle to grave). “Life cycle” is all consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. The procedures of LCA are part of the ISO 14000 environmental management standards: ISO 14040:2006 and 14044:2006.

The LCA process consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation as illustrated in Figure 2.8.

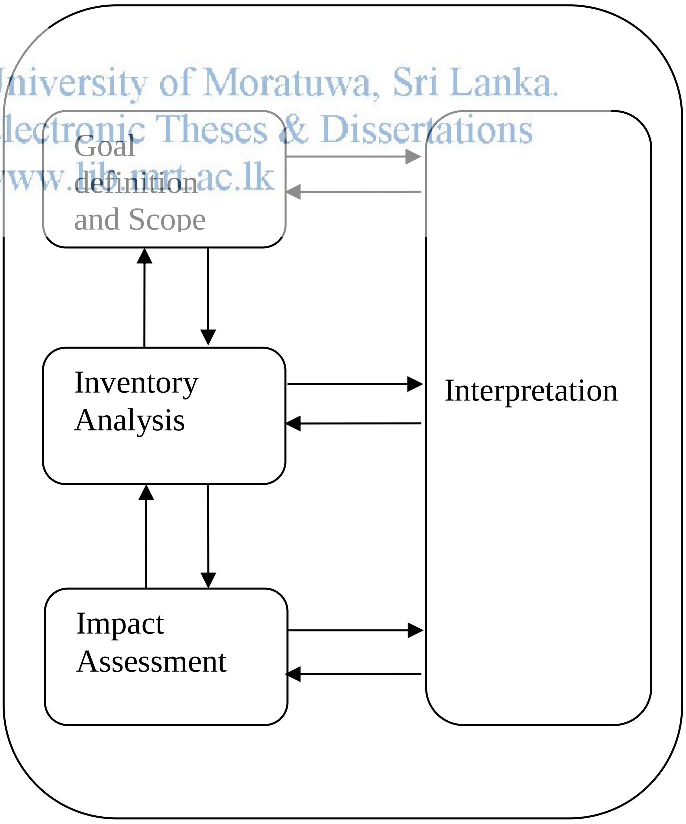

Figure 2-8: LCA process

A. Goal Definition and Scoping - Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.
B. Inventory Analysis - Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, wastewater discharges).
C. Impact Assessment - Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
D. Interpretation - Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

2.5.1 Goal & Scope definition

Goal definition and scoping is the first phase of the LCA process that defines the purpose and method of including life cycle environmental impacts into the decision-making process. In this phase, the following items must be determined: the type of information that is needed to add value to the decision-making process, how accurate the results must be to add value, and how the results should be interpreted and displayed in order to be meaningful and usable.

2.5.2 Inventory Analysis

A life cycle inventory is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity. It consists of detailed tracking of all the flows in and out of the product system, including raw resources or materials, energy by type, water, and emissions to air, water and land by specific substance.

Following steps are used in life cycle inventory analysis

a) Develop a flow diagram of the processes being evaluated.
b) Develop a data collection plan.

c) Collect data.
d) Evaluate and report results.

Every inventory consists of a mix of factual data and assumptions. Assumptions allow the analyst to evaluate a system condition when factual data either cannot be obtained within the context of the study or do not exist. Inputs in the Product Life-Cycle Inventory Analysis are raw material, energy and water. Three categories of environmental releases or emissions: atmospheric emissions, waterborne waste, and solid waste are considered as the outputs of a Life-Cycle Inventory Analysis.

2.5.3 Life Cycle Impact Assessment

Next step of LCA is the Life Cycle Impact Assessment and followings are the key steps.

i. Selection and Definition of Impact Categories - identifying relevant environmental impact categories (e.g., global warming, acidification, terrestrial toxicity).
ii. Classification - assigning Life cycle Inventory (LCI) results to the impact categories (e.g., classifying carbon dioxide emissions to global warming).
iii. Characterization - modelling LCI impacts within impact categories using science-based conversion factors (e.g., modelling the potential impact of carbon dioxide and methane on global warming).
iv. Normalization - expressing potential impacts in ways that can be compared (e.g. comparing the global warming impact of carbon dioxide and methane for the two options).
v. Grouping - sorting or ranking the indicators (e.g. sorting the indicators by location: local, regional and global).
vi. Weighting - emphasizing the most important potential impacts.
vii. Evaluating and Reporting Life cycle Inventory Assessment (LCIA) Results - gaining a better understanding of the reliability of the LCIA results.

According to the ISO 14042, Life Cycle Impact Assessment (ISO 1998), first three steps: impact category selection, classification and characterization are mandatory steps for an LCIA.

For each LCA a special set of impact categories can be defined, representing the system under investigation and its threats to the environment. The following categories are regularly used:

- mineral resources
- fossil resources
- land use
- water use
- waste
- human-/eco-toxicity
- acidification
- greenhouse effect
- ozone depletion
- eutrophication
- photochemical oxidants
- noise and odour
- waste heat
- ionising radiation
- biodiversity
- soil function

2.5.4 Interpretation

Final step of LCA is the interpretation of the LCA impacts. ISO has defined the following two objectives of life cycle interpretation:

A. Analyse results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner.

B. Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study.

Within the ISO standard, the following steps to conducting a life cycle interpretation are identified and discussed:

a. Identification of the Significant Issues Based on the LCI and LCIA.

b. Evaluation which Considers Completeness, Sensitivity and Consistency Checks.

c. Conclusions, Recommendations and reporting.

2.6 Standards and guidelines associated with LCA

Standards and guidelines associated with LCA are as follows.

- ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework
- ISO 14044:2006 - Environmental management - Life cycle assessment - Requirements and guidelines
- ISO 14021:1999 - Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling)
- ISO 14024:1999 - Environmental labels and declarations - Type I environmental labelling - Principles and procedures
- ISO 14025:2006 - Environmental labels and declarations - Type III environmental declarations - Principles and procedures
- ISO 14067:2013 - Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication
- ISO 14064:2006 - Greenhouse Gases – Part 1,2 and 3
- GHG protocol product standard: Product life cycle Accounting and reporting Standard
- ILCD: International Reference Life Cycle Data System
- PAS 2050: UK's Product Carbon Footprint Standard

More specific detail concerning the application of LCA to building products is in ISO 21930:2007 Sustainability in building construction – Environmental declaration of building products. A recent European standard published in 2012, EN 15804, is also attracting interest both from within and outside Europe as a basis for applying LCA to construction products. (level, The Authority on Sustainable Building, New Zealand, 2014)

Others standards which are specifically developed for construction are as follows:

- ISO 15392:2008 - Sustainability in building construction – General Principles
- ISO 21929-1:2011 - Sustainability indicators – Part 1: Framework for development of indicators for buildings

- ISO 21931-1:2010 - Framework for methods of assessment of environmental performance of construction works – Part 1: Buildings

ISO 14040 and ISO 14044

“ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements. ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.” (ISO 14040:2006)

“ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.” (ISO 14044:2006)

2.7 Life Cycle Energy Assessment (LCEA)

Life Cycle Energy Assessment (LCEA) is an approach in which all energy inputs to a product are accounted for: not only direct energy inputs during manufacture, but also all energy inputs required to produce components, materials and services needed for the manufacturing process.

Three categories of energy are quantifiable: process, transportation, and energy of material resources (inherent energy). Process energy is the energy required to operate and run the subsystem process (es). Transportation energy is the energy required to power various modes of transportation.

2.8 Benefits of Conducting an LCA

An LCA can help decision-makers select the product or process that result in the least impact to the environment. This information can be used with other factors, such as cost and performance data to select a product or process.

Direct applications of LCA are product development and improvement, strategic planning, public policy making, and marketing. Further applications include environmental management systems and environmental performance evaluation (ISO 14001, ISO 14004 and ISO 14031) environmental labels and declarations, environmental communication etc.

2.9 LCA tools

Followings are some of the tools available for LCA

- Sima pro - developed by PRé Consultants
    - (http://www.pre-sustainability.com/simapro)
- open LCA
    - (http://www.openlca.org/)
- umberto
    - (http://www.umberto.de/en/versions/umberto-nxt-lca/)
- Environmental Choice New Zealand
    - (http://www.environmentalchoice.org.nz/)
- Eco-hierarchy Tool
    - (http://www.level.org.nz/material-use/life-cycle-assessment/eco-hierarchy-tool/)
- Ecospecifier (Australia)
    - (http://www.ecospecifier.com.au/)
- Greenspec (United Kingdom)
    - (http://www.greenspec.co.uk/)
- Gabi - developed by PE International
    - (http://www.gabi-software.com/international/index/)

2.10 LCA Inventories

- **Ecoinvent** (http://www.ecoinvent.org/database/)

  The ecoinvent Centre hosts the world’s leading database of consistent, transparent, and up-to-date Life Cycle Inventory (LCI) data. With several thousands of LCI datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction and packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment, they offer one of the most comprehensive international LCI databases.

- **Inventory of Carbon and Energy (ICE)** (http://www.bath.ac.uk/mech-eng/research/sert/)

  Developed by the University of Bath, the ICE (Jones, 2011) is a database of embodied carbon and energy values for common construction materials. As such it has been widely used in many assessment tools developed by others and in many construction embodied carbon studies.

  It is important to note that the ICE is not the product of a rigorous LCA study but rather a review of published information from other sources. As such, the values in the database are variable in terms of quality and consequently data from the ICE should be used with care in comparative embodied carbon studies. The scope of ICE is ‘cradle-to-gate’ only

- **PE International** (http://www.pe-international.com/international/index/)

  PE International has recently worked with the UK timber industry to produce LCA datasheets (Wood for good) providing cradle to gate, distribution and end of life data for the different disposal routes used by timber products used in the UK, and with the steel industry to provide end of life datasets for structural materials used in the UK (SteelConstruction.info). Gabi software offered by PE international is a leading software for LCA.

- **Green Design Guidelines** (http://srilankagbc.org/)

  "Green Design Guidelines" published by Sri Lanka Green Building Council has embedded energy values of common construction materials for Sri Lankan scenario. But it doesn't contain emission factors of them.

  Other countries, such as the Netherlands and Germany, have published national databases of LCA data for construction products and included mandatory building level LCA within their Building Regulations. Centre for Building Performance Research in New Zealand has published embodied energy and CO_2 coefficients for NZ building materials (Alcorn, 2003)

2.11 Embedded energy

The embedded energy of a building material comprises all the energy consumed in acquiring and transforming the raw materials into finished products and transporting them to the place of building site. On the basis of energy intensity, the gross energy requirement to manufacture unit weight, building materials can be divided into very high, high, medium and low energy intensive as described below.

- Very high energy intensity - Aluminum, plastics, copper, stainless steel
- High energy intensity - steel, glass, cement, plasterboard
- Medium energy intensity - clay bricks and tiles, concrete, timber
- Low energy intensity - sand, aggregate, fly ash

2.12 LCA already conducted on biogas

Arif, Usmani & Chandra (2006) have carried out a detailed life cycle analysis to meet energy demand of Khadi and Village Industries Commission (KVIC) biogas plants model for 40 days retention period. Embodied Energy Value (EEV) from building materials has been evaluated to predict Energy Pay Back Time (EPBT) for different capacities biogas plants viz. 2 m^3, 3 m^3, 4 m^3, 6 m^3, 8 m^3 and 10 m^3.

Table 2-4: Embodied Energy Value, Net Energy Output and Energy Pay Back Time (EPBT) for various biogas plants (Arif, Usmani, & Chandra, 2006)

Cubic Capacity of Biogas Plants (m^3)	**EEV(MJ)**	**Net Energy Output (MJ/day)**	**EPBT(Years)**
2	17337.1	375.6	0.13
3	20619.9	563.4	0.10
4	23747.0	751.2	0.09
6	28169.6	1126.8	0.07
8	33234.1	1502.4	0.06
10	35343.9	1878.0	0.05

Using regression technique, a model equation was developed to predict EPBT as follows with $R^2 = 0.98$

$$EPBT = 0.0013(X^{3})^{2} - 0.0237(X)^{3} + 0.1642$$

Where, X is the cubic capacity of biogas plant.

Hartmann (2006) and Stenull (2010) have carried out LCA with the objective of determining the ecological effects of electricity generation via biogas in industrial scale biogas plants.

"According to the LCA it can be assumed that electricity generated from biogas causes comparable ecological effects as the state of the art electric energy mixture in Germany. The standard scenario causes 28.2% more ecological effects; the utilisation of a fuel cell would reduce to overall effects to 64.2% of the average ecological effects from the state of the art electricity mixture from the grid." (Hartmann, 2006)

Anker & Wenzel (2007) have done a research with the aim of making an environmental LCA of Xergi's (in Aalborg, Denmark) biogas production based on maize silage and animal manure showing both environmental impacts and impacts on resource consumption. The study is conducted according to the principles of consequential LCA in order to identify the environmental consequence of choosing one alternative over the other. The overall conclusions on manure based biogas are that: the biogas from manure stands out as having very high reduction in greenhouse gas emissions and very high fossil fuel savings compared to the conventional storage and soil application of the manure.

Lindner, Lozanovski & Bos (2010) prepared final evaluation report to present the results of the environmental and socio-economic assessment of the demonstration activities in Biogasmax in different sites. The environmental implications are presented in this report as the results of a Life Cycle Assessment (LCA) study.

Although there are several LCA studies carried out on biogas systems, their scope and the methodology are different from one to another. So that results of those LCA couldn’t be compared.

Other research carried out in Sri Lanka on biogas

National Engineering Research Development Center (NERDC) has introduced Dry Batch biogas digester which enables the treatment of straw, market garbage and water borne plants such as Salvinia, Water Hyacinth as their main digestive material. In respects to this digester NERDC won the Silver Award in 1996 at the International Inventors Competition in Switzerland. (NERDC, 2002)

Kularathna (2010) has carried out a project to design and construct a pilot scale biogas plant utilizing food waste obtained from a university canteen for producing and upgrading biogas as a vehicle fuel and subsequent demonstration of the concept. According to the test runs conducted by replacing the Liquid petroleum Gas (LPG) fuel with cleaned and compressed biogas, it has showed that the biogas which is produced from waste and upgraded by removing carbon dioxide, hydrogen sulphide and moisture vapour is suitable for transportation in Sri Lanka**.**

Sri Lanka Sustainable Energy Authority in collaboration with the Colombo Municipal Council has implemented the first pilot project using market waste at Jathikapola in Narahenpita. The digester was fed about two tons of market garbage during November 2012 to March 2013 except five tons of initial feeding of cow dung. According to the observation of this project biogas production potential from market garbage is 40-50 liters per kg of market garbage per day. (Dilhani, 2013)

And also some research has taken place on producing biogas from water hyacinth and sugar cane molasses.

3. METHODOLOGY

3.1 Biogas survey

As a pre requisite for the LCA, survey was carried out in order to find out the existing situation of biogas units installed in Sri Lanka. Although biogas plants are scattered in all parts of the country, there is no centralized data about them. Therefore a data collection mechanism about the already installed biogas units in Sri Lanka was done with Sri Lanka Sustainable Energy Authority (SLSEA).

This survey covered a total of 167 biogas units in the country. Uva province was selected for the first phase of the field survey and 35 units were surveyed in 2014. North-western province was selected for the second phase of the field survey covering 25 units. The information of rest of 107 units were taken from postal survey from the SLSEA registered biogas masons and suppliers.

Survey was done in the form of an interview based questionnaire in Uva and North Western provinces. This questionnaire is attached as Appendix A. Data were collected mainly on the following: capacity, type, condition (whether functioning or not) of the unit, year of commencing operation, cost & subsidy if any, use of biogas and raw materials used for biogas production.

3.2 Life cycle assessment

Life cycle assessment (LCA) was conducted according to the ISO 14040 & ISO 14044 standards and it consists of four steps as follows.

I. Goal and Scope Definition
II. Inventory Analysis
III. Impact Assessment
IV. Interpretation

3.2.1 Goal and Scope

The first phase of an LCA is the definition of goal and scope.

3.2.1.1 Goal

To calculate CO_2 emissions, Embedded Energy Values (EEV), and Energy Pay-Back Time (EPBT) of domestic biogas systems in Sri Lanka

3.2.1.2 Scope

Product System

Based on the survey it was found that the most popular type of the biogas plant at domestic level in Sri Lanka is Chinese fixed dome type plant. Therefore the product system was selected to include the unit processes of Chinese fixed dome type plants as shown in Figure 3.1 with different capacity viz. 8 m^3, 10 m^3, 12 m^3, 15 m^3, 22 m^3, 30 m^3, 35 m^3 and 65 m^3.

Function and Functional Unit

Function of the biogas system is producing biogas. 1m^3 of biogas is considered as the functional unit for this LCA study because the functional unit is the quantified definition of the function of a product system for use as a reference unit. But for the analysis, 1m^3 of the capacity is used in some places.

System boundaries

The system boundary defines the unit processes to be included in the system. The choice of elements of the physical system to be modelled depends on the goal & scope definition of the study, its intended application, assumptions made and data constraints.

So the system boundary for the LCA was selected to include only the raw material acquisition, construction and biogas production as shown in the figure 3.1. Figure 3.1 describes the product system using a process flow diagram showing the processes and the relationships.

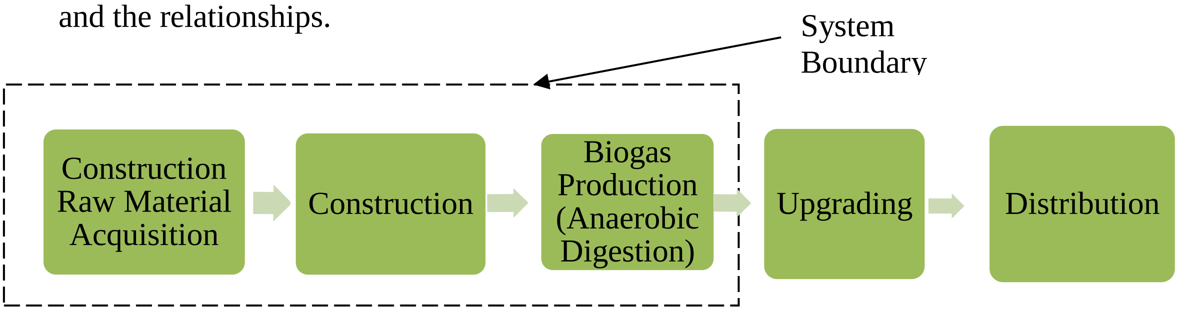

Figure 3-1: Product System for LCA

Assumptions and limitations

- Transportation energy used to carry the building materials to the site is not considered in this analysis because it varies according to the location of each biogas plant.

- Since CO_2 emission reduction at the biogas consumption stage is varying with the fuel replaced by the biogas, only the embedded CO_2 values were considered in CO_2 emission analysis.
- For bricks and lime only the energy consumption associated with manufacturing was considered.

3.2.2 Inventory Analysis

Inventory analysis involves the compilation and quantification of inputs & outputs for a given product system throughout its life cycle. According to the goal of this study it is needed to find the GHG emissions from biogas units and energy payback time of different sizes of biogas units, in order to find out whether there is an impact of the size to the above. So that the construction materials used for different sizes of biogas units were analysed using the LCA. Therefore during the survey Bill of Quantities (BOQ)s which include the amount of construction materials used were collected. The data so collected were used in carrying out the analysis in this thesis. However it was revealed that most of the biogas units in one area were constructed by the same mason. And also most of masons have used the same BOQ. So that the BOQs used for construction were quite similar for several units. Table 3.1 shows one set of BOQs of chinese type biogas plants used for the life cycle analysis.

Table 3-1 : BOQs of Chinese type biogas units (ITDG, Biogas technology, 2006)

Description	**Unit**	**$6m^3$**	**$8m^3$**	**$10m^3$**	**$12m^3$**
Engineering Bricks	1	1,750	2,000	2,250	2,500
Cement	50kg	8	10	12	14
Sand	cube	1	1	1	1.5
3/4" metal	ft^3	4	4	5	6
Limestone	kg	50	50	50	75
Padlo Cement	kg	2	2	2	2
10mm Iron bar	1 bar	2	2	2	2
10mm PVC pipe	1 length	0.5	0.5	0.5	0.5
4"/6" PVC pipe	1 1ength	2	2	2	2
Binding wire	g	50	50	50	50

Biogas production rate of each unit was not readily available for most of the units, even the owners didn't have any idea about the amount of biogas they were using. Therefore using the amount of LPG reduced after installation of biogas unit and considering the norms, daily biogas production rate was estimated as 25% of the volume of the biogas unit.

Calorific value of biogas varies with the methane content. According to the calorific value of methane, for 50 -70% methane content calorific value of 1m^3 of biogas varies between 20 -28 MJ (Fuels - Higher Calorific Values). For this study calorific value of biogas is approximately taken as 20 MJ (for 50% methane content).

Embedded energy values

Embedded energy values were available in "Green Design Guidelines" published by Green Building Council for Sri Lankan scenario. "Inventory of Carbon & Energy" (ICE) (Geoff Hammond, Craig Jones, 2011) published by the Bath University have a wide variety of energy and carbon values for world scenario.

CO_2 emission factors

CO_2 emission factors for all materials were taken from "Inventory of Carbon & Energy" (ICE) database except for cement as the CO_2 emission factor for the production of cement in Sri Lanka was available.

First a sample calculation was done using the embedded energy and CO_2 emission values available in above two sources and it was revealed that cement, bricks, limestone, iron and steel have the major contribution to the final value. So that the embedded energy values of cement, bricks and limestone were calculated for Sri Lankan scenario by collecting energy consumption data from the manufactures. Embedded values of steel and iron were taken from the ICE database.

Cement

The amount of embedded energy for the production of cement in Sri Lanka was available at Puttlam cement factory. Direct energy consumption in manufacturing of cement at Puttlam cement factory, energy consumption for ancillary inputs and energy consumption for raw material extraction & transportation was analysed to find out this embodied energy vale. The total national energy requirement to produce one ton of cement in Sri Lanka was found to be 2800 MJ based on the present energy mix of electricity generation. Using this value CO_2 emission factor was calculated using the current energy mix of cement manufacturing and it is 647 kg CO_2 per ton of cement. (Fernando, 2015)

Bricks

Energy consumption for manufacturing of bricks was collected by field visits to the manufacturing sites and average energy consumption per one unit was calculated using a sample of 20 bricks manufacturers. In brick industry energy is used only to burn the clay block which ultimately becomes the brick. Main energy source used is firewood and some people use paddy husk & saw dust as supplementary fuels.

Energy consumption for production of one engineering brick ($2*4*9cm^3$) – 2.7 MJ

Lime

Energy consumption for lime production was collected by few manufacturers because most of them didn’t have any record of the energy usage. They use firewood as the energy source and average energy consumption is as below.

Energy consumption for 1kg of lime production – 6.15 MJ

Since the EEV of lime in ICE database is 5.3 MJ/kg, the above value is reasonable and it is used in the following analysis.

Embedded energy values and CO_2 emission factors used in this study are shown in the Table 3.2.

Table 3-2: Embedded energy values and CO_2 emission factors

Item	EEV (MJ/kg)	CO_2 emission factor (kg CO_2/kg)
Engineering Bricks (2*4*9cm^3)	2.7 per unit	0.53 per unit
Steel	17.4	1.31
Cements	2.8	0.647
Iron	25	1.91
Lime	6.15	0.74
Polythene	76.7	1.57
PVC	95.6	2.56
¾" Concrete Metal	99 per m^3	0.0048

Embedded Energy Value (EEV) and Energy Pay Back Time (EPBT)

The Embedded Energy Value (EEV) has been evaluated using the amount of building materials used to construct the biogas unit. Then Energy Pay Back Time (EPBT) is evaluated from EEV and energy production of biogas plants.

Equation 3.1, 3.2 and 3.3 were used for the evaluation of EEV and EPBT.

Embedded Energy $= \sum m_i e_i$ Equation 3-1

Where,

m_i = quantity of materials used in constructing biogas plants in kg

e_i = Energy density (Embedded Energy) of the material in MJ/kg

Net energy output $= CV * V * G$ Equation 3-2

Where,

CV = Calorific value of biogas in MJ/m^3

V = Capacity of the biogas plant in m^3

G = Gas production per day in m^3 per 1m^3 biogas plant capacity

Energy payback time,

EPBT = Embedded Energy/ Net energy output Equation 3-3

CO_2 emission

Equation 3.4 was used to calculate the CO_2 emission

CO_2 emission = $\sum m_i CF_i$ Equation 3-4

Where,

m_i = quantity of materials used in constructing biogas plants in kg

CF_i = Carbon factor (CO_2 emission factors) of the material in kg/kg

3.2.3 Life Cycle impact Assessment and Interpretation

Life Cycle impact Assessment and Interpretation are discussed in the following chapter.

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 Results of the survey

Uva province

Currently biogas development program is being carried out in Uva province through the Provincial Power & Energy Ministry and most of the plants use household waste and sewage sludge as raw material. 35 number of biogas plants were visited with the guidance of an officer working in the Uva Provincial Power & Energy Ministry. Out of the 35 units surveyed in Uva province 29 units were at households, two were in restaurants, one was in a temple and other three units were municipal council units. All digesters were 20 m^3 capacities except the plants owned by municipal council which were constructed at the market and public places like children park. All biogas units were chinese fixed dome type digesters. 50% of the cost had been donated by the provincial council along with the technical advice. In almost all the places main input was sewage and it was also promoted as a solution to the landslides which could occur due to the construction of typical sewage pits in this hill country region. Few biogas units are shown in figure 4.1.

Figure 4-1: Biogas plants in Uva Province

North Western province

25 number of biogas plants were visited with the guidance of regional officer of Department of animal Production & Health. All most all of the biogas plants surveyed in North Western Province are Chinese model with the size of $8m^3$ and they were based on animal husbandry.

Figure 4-2 : Biogas plant in North Western Province

The generated biogas is mostly used for cooking (144 units out of 167 units).Only 10 owners used biogas for cooking as well as lighting (with lamp) and there was one case reporting where electricity generation .

The bio gas plant at Dikkanda plantation with a capacity of 500 m^3, generate 80 kW and it is the first grid connected biogas plant in Sri Lanka. The technology has been provided by a Thailand Company with PVC balloon for storing gas.

Few issues of biogas users were identified; the main issue was lack of knowledge on biogas plants, their function and repairs. Due to this reason most of the biogas plants were not functioning well at the time of survey. Most of the biogas plants had been built with donations without any knowledge or interest on biogas.

There were technical errors in the biogas unit itself at the initial step such as, lack of slope of the inlet, long distance between inlet and dome, not enough space to enter the dome etc.

Table 4.1 shows the Size distribution and Table 4.2 shows a summary of functioning and non-functioning biogas systems. Database of the surveyed biogas plants is given in appendix B.

Table 4-1: Size distribution of biogas plants

Size of the unit (m^3)	**No of units**
Above 100	4
50-100	3
20-50	17
10-20	48
Below 10	95
Total	167

Table 4-2: Condition of biogas plants

	Functioning	**Non-functioning**	**Total**
No. of household plants	81	17	98
No. of institution plants	60	9	69
Total	**141**	**26**	**167**

According to the table 4.1 it is obvious that 86% are domestic units with a capacity less or equal than 20 m^3. Biogas plants having capacity more than 20 m^3 were constructed mainly in hospitals, rice mills and public places.

About 16% of the above sample was not functioning at the time of this survey.

Location of the visited biogas plants were taken using a GPS meter and the locations of the others were marked according to the grama niladhari division.

Figure 4.3 shows the locations of the surveyed biogas plants.

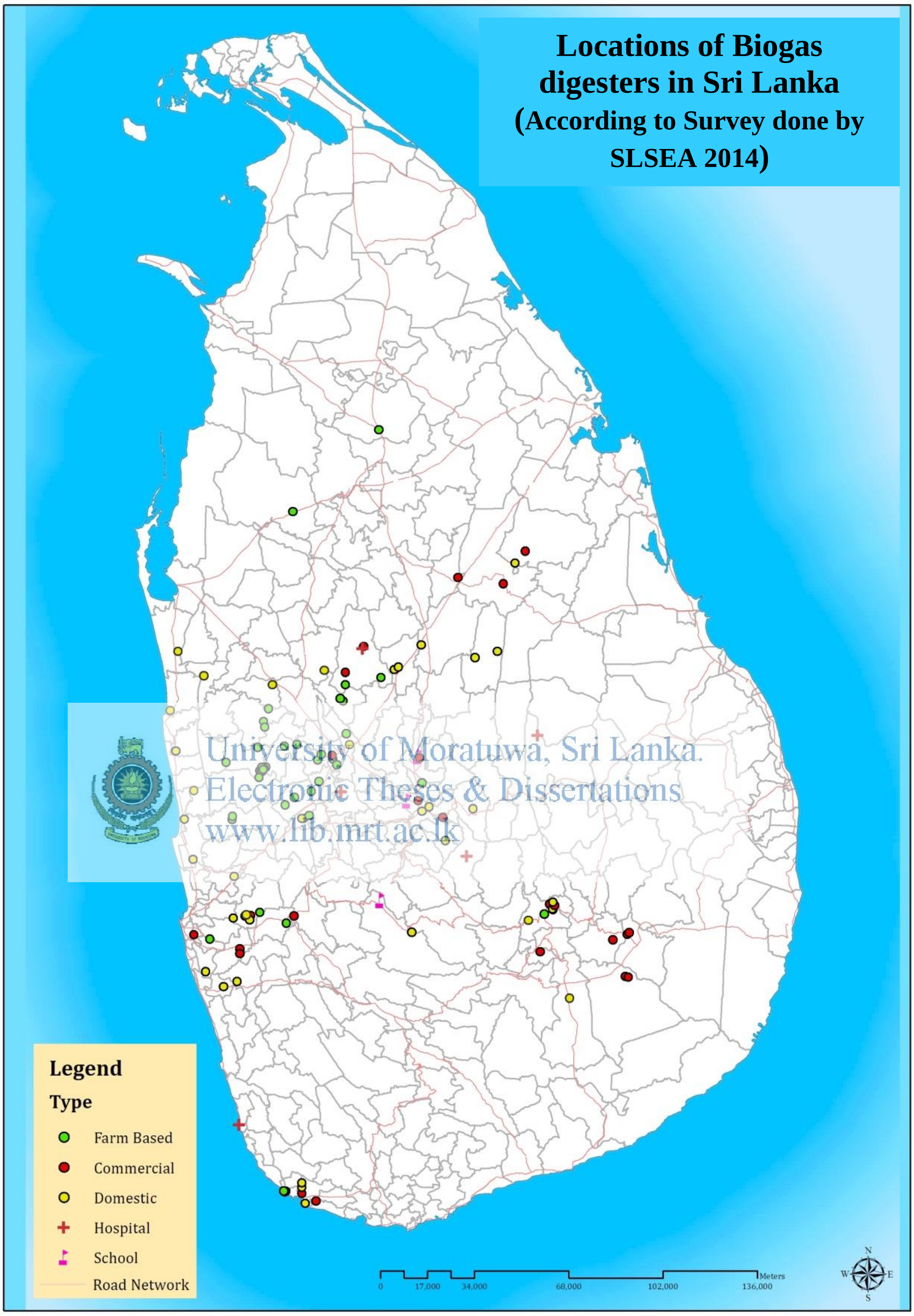

Figure 4-3: Locations of Surveyed Biogas digesters in Sri Lanka

4.1.2 Embedded Energy Value (EEV)

Calculations of embedded energy values (EEV) and energy pay back times (EPBT) are given in appendix C and a summary is tabulated in Table 4.3.

Table 4-3: Evaluated EEV and EPBT

Capacity of Biogas plant (m^3)	**EEV (MJ)**	**EPBT (days)**	**EEV per 1 m^3 capacity (MJ/m^3)**
6	6,531	218	1,088
8	7,058	176	882
10	8,442	169	844
12	10,414	174	868
15	14,594	195	973
22	16,497	150	750
30	20,833	139	694
35	23,501	134	671
65	33,834	104	521

The EEVs were plotted against the capacity of biogas plants as shown in the figure 4.4.

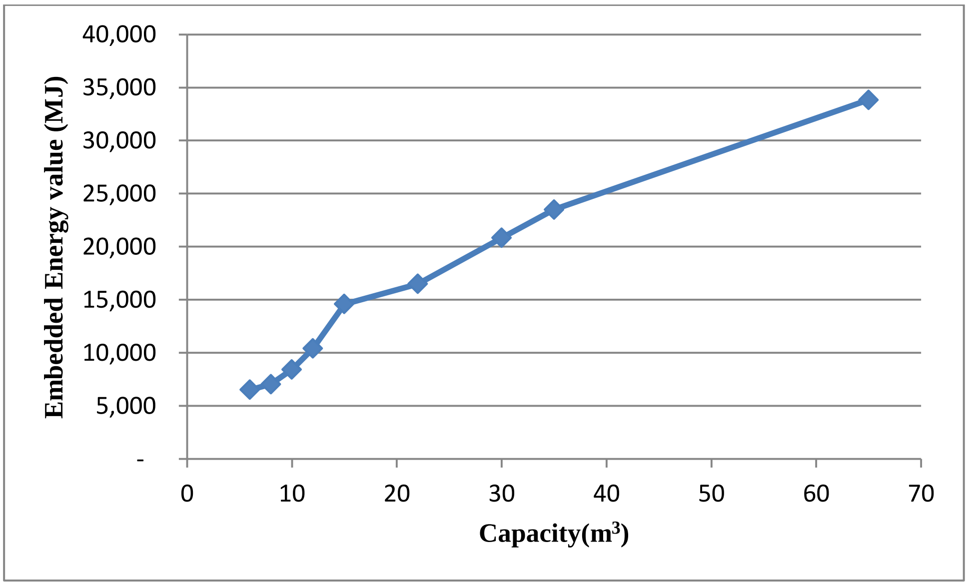

Figure 4-4: EEV vs. the capacity of biogas plants

EEV/m^3 values for each capacity are shown in the figure 4.5.

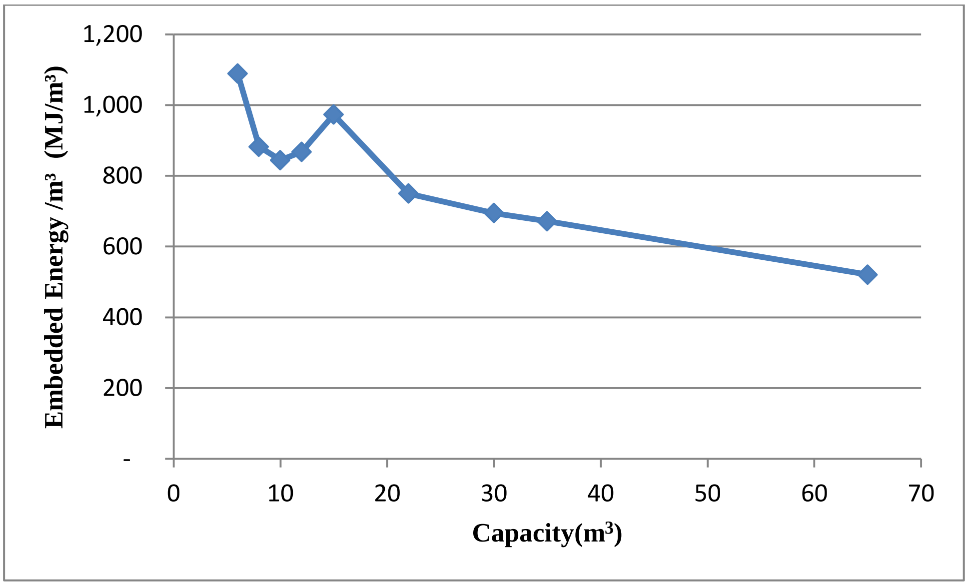

Figure 4-5: EEV / m^3 vs. the capacity of biogas plants

According to the above figure EEV per 1 m^3 capacity of the biogas plant reduce with the size of the plant.

EPBT variation with respect to the capacity of the biogas plant is as follows.

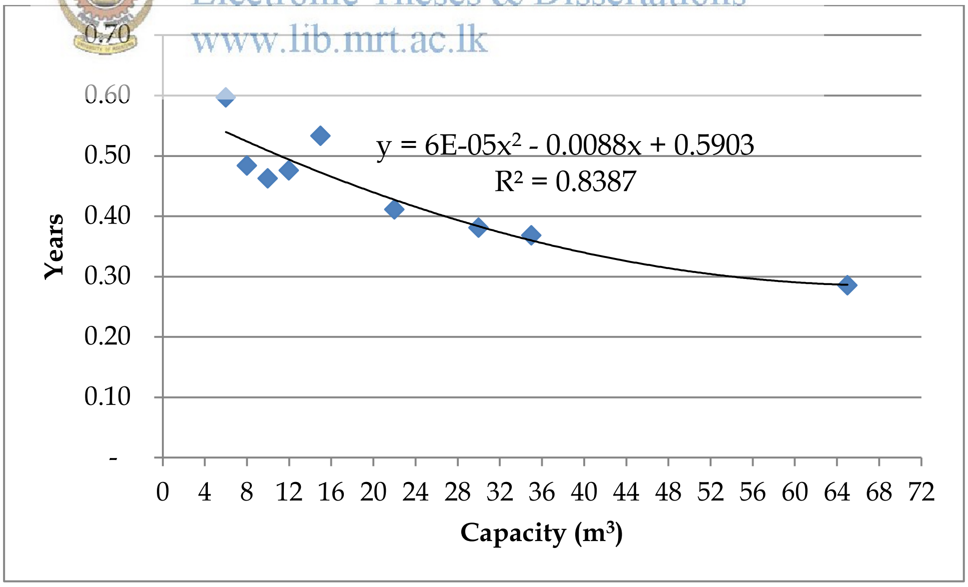

Figure 4-6: EPBT vs. the capacity of biogas plants

Using the above Figure 4.6 an equation was obtained to show the relationship between Energy pay-back time and the capacity of the plant.

EPBT, $y = 0.0006x^2 - 0.008x + 0.590$

Where, x is the capacity of the biogas plant

4. 1.3 CO_2 emission

CO_2 emissions calculations for each capacity are given in appendix D and a summary is shown in the table 4.4.

Table 4-4: CO_2 emissions

Capacity of Biogas plant (m^3)	**CO_2 emission (kg)**	**CO_2 emission per 1 m^3 capacity (kg/m^3)**
6	1,252	157
8	1,300	150
10	1,595	150
12	1,849	144
15	2,266	151
22	2,918	133
30	3,167	106
35	4,198	120
65	6,027	93

CO_2 emissions of different sizes of biogas plants are plotted in the Figure 4.7.

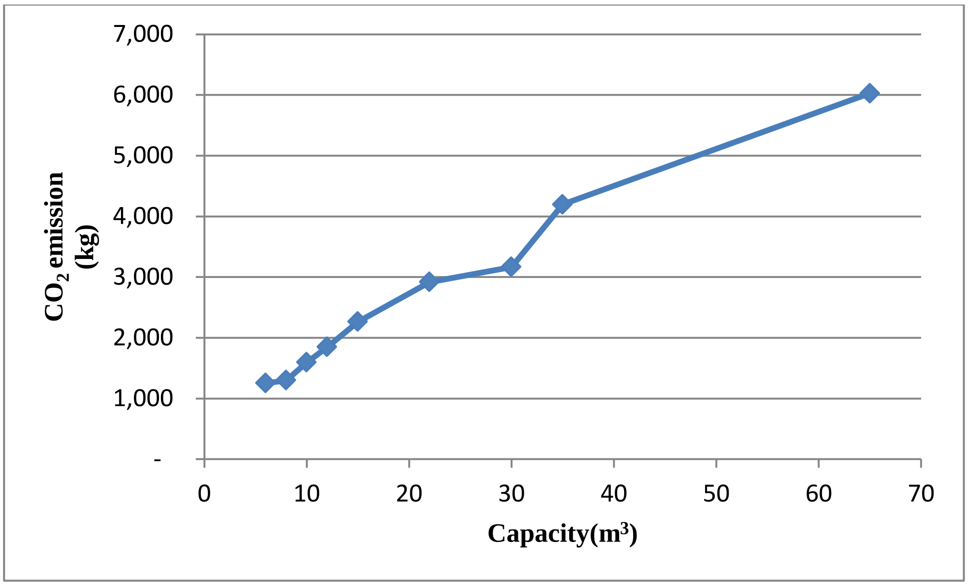

Figure 4-7 : CO$_2$ emissions vs. the capacity of biogas plants

CO$_2$ emissions per 1 m^3 capacity of each plant are shown in the figure 4.8.

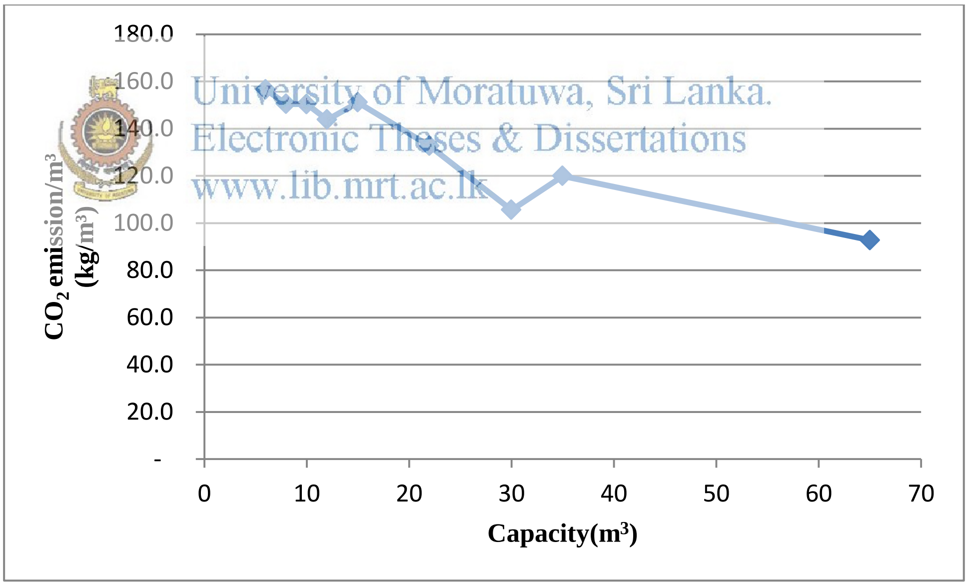

Figure 4-8 : CO$_2$ emissions / m^3 vs. the capacity of biogas plants

Similar to the embedded energy, CO$_2$ emissions per 1 m^3 capacity of biogas plant reduces with the increase of capacity of the plant. However for 30m^3 capacity biogas plant there is a small deviation from this pattern and it may be due the different amount of material usage by each manufacturer to construct the same size plant.

4.2 Discussion

4.2.1 Life Cycle Impact Assessment

The results of the LCI are described and evaluated in this phase, i.e. inventory data are categorised into potential effects on the environment and are also classified into impact categories.

Impact categories mainly discussed here are the global warming and energy consumption which was analysed through the indicators of greenhouse gas emission from CO_2 and energy consumption from different types of fuels.

Global warming

Gases that trap heat in the atmosphere are called greenhouse gases. Carbon dioxide (CO_2) and Methane (CH_4) are the greenhouse gases relevant to this study which will contribute to global warming. Carbon dioxide is constantly being exchanged among the atmosphere, ocean, and land surface as it is both produced and absorbed by many microorganisms, plants, and animals. However, emissions and removal of CO_2 by these natural processes tend to balance. But due to the man-made activities this balance is interrupted and the level of greenhouse gases increases. So it will lead to global warming.

Some direct and indirect effects of global warming are; exposure to thermal extremes causing altered rates of illnesses and death, changes in range and activity of vectors and parasites, sea-level rise causing population displacement, damage to infrastructure, and also an increased risk of infectious disease and psychological disorders.

In the stage of biogas production there is no net CO_2 emission because it will offset the amount of CO_2 absorbed by the waste. Sometimes CH_4 is released to the environment if biogas is discharged without burning. So it is very dangerous because it has a 21 times global warming potential than CO_2. Only the CO_2 emission for construction material is the significant and it is discussed in the interpretation of results.

Depletion of Fossil fuels

For the manufacturing of raw materials used in construction of biogas plant consume different types of energy and they were discussed above. But the biogas replaces the requirement of liquid petroleum gas (LPG) or kerosene for cooking and it will show a positive impact on those fossil fuels. 1m^3 of biogas is equivalent to 0.64 liter of kerosene (ITDG, Biogas technology, 2006). The amount of LPG that can be replaced by 1m^3 of biogas is 0.4 kg, whereas the firewood replacement is 1.3kg (Fuels - Higher Calorific Values). Since Sri Lanka has a tropical climate with a favourable temperature for the biogas production there is no need for heating which consumes a part of energy generated by the unit. So it is an added advantage for our country.

- Although only the global warming and energy consumption were discussed in this research, there are some other impacts associated with biogas systems and they are discussed briefly in the following.

Displacement of artificial fertilizer

As a by-product of biogas system slurry is produced that this is having a high nutrient content. The slurry does not smell and does not attract flies as the case with cow dung. During the conversion process a lot of micro-organism, that represents a health risk, are killed. The most important benefit is that the slurry is a very effective fertilizer that can improve the growth of the crops. The liquid slurry can with easily be brought to places that need organic fertilizers. As a result less artificial fertilisers have to be produced, causing less natural gas and fossil oil consumption. On the other hand the displacement of inorganic fertiliser resulted in a significant reduction in impacts towards climate change, radiation, ozone layer depletion, minerals and fossil fuel resources depletion. These savings are caused by the preservation of mineral fertilisers due to nutrient recycling.

Depletion of resources

For the production of materials used in construction of biogas systems different types of raw materials and energy sources are used and a quantification analysis was done in this study. Major materials used for construction are cement, bricks, limestone, iron and steel. Limestone, marl and clays are the main raw materials used for production of cement and they are extracted using drilling and blasting techniques. For bricks manufacturing clay is used as the raw material. So that by construction of biogas plants limestone and clay reserves will be depleted. Further steel and iron is used for reinforcement of concrete and for the production of them mineral resources as well as fossil fuels are used.

The consumption of resources leads to a decrease in the resources' quality. The resources' quality is a unit of measurement for the efforts that have to be made to exploit resources. This means that in future it will become more complicated and therefore more energy intensive to exploit resources, given that easier to exploit resources are already consumed.

Climate change

The production of biogas showed a negative effect on the impact category of climate change. This was due to the potential carbon dioxide emissions sequestered from the organic matter. The CO_2 fixation was accounted for as a consumption of the CO_2 resource. This theory assumed that carbon dioxide was consumed to generate the feedstock and therefore was required within the plant. The CO_2 is stored within the biogas in the form of CH_4 and some CO_2 until the biogas is combusted.

4.3 Interpretation

In this study construction of biogas units were analysed in terms of energy consumption and CO_2 emissions in order to establish a baseline GHG standard.

4.3.1 CO_2 emissions

CO_2 emission of 6 m^3 plant is 1,252 kg and for 65 m^3 plant it is 6,027 kg. When considering the CO_2 emission per 1 m^3 capacity, 6 m^3 plant emits 157 kg whereas, 93 kg CO_2 emission for 65 m^3 plant.

When a biogas plant is constructed LPG, kerosene or firewood used for cooking purposes can be replaced by the biogas. According to the survey it was found that for a small family with 4 members need 13.5kg of LPG per month. Therefore having a properly maintained 6 m^3 capacity is more than enough for the cooking fuel requirement of a family.

When considering the CO_2 emission 1kg of LPG will emit 3kg of CO_2 during the combustion and with the use of biogas that amount will be saved (Combustion of Fuels - Carbon Dioxide Emission). Since biogas is produced using organic waste CO_2 emission in combustion is cancelled off to the amount of CO_2 absorbed by the waste. If 13.5 kg of LPG is replaced per month by biogas CO_2 emission in the construction phase will be recovered within 2.5 years. If the embedded energy of LPG is considered it will recover within very short time may be less than one month. On the other hand if firewood has been replaced it will contribute to reduce a high amount of particulate matter to the environment.

4.3.2 Energy Consumption

Although EEV per 1 m^3 capacity of the biogas plant reduces with the size of the plant, there is no linear relationship between them. 10 m^3 plant has a value of 844 MJ/m^3 whereas the 65 m^3 has a value of 521 MJ/m^3. However it is obvious that higher capacity plant requires less amount of energy to produce 1 m^3 of biogas.

As shown in the figure 4.3 (EPBT vs. the capacity of biogas plants) EPBT time reduce as the capacity increase. But all the capacities of biogas plants analyzed here will recover the energy consumed for construction within less than a year. 6 m^3 plant which is the smallest biogas plant available in Sri Lanka has EPBT time of 7 months. And 65 m^3 plant has a EPBT of 3.5 months. When considering the energy consumption for the construction of biogas plant, it is a very low value compared to the energy generation from the biogas plant. For this study daily biogas production rate was estimated as 25% of the volume of the biogas unit and it may vary with the feedstock of the unit. However the EPBT will not exceed 1 year, although 50% variation is considered.

Considering the above facts itcan be concluded that higher capacity biogas plants are more effective than smaller ones in terms of energy consumption.

But due to different types of reasons it may not be feasible to construct a larger unit, such as the issues associated with the collection of wastes, transportation of them and distribution of biogas. Also there may be social problems when constructing a community scale unit. Most of the people might not like to construct the biogas plant near their houses, but they may like to use the biogas generated from this plant.

5. CONCLUSION

Table 5.1 presents the summary of results from this LCA study.

Table 5-1: Summary of results

Capacity of Biogas plant (m^3)	EEV (MJ)	EPBT (days)	EEV per 1 m^3 capacity (MJ/m^3)	CO_2 emission (kg)	CO_2 emission per 1 m^3 capacity (kg/m^3)
6	6,531	218	1,088	1,252	157
8	7,058	176	882	1,300	150
10	8,442	169	844	1,595	150
12	10,414	174	868	1,849	144
15	14,594	195	973	2,266	151
22	16,497	150	750	2,918	133
30	20,833	139	694	3,167	106
35	23,501	134	671	4,198	120
65	33,834	104	521	6,027	93

According to the table 5.1 CO_2 emission of 6 m^3 plant is 1,252 kg and for 65 m^3 plant it is 6,027 kg. Biogas plants having other capacities have CO_2 emissions in between these two values. When considering the CO_2 emission per 1 m^3 capacity, 6 m^3 plant emits 157 kg whereas, 93 kg CO_2 emission for 65 m^3 plant. Although EEV per 1 m^3 capacity of the biogas plant reduces with the size of the plant, there is no linear relationship between them. 6 m^3 plant has a value of 1,088 MJ/m^3 whereas the 65 m^3 plant has a value of 521 MJ/m^3. However it is obvious that higher capacity plant requires less amount of embedded energy to produce 1 m^3 of biogas.

So it is obvious that construction of higher capacity plant is more energy efficient than a smaller capacity one and also the environmental effects can be minimized.

Although there are negative impacts from CO_2 emissions in the construction stage, there is a reduction of CO_2 emissions in the biogas consumption stage due to the replacement of fossil fuels with biogas.

Although there are negative impacts of CO_2 emissions in the construction stage, there is a reduction of CO_2 emissions in the biogas consumption stage due to the replacement of fossil fuels with biogas. While the LPG / kerosene replacement reduces the CO_2 emissions, firewood replacement reduces the amount of particulate matters emitted to the environment. So this will contribute towards a reduction in climate change impact, giving the plant an overall positive impact on climate change. However due to different types of reasons such as waste collection issues, gas distribution issues, social issues always it may not be optimum solution to construct a larger unit. So initially the situation should be carefully studied and then only is should be constructed the largest unit feasible for that application.

Biogas projects come under the category of “switching fossil fuels” in Clean Development Mechanism (CDM) as biogas replaces the domestic fossil fuel requirement in cooking and lighting. Although the burning of biogas releases CO_2, this amount is absorbed by the regrowth of the agricultural products. Therefore biogas can be considered as carbon neutral. When biogas substitutes conventional domestic fuels that are not carbon neutral, it will contribute to reduce GHG emissions. In addition to that it will contribute for GHG emission reduction by substituting chemical fertilizer and giving solution to the waste management problem. Although all the biogas units in Sri Lanka have a high CDM potential and it should be calculated with the precise no of biogas units currently functioning in Sri Lanka.

For the success of any rural oriented technology, it is essential that it should be appropriate to the social and economic conditions of the country. As Sri Lanka is an agricultural country, biogas technology perfectly blends with our culture and society. However, the success of promoting biogas technology depends on careful planning, management, implementation, training and monitoring.

Further research is needed on LCA of other types of domestic biogas units especially about the prefabricated plastic type biogas unit as it is getting popular in the country.

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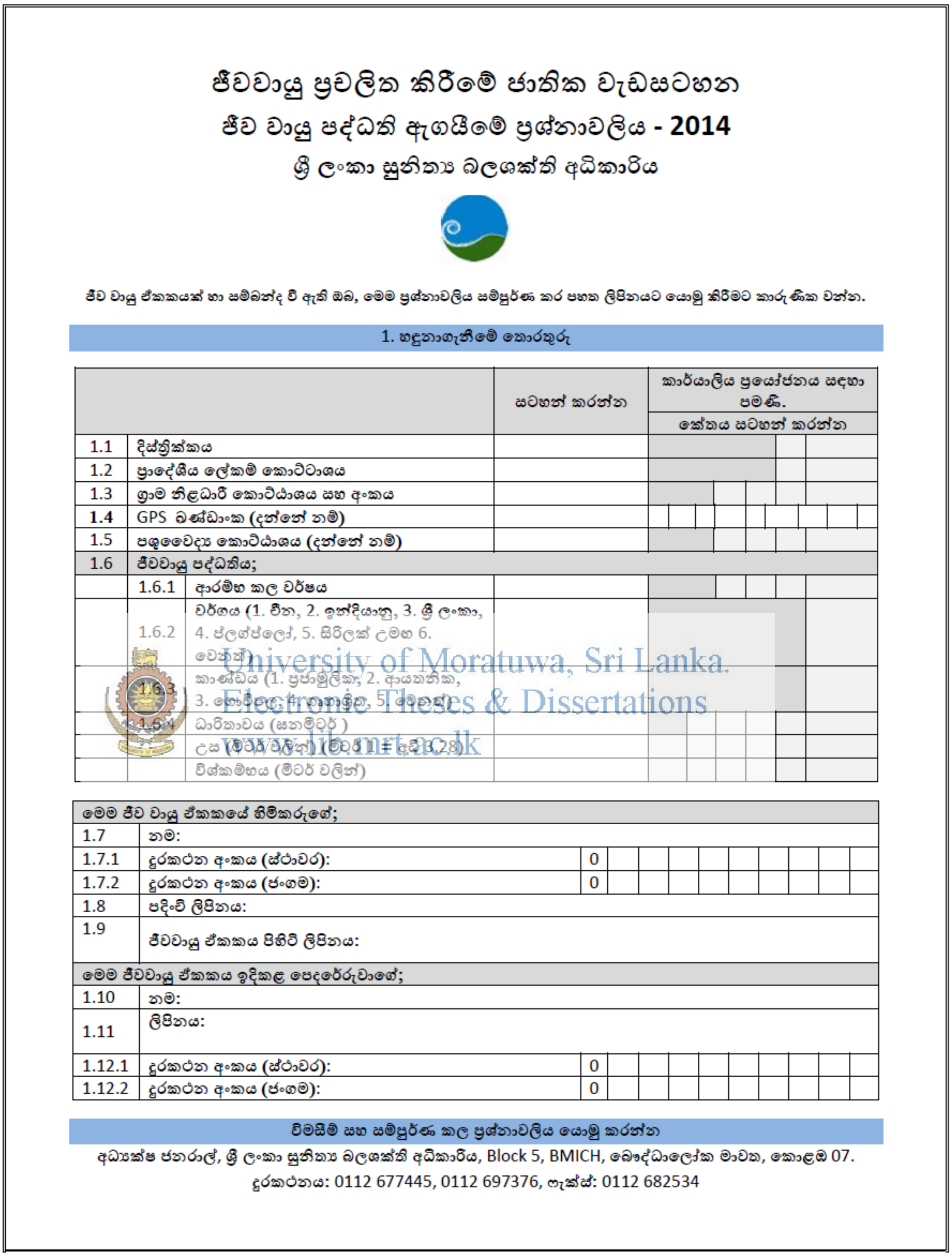
APPENDICES

Appendix A: Survey Questionnaire



ජීවවායු ප්‍රචලිත කිරීමේ ජාතික වැඩසටහන

ජීව වායු පද්ධති ඇගයීමේ ප්‍රශ්නාවලිය - 2014

ශ්‍රී ලංකා සුනිත්‍ය බලශක්ති අධිකාරිය

ජීව වායු ඒකකයක් හා සම්බන්ද වී ඇති ඔබ, මෙම ප්‍රශ්නාවලිය සම්පූර්ණ කර පහත ලිපිනයට යොමු කිරීමට කාරුණික වන්න.

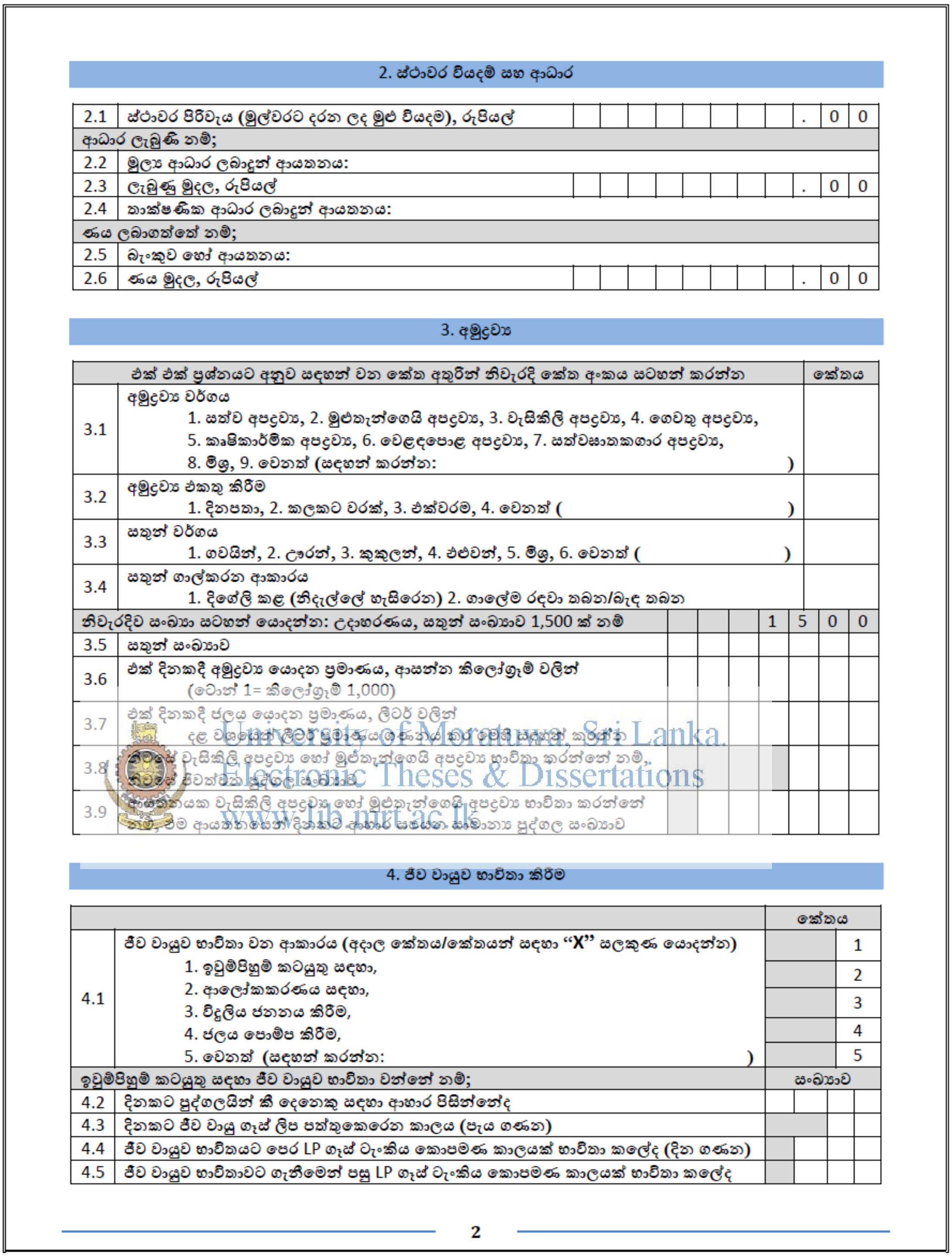
1. හඳුනාගැනීමේ තොරතුරු

			සටහන් කරන්න	කාර්යාලිය ප්‍රයෝජනය සඳහා පමණි.
				කේතය සටහන් කරන්න
1.1	දිස්ත්‍රික්කය			
1.2	ප්‍රාදේශීය ලේකම් කොට්ඨාශය			
1.3	ග්‍රාම නිළධාරී කොට්ඨාශය සහ අංකය			
1.4	GPS ඛණ්ඩාංක (දන්නේ නම්)			
1.5	පශුවෛද්‍ය කොට්ඨාශය (දන්නේ නම්)			
1.6	ජීවවායු පද්ධතිය;			
	1.6.1	ආරම්භ කල වර්ෂය		
	1.6.2	වර්ගය (1. චීන, 2. ඉන්දියානු, 3. ශ්‍රී ලංකා, 4. ප්ලග්ප්ලෝ, 5. සිරිලක් උමඟ 6. වෙනත්)		
	1.6.3	කාණ්ඩය (1. ප්‍රජාමූලික, 2. ආයතනික, 3. ගොවිපළ, 4. ගෘහාශ්‍රිත, 5. වෙනත්)		
	1.6.4	ධාරිතාවය (ඝනමීටර්)		
		උස (මීටර් වලින්) (මීටර් 1 = අඩි 3.28)		
		විශ්කම්භය (මීටර් වලින්)		

මෙම ජීව වායු ඒකකයේ හිමිකරුගේ;											
1.7	නම:										
1.7.1	දුරකථන අංකය (ස්ථාවර):	0									
1.7.2	දුරකථන අංකය (ජංගම):	0									
1.8	පදිංචි ලිපිනය:										
1.9	ජීවවායු ඒකකය පිහිටි ලිපිනය:										
මෙම ජීවවායු ඒකකය ඉදිකළ පෙදරේරුවාගේ;											
1.10	නම:										
1.11	ලිපිනය:										
1.12.1	දුරකථන අංකය (ස්ථාවර):	0									
1.12.2	දුරකථන අංකය (ජංගම):	0									

විමසීම් සහ සම්පූර්ණ කල ප්‍රශ්නාවලිය යොමු කරන්න

අධ්‍යක්ෂ ජනරාල්, ශ්‍රී ලංකා සුනිත්‍ය බලශක්ති අධිකාරිය, Block 5, BMICH, බෞද්ධාලෝක මාවත, කොළඹ 07.
දුරකථනය: 0112 677445, 0112 697376, ෆැක්ස්: 0112 682534



2. ස්ථාවර වියදම් සහ ආධාර

2.1	ස්ථාවර පිරිවැය (මුල්වරට දරන ලද මුළු වියදම), රුපියල්									.	0	0
ආධාර ලැබුණි නම්;												
2.2	මූල්‍ය ආධාර ලබාදුන් ආයතනය:											
2.3	ලැබුණු මුදල, රුපියල්									.	0	0
2.4	තාක්ෂණික ආධාර ලබාදුන් ආයතනය:											
ණය ලබාගත්තේ නම්;												
2.5	බැංකුව හෝ ආයතනය:											
2.6	ණය මුදල, රුපියල්									.	0	0

3. අමුද්‍රව්‍ය

	එක් එක් ප්‍රශ්නයට අනුව සඳහන් වන කේත අතුරින් නිවැරදි කේත අංකය සටහන් කරන්න	කේතය
3.1	අමුද්‍රව්‍ය වර්ගය 1. සත්ව අපද්‍රව්‍ය, 2. මුළුතැන්ගෙයි අපද්‍රව්‍ය, 3. වැසිකිළි අපද්‍රව්‍ය, 4. ගෙවතු අපද්‍රව්‍ය, 5. කෘෂිකාර්මික අපද්‍රව්‍ය, 6. වෙළඳපොළ අපද්‍රව්‍ය, 7. සත්වඝාතකගාර අපද්‍රව්‍ය, 8. මිශ්‍ර, 9. වෙනත් (සඳහන් කරන්න:)	
3.2	අමුද්‍රව්‍ය එකතු කිරීම 1. දිනපතා, 2. කලකට වරක්, 3. එක්වරම, 4. වෙනත් ( )	
3.3	සතුන් වර්ගය 1. ගවයින්, 2. ඌරන්, 3. කුකුලන්, 4. එළුවන්, 5. මිශ්‍ර, 6. වෙනත් ( )	
3.4	සතුන් ගාල්කරන ආකාරය 1. දිගේලි කළ (නිදැල්ලේ හැසිරෙන) 2. ගාලේම රඳවා තබන/බැඳ තබන	

නිවැරදිව සංඛ්‍යා සටහන් යොදන්න: උදාහරණය, සතුන් සංඛ්‍යාව 1,500 ක් නම්					1	5	0	0
3.5	සතුන් සංඛ්‍යාව							
3.6	එක් දිනකදී අමුද්‍රව්‍ය යොදන ප්‍රමාණය, ආසන්න කිලෝග්‍රෑම් වලින් (ටොන් 1= කිලෝග්‍රෑම් 1,000)							
3.7	එක් දිනකදී ජලය යොදන ප්‍රමාණය, ලීටර් වලින් දළ වශයෙන් ලීටර් ප්‍රමාණය ගණනය කර මෙහි සඳහන් කරන්න							
3.8	නිවසේ වැසිකිළි අපද්‍රව්‍ය හෝ මුළුතැන්ගෙයි අපද්‍රව්‍ය භාවිතා කරන්නේ නම්, නිවසේ ජීවත්වන පුද්ගල සංඛ්‍යාව							
3.9	ආයතනයක වැසිකිළි අපද්‍රව්‍ය හෝ මුළුතැන්ගෙයි අපද්‍රව්‍ය භාවිතා කරන්නේ නම්, එම ආයතනයෙන් දිනකට ආහාර සපයන සාමාන්‍ය පුද්ගල සංඛ්‍යාව							

4. ජීව වායුව භාවිතා කිරීම

		කේතය			
4.1	ජීව වායුව භාවිතා වන ආකාරය (අදාල කේතය/කේතයන් සඳහා **“X”** සලකුණ යොදන්න) 1. ඉවුම්පිහුම් කටයුතු සඳහා, 2. ආලෝකකරණය සඳහා, 3. විදුලිය ජනනය කිරීම, 4. ජලය පොම්ප කිරීම, 5. වෙනත් (සඳහන් කරන්න:)		1 2 3 4 5		
ඉවුම්පිහුම් කටයුතු සඳහා ජීව වායුව භාවිතා වන්නේ නම්;		සංඛ්‍යාව			
4.2	දිනකට පුද්ගලයින් කී දෙනෙකු සඳහා ආහාර පිසින්නේද				
4.3	දිනකට ජීව වායු ගෑස් ලිප පත්තුකෙරෙන කාලය (පැය ගණන)				
4.4	ජීව වායුව භාවිතයට පෙර LP ගෑස් ටැංකිය කොපමණ කාලයක් භාවිතා කලේද (දින ගණන)				
4.5	ජීව වායුව භාවිතාවට ගැනීමෙන් පසු LP ගෑස් ටැංකිය කොපමණ කාලයක් භාවිතා කලේද				

2

	(දින ගණන)	
ආලෝකකරණය සඳහා ජීව වායුව භාවිතා වන්නේ නම්;		සංඛ්‍යාව
4.6	දිනකට පත්තුකෙරෙන ලාම්පු ගණන	
4.7	දිනකට ලාම්පු පත්තුවන කාලය (පැය ගණන)	
විදුලිය නිපදවීම සඳහා ජීව වායුව භාවිතා කෙරෙන්නේ නම්;		
4.8	විදුලිය නිපදවන්නේ නම් ජනනය කෙරෙන විදුලි ධාරිතාව (kW, කිලෝ වොට්)	
4.9	ජනනය කෙරෙන ජීව වායුව ඔබේ අවශ්‍යතාවයන්ට ප්‍රමාණවත්ද (කේතය තෝරන්න) 1. ප්‍රමාණවත්ය, 2. ප්‍රමාණවත් නැත, 3. අමතර ප්‍රමාණයක් ජනනය කෙරේ	

5. ජීව පොහොර නිෂ්පාදනය සහ භාවිතය

5.1	දිනකට දියර ජීව පොහොර නිපදවෙන ප්‍රමාණය, (ලීටර්)	
5.2	ජීව පොහොර භාවිතා වන්නේ 1. අලෙවි කිරීම, 2. තමන්ගේම ගොවිපලේ භාවිතයට, 3. අලෙවිය සහ තමන්ගේම ගොවිපල භාවිතයට	කේතය සඳහන් කරන්න
තමන්ගේම ගොවිපලේ භාවිතයට ගන්නේ නම්;		
5.3	ජීව පොහොර යොදවන්නේ; (කේතය තෝරන්න) 1. එළවළු වගාව, 2. වී වගාව, 3. මිරිස් වගාව, 4. මල් වගාව, 5. තණකොළ, 6. සත්ව ආහාර, 7. මිශ්‍ර, 8. වෙනත් (සඳහන් කරන්න:)	අදාල කේතය/කේතයන් සඳහා “X” සලකුණ යොදන්න 1 2 3 4 5 6 7 8
5.4	නිපදවෙන ජීව පොහොර ප්‍රමාණවත්ද 1. ප්‍රමාණවත්ය, 2. ප්‍රමාණවත් නැත 3. අතිරික්තයක් ඇත	කේතය සඳහන් කරන්න
5.5	ජීව පොහොර භාවිතයෙන් පසු වගාවේ අස්වැන්න, 1. වැඩිවිය, 2. වෙනසක් නැත, 3. වෙනත් ගැටළු ඇතිවිය	කේතය සඳහන් කරන්න
ජීව පොහොර භාවිතයට පෙර		
5.6	මාසයකට රසායනික පොහොර කොපමණ ප්‍රමාණයක් භාවිතා කලේද (කිලෝග්‍රෑම්)	
5.7	රසායනික පොහොර සඳහා මාසයකට කොපමණ වියදම් කලේද (රුපියල්)	

6. වෙනත් කරුණු

6.1	ජීව වායු ඒකකය පිහිටුවීමට පෙර කසල බැහැර කිරීමේ ක්‍රමය 1. ගෙවත්තේ බැහැර කිරීම, 2. වෙනත් ස්ථානයකට බැහැර කිරීම, 3. නගර සභාව හෝ ප්‍රාදේශීය සභාවට යොමු කිරීම, 4. විකිණීම, 5. කොම්පෝස්ට් පොහොර නිපදවීම	කේතය සඳහන් කරන්න
6.2	ජීව වායු ජනනය පිළිබඳ ඔබේ අදහස කුමක්ද 1. ඉතා ප්‍රයෝජනවත්ය, 2. පරිසර හිතකාමීය, 3. මුදල් ඉතිරි කරයි, 4. මුදල් වැයකිරීමකි, 5. කරදරකාරිය, 6. අනවශ්‍යය	(අදාල කේතයන් සඳහා “X” සලකුණ යොදන්න) 1 2 3 4 5 6
6.3	මෙම ජීව වායු ඒකකය පවත්වාගෙන යාමේදී ඔබ මුහුණදුන් ගැටළු (වෙනත්) ඇත්නම් සටහන් කරන්න	
6.4	පුහුණු වැඩසටහන් සහ/හෝ හඳුන්වාදීමේ වැඩසටහනකට ඔබ ආයතනය හෝ ජීව වායු ඒකකය ලබාදීමට එකග වන්නේද (විස්තර කරන්න)	

7. අදහස් සහ යෝජනා

7.1	ජීව වායු ජනනය සහ මෙම පරිසර හිතකාමී වැඩසටහන් පිළිබද ඔබගේ අදහස් ඇත්නම් සඳහන් කරන්න
7.2	ශ්‍රී ලංකා සුනිත්‍ය බලශක්ති අධිකාරිය වෙත යොමු කිරීමට ඔබට කිසියම් යෝජනාවන් ඇත්නම් සඳහන් කරන්න
7.3	ආනගතයේදී මෙම තාක්ෂණය දියුණු කිරීම සඳහා ඔබගේ යෝජනා ලබාදෙන්න

8. තොරතුරු සහතික කිරීම

මෙහි සඳහන් කළ තොරතුරු සත්‍ය සහ නිවැරදි තොරතුරු බවට සහතික කරමි.

	නම	අත්සන	දිනය	දුරකථන අංක
ජීව වායු ඒකකයේ හිමිකරු				
තොරතුරු සපයන්නා (තනතුර හෝ හිමිකරුට ඇති සම්බන්ධතා)				
සමීක්ෂණ නිලධාරියා				

9. කේත යෙදීම සහ පරිගණකගත කිරීම (කාර්යාලිය ප්‍රයෝජනය සඳහා පමණි)

	නිලධාරියා		අධීක්ෂණය	
	නම	දිනය සහ අත්සන	නම	දිනය සහ අත්සන
කේත යෙදීම				
පරීක්ෂා කිරීම				
පරිගණකගත කිරීම				

ඔබටත් ඔබ දරුවන්ටත් වඩාත් යහපත් අනාගතයක් උදෙසා බලශක්තිය සුරකිමු.

හැකිතරම් පරිසර හිතකාමී බලශක්ති ප්‍රභවයන් වෙත යොමු වෙමු. පුනර්ජනනීය බලශක්තීන් ප්‍රචලිත කරමු.

අප අවට පරිසරය පිරිසිදුව සහ සුන්දරව තබාගනිමු.

Appendix B: Database of surveyed biogas units

No	Location*	Year of establishment	Type**	Capacity (m3)	Active/ Non-active
1	MC Road, Matale	2012	C	50	Active
2	Pallekale	2013	C	116	Active
3	Dambulla	2014	C	15	Active
4	Theldeniya	2014	C	10	Active
5	Rikiligaskada	2014	C	10	Active
6	Vihara Road, Matale	2014	C	10	Active
7	Pujapitiya	2014	C	10	Active
8	Gangawatha korale	2014	C	10	Active
9	Ambagamuwa	2014	C	10	Active
10	Gangawatha korale	2014	C	3	Active
11	Varadala	2008	C	10	Non-Active
12	Badalgama, Diklanda	2008	C	20	Non-Active
13	Thalawathugoda	2009	C	10	Non-Active
14	Dompe	2008	C	15	Active
15	Wekada, Diulapitiya	2008	C	10	Non-Active
16	Aluthgama	2011	C	15	Active
17	Idigolla	2009	C	15	Active
18	Sirimalwatta, Kottawa	2009	C	10	Non-Active
19	Yakkala	2008	C	10	Active
20	Pathiyagoda	2012	C	15	Active
21	Guruwala	2014	C	15	Active
22	Kuruduwatta	2014	C	15	Active
23	Seeduwa		C	8	Non-Active
24	Kochchikade	2009	C	10	Active
25	Palugama	under construction	C	15	Non-Active
26	Kanupalalla	2010	C	20	Active
27	Badulla	2010	C	20	Active

28	Kanupalalla	2010	C	12	Active
29	Hindagoda	2010	C	20	Active
30	Pilipothagama	2010	C	20	Active
31	Uwapalwatta	2010	C	20	Active
32	Siiyabalanduwa	2010	C	20	Active
33	Gonaganara	2012	C	20	Active
34	Punsisigama	2012	C	20	Active
35	Egodagama	2013	C	20	Active
36	Nakkala	2013	C	20	Active
37	Okkampitiya	2013	C	20	Active
38	Nakkala	2009	C	20	Active
39	Hamurugala	2013	C	20	Active
40	Badulupitiya	2013	C	12	Active
41	Uwapalwatta	2013	C	20	Active
42	Uwapalwatta	2013	C	20	Active
43	Okkampitiya	2013	C	20	Active
44	Aththanapitiya	2014	C	20	Active
45	Bogahakubura	2014	C	20	Active
46	Kasbewa		C	12	Active
47	Damana,Galewala		C	8	Active
48	Damunaruwa, Galewala		C	12	Active
49	Kospotha, Galewala		C	10	Active
50	Daduhagolla, Galewala		C	12	Active
51	Pathkolagolla, Galewala		C	12	Active
52	Pahalawawa, Galewela		C	10	Active
53	Nikapitiya, Ussahapitiya		C	12	Active
54	Ihala Baulana, Delthota		C	12	Active
55	Madampe		C	10	Active
56	Alawwa		C	12	Active

57	Alawwa		C	10	Active
58	Haton		C	10	Active
59	Anuradhapura		C	30	Active
60	Diulankadawala		C	12	Active
61	Madiyawala		C	10	Active
62	Ibbankatuwa		C	10	Active
63	Atampitiya	2010	C	10	Non-Active
64	Rajanganaya	2011	C	8	Active
65	Weera, Polonnaruwa	2011	C	5	Active
66	Kirimatiya, Polonnaruwa	2011	C	8	Active
67	Malwana	2011	C	8	Active
68	Anuradhapuraya	2004	C	8	Active
69	Yaya 01, Rajanganaya	2000	C	8	Active
70	Tower No.2, A'pura	2006	C	10	Active
71	Mawathagama	2012	C	10	Active
72	Waduragala, Kurunegala	2012	C	8	Active
73	Horana,Pokunuwita	2012	C	8	Active
74	Muslim Kolani, Kaduruwela	2012	C	100	Active
75	Kamburugoda,Panadura	2012	C	8	Non-Active
76	Waduragala	2012	C	8	Non-Active
77	Madirigiriya	2012	C	50	Non-Active
78	Minneriya	2012	C	50	Non-Active
79	Kalagedihena	2013	C	8	Active
80	Madawachchiya	2013	C	10	Active
81	Streepura, Anuradhapura	2013	C	10	Active
82	Anuradapura	2014	C	40	Active
83	Nochchiyagama		C	100	Active
84	Keralankadawala		C	8	Active
85	Thalawaththegedara		C	8	Active

86	Nikadalupotha		C	8	Active
87	Nikadalupotha		C	8	Active
88	Nikadalupotha		C	8	Active
89	Neththipola		C	8	Active
90	Polgahawela		C	8	Active
91	Kurunegala		C	10	Active
92	Lokahettiya		C	10	Active
93	Walakulpola, Kurunegala		C	8	Active
94	Narammala		C	10	Active
95	Maharchchimulla		C	8	Active
96	Kurunegala		C	10	Active
97	Uhumeeya		C	8	Active
98	Uhumeeya		C	8	Active
99	Uhumeeya		C	8	Active
100	Egodagama		C	10	Active
101	Wellawa		C	8	Active
102	Matiyagane		C	8	Active
103	Boyagane		C	8	Active
104	Wewagama	2001	C	10	Active
105	Wewagama	2002	C	10	Active
106	Kirindawa	2002	C	10	Active
107	Deegalla	2002	C	10	Active
108	Wewagama	2002	C	10	Non-Active
109	Wewagama	2002	C	10	Non-Active
110	Apaladeniya	2003	C	10	Active
111	Nikawala	2003	C	10	Non-Active
112	Munamaldeniya	2003	C	10	Active
113	Wewagama	2003	C	8	Non-Active
114	Wewagama	2003	C	10	Active

115	Keenalawa	2003	C	10	Active
116	Wewagama	2003	C	10	Non-Active
117	Madakumburumulla	2003	C	10	Non-Active
118	Thuththiripitigama	2003	C	10	Non-Active
119	Hettipola	2003	C	10	Active
120	Moragaha	2003	C	10	Active
121	Thuththiripitigama	2003	C	10	Active
122	Wewagama	2003	C	10	Non-Active
123	Wewagama	2003	C	10	Non-Active
124	Mundalama	2011	C	10	Active
125	Karuwalagaswawa	2010	C	15	Active
126	Puttlam	2012	C	8	Active
127	Wannigama	2009	C	8	Active
128	Bongadeniya	2010	C	8	Active
129	Thorayaya	2009	C	8	Active
130	Lunuwila	2010	C	10	Active
131	Nagollagama	2010	C	15	Active
132	Serukale	2012	C	12	Active
133	Bangadeniya		C	8	Active
134	Kudanelumkulawa, A'pura		C	15	Active
135	Dompe		C	15	Active
136	Batticalo		C	8	Active
137	Nawala	2008	C	12	Active
138	Haguranketha	2010	C	15	Non-Active
139	Habarana	2011	C	30	Active
140	Pallekele	2011	C	30	Active
141	Pallekele	2011	C	25	Active
142	Katugasthota	2012	C	30	active
143	Thunthana	2012	C	20	Active

144	Malkaduwawa	2013	C	25	Non-Active
145	Akkareipaththuwa	2013	C	30	Active
146	Borella	2013	C	6	Active
147	Seethawaka	2013	C	42	Active
148	Homagama	2013	C	6	active
149	Trincomalee	2010	C	65	Active
150	Kankasanthure	2011	C	65	Active
151	Mathale	2012	C	22.5	Active
152	Polonnaruwa	2012	C	65	Active
153	Bataduwa,Galle	2013	C	22.5	Active
154	Akmeemana	2009	C	12	Active
155	Ananigoda,Halila	2014	C	22.5	Active
156	Unawatuna	2010	C	8	Active
157	Akmeemana	2007	C	8	Active
158	Galle	2007	C	8	Non-Active
159	Dadalla, Galle	2005	C	8	Active
160	Dadalla, Galle	2002	C	12	Non-Active
161	Dadalla, Galle	2002	C	12	Non-Active
162	Dadalla, Galle	1999	C	8	Active
163	Dadalla, Galle	2004	C	8	Active
164	Dadalla, Galle	2005	C	8	Active
165	Karapitiya, Galle	2006	C	22.5	Active
166	Balapitiya	2007	C	22.5	Active
167	Aththanagalla	2012	P	500	Active

***eg: Grama Niladhari Division, DS division, etc.**

****C - Chinese fixed dome /P - PVC balloon type**

Appendix C: Total Embedded Energy Value (EEV) calculation

Sample 1

	Biogas plant capacity	6m^3	8m^3	10m^3	12m^3					
No	**Items**	**Quantity**				**unit**	**EEV per unit (MJ)**	**per**	**Conversion factor**	
1	Engineering Bricks	1,750	2,000	2,250	2,500	unit	2.7	unit	1	
2	Cement	8	10	12	14	bags	2.8	kg	50	kg/bag
3	3/4" metal	4	4	5	6	ft^3	99	m^3	0.0283	m^3/ft^3
4	limestone	50	50	50	75	kg	6.15	kg	1	
5	10mm Iron bar	2	2	2	2		25	kg	7.32	kg/ bar
6	binding wire	50	50	50	50	g	25	kg	0.001	kg/g

No	Items	6m^3	8m^3	10m^3	12m^3
1	2*4*9 Engineering Bricks	4,725.00	5,400.00	6,075.00	6,750.00
2	Cement	1,120.00	1,400.00	1,680.00	1,960.00
3	3/4" metal	11.21	11.21	14.01	16.81
4	limestone	307.50	307.50	307.50	461.25
5	10mm Iron bar	366.00	366.00	366.00	366.00
6	binding wire	1.25	1.25	1.25	1.25

Total EE value	6,530.96	7,485.96	8,443.76	9,555.31	MJ
Energy production rate per day	30.00	40.00	50.00	60.00	MJ
EPBT	0.60	0.51	0.46	0.44	Years
	217.70	187.15	168.88	159.26	Days
EE/m3	1,088.49	935.74	844.38	796.28	MJ/m3

Sample Calculation for capacity of 6 m^3 in Sample no. 1

Total Embedded Energy = $\sum m_i e_i$

Where,

m_i= quantity of materials used in constructing biogas plants in kg

e_i = Energy density (Embedded Energy) of the material in MJ/kg

For bricks:

$$\text{EE Value for Engineering bricks} = \text{No of bricks (Ea)} \times \text{EE Value } (\frac{\text{MJ}}{\text{Ea}}) \times \text{Conversion factor}$$

$$\text{EE Value for Engineering bricks} = 1{,}750\ \text{(Ea)} \times 2.7\ \left(\frac{\text{MJ}}{\text{Ea}}\right) \times 1 = 4{,}725\ \text{MJ}$$

For Cement:

$$\text{EE Value for Cement} = \text{No of bags (Ea)} \times \text{EE Value } \left(\frac{\text{MJ}}{\text{kg}}\right) \times \text{Conversion factor}(\frac{\text{kg}}{\text{Ea}})$$

$$\text{EE Value for Cement} = 8\ \text{(Ea)} \times 2.8\ \left(\frac{\text{MJ}}{\text{kg}}\right) \times 50\ \left(\frac{\text{kg}}{\text{Ea}}\right) = 1{,}120\ \text{MJ}$$

For 3/4” metal:

$$\text{EE Value for 3/4" metal} = \text{Metal volume } (\text{m}^3) \times \text{EE Value } \left(\frac{\text{MJ}}{\text{ft}^3}\right) \times \text{Conversion factor}(\frac{\text{ft}^3}{\text{m}^3})$$

$$\text{EE Value for 3/4" metal} = 4\ \ (\text{m}^3) \times 99\ \left(\frac{\text{MJ}}{\text{ft}^3}\right) \times 0.0283\ (\frac{\text{ft}^3}{\text{m}^3}) = 11.21\ \text{MJ}$$

For limestone:

$$\text{EE Value for Limestone} = \text{Limestome weight (kg)} \times \text{EE Value} \left(\frac{\text{MJ}}{\text{kg}}\right) \times \text{Conversion factor}$$

$$\text{EE Value for Limestone} = 50\ (\text{kg}) \times 6.15 \left(\frac{\text{MJ}}{\text{kg}}\right) \times 1 = 307.50\ \text{MJ}$$

For 10 mm Iron bar:

$$\text{EE Value for 10 mm Iron bar} = \text{No of Iron bars (Ea)} \times \text{EE Value} \left(\frac{\text{MJ}}{\text{kg}}\right) \times \text{Conversion factor} \left(\frac{\text{kg}}{\text{bar}}\right)$$

$$\text{EE Value for 10 mm Iron bar} = 2\ (\text{Ea}) \times 25 \left(\frac{\text{MJ}}{\text{kg}}\right) \times 7.32 \left(\frac{\text{kg}}{\text{bar}}\right) = 366\ \text{MJ}$$

For binding wire:

$$\text{EE Value for binding wire} = \text{Binding wire weight (g)} \times \text{EE Value} \left(\frac{\text{MJ}}{\text{kg}}\right) \times \text{Conversion factor} \left(\frac{\text{kg}}{\text{g}}\right)$$

$$\text{EE Value for binding wire} = 50\ (\text{g}) \times 25 \left(\frac{\text{MJ}}{\text{kg}}\right) \times 0.001 \left(\frac{\text{kg}}{\text{g}}\right) = 1.25\ \text{MJ}$$

Total Embedded Energy Value = $\sum m_i e_i$

$$\text{Total EE Value} = \sum \text{EEV of Engineering bricks, Cement, 3/4" metal, limestone, 10 mm iron bar, binding wire}$$

$$\text{Total EE Value} = \sum 4725, 1120, 11.21, 307.50, 366, 1.25 = 4725 + 1120 + 11.21 + 307.50 + 366 + 1.25 = 6530.96\ \text{MJ}$$

$$\text{Energy production rate per day} = \text{Biogas plant capacity} \times \text{Biogas production rate per } 1m^3 \text{capacity} \times \text{Calorific value of biogas}$$
$$= 6 \times 0.25 \times 20 = 30\ \text{MJ}$$

$$\text{EPBT} = \frac{\text{Total EE Value}}{\text{Energy production rate per day} \times 365} = \frac{6530.96\ \text{MJ}}{30\ \text{MJ} \times 365} = 0.60\ \text{years}$$

$$\frac{\text{EE Value}}{\text{m}^3} = \frac{\text{Total EE Value}}{\text{Biogas plant capacity}} = \frac{6530.96\ \text{MJ}}{6\ \text{m}^3} = 1{,}088.49\ \frac{\text{MJ}}{\text{m}^3}$$

Sample 02

No	Items	8m³	10m³	12m³	30m³
1	2*4*9 Engineering Bricks	3240	4050	4860	11475
2	Cement	1960	2380	2800	7280
3	3/4" metal	1	1	1	4
4	limestone	31	31	31	62
5	GI pipe	729	365	365	365
6	10mm steel bar	0	0	0	1610
7	binding wire	6	6	6	38

Total EE value	5966.70	6832.20	8062.20	20833.07	MJ
Energy production rate per day	40	50	60	150	MJ
EPBT	0.409	0.374	0.368	0.381	Years
	149	137	134	139	Days
EE/ m^3	745.84	683.22	671.85	694.44	MJ/ m^3

Sample 03

No	Items	8m³	10m³	12m³	15m³	22m³	35m³	65m³
1	2*4*9 Engineering Bricks	4050	5400	5940	6210	8100	10800	14850
2	12mm steel	0	0	928	928	1114	1856	2599
3	10mm steel	966	966	1159	1159	1610	1932	2899
4	6mm steel	261	261	487	487	261	435	696
5	Cement	1680	2520	2800	3500	4667	7467	11200
6	Binding wire	75	75	63	63	250	375	625
7	Polythene	384	384	1074	1074	0	0	0
8	3" Nails	13	13	25	25	25	25	50
9	2" Nails	13	13	25	25	50	50	75
10	¾" Concrete Metal	140	280	420	420	420	560	841
11	1/2" GI pipe	0	0	183	183	0	0	0
12	¾" GI Pipe	140	140	0	0	0	0	0

Total EE value	7720.35	10050.44	13104.34	14074.34	16497.03	23500.68	33833.90	MJ
Energy production rate per day	40	50	60	75	110	175	325	MJ
EPBT	0.529	0.551	0.598	0.514	0.411	0.368	0.2852	Years
	193	201	218	188	150	134	104	Days
EE/ m^3	965.04	1005.04	1092.03	938.29	749.87	671.45	520.52	MJ/ m^3

	Biogas plant capacity	**6m³**	**8m³**	**10m³**	**12m³**	**15m³**	**22m³**	**30m³**	**35m³**	**65m³**	**Unit**
Total EE value	**Sample 1**	6,531	7,486	8,444	9,555						MJ
	Sample 2		7,720	10,050	13,104	14,074	16,497		23,501	33,834	MJ
	Sample 3		5,967	6,832	8,062			20,833			MJ
	Avg	6,531	7,058	8,442	10,241	14,074	16,497	20,833	23,501	33,834	MJ
EPBT	**Sample 1**	0.60	0.51	0.46	0.44						Years
	Sample 2		0.53	0.55	0.60	0.51	0.41		0.37	0.29	Years
	Sample 3		0.41	0.37	0.37			0.38			Years
	Avg	0.60	0.48	0.46	0.47	0.51	0.41	0.38	0.37	0.29	Years
		218	176	169	171	188	150	139	134	104	Days
EE/m3	**Sample 1**	1,088	936	844	796						MJ/m³
	Sample 2		965	1,005	1,092	938	750		671	521	MJ/m³
	Sample 3		746	683	672			694			MJ/m³
	Avg	1,088	882	844	853	938	750	694	671	521	MJ/m³

Appendix D: Total CO_2 emission calculation

Total CO_2 emission = $\sum m_iCF_i$

Where,

m_i= quantity of materials used in constructing biogas plants in kg

CF_i = Carbon factor of the material in kg/kg

Sample 01

No	Items	$6m^3$	$8m^3$	$10m^3$	$12m^3$
1	2*4*9 Engineering Bricks	928	1060	1192.5	1325
2	Cement	259	323.5	388.2	452.9
3	3/4" metal	0	0	0	0
4	limestone	38	38	38	57
5	10mm Iron bar	28	27.96	27.96	27.96
6	binding wire	0	0.10	0.10	0.10

Total CO_2 value	1252.36	1449.56	1646.76	1862.96	kg CO_2
CO_2/ m^3	156.54	144.96	137.23	124.20	kg CO_2/ m^3

Sample Calculation for capacity of 6 m^3 in Sample no. 1

Total CO_2 emission = $\sum m_i CF_i$

Where,

m_i = quantity of materials used in constructing biogas plants in kg

CF_i = Carbon factor (CO_2 emission factors) of the material in kg/kg

For bricks:

$$\mathrm{CO_2\ emission\ \ for\ Engineering\ bricks} = \mathrm{No\ of\ bricks\ (Ea)} \times \mathrm{CO_2\ emission\ factor}\ \left(\frac{\mathrm{kg}}{\mathrm{Ea}}\right) \times \mathrm{Conversion\ factor}$$

$$\mathrm{CO_2\ emission\ \ for\ Engineering\ bricks} = 1{,}750\ \mathrm{(Ea)} \times 0.53\ \left(\frac{\mathrm{kg}}{\mathrm{Ea}}\right) \times 1 = 927.5\ \mathrm{kg}$$

For Cement:

$$\mathrm{CO_2\ emission\ \ for\ Cement} = \mathrm{No\ of\ bags\ (Ea)} \times \mathrm{CO_2\ emission\ factor}\ \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times \mathrm{Conversion\ factor}\left(\frac{\mathrm{kg}}{\mathrm{Ea}}\right)$$

$$\mathrm{CO_2\ emission\ \ for\ Cement} = 8\ \mathrm{(Ea)} \times 0.647\ \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times 50\ \left(\frac{\mathrm{kg}}{\mathrm{Ea}}\right) = 258.8\ \mathrm{kg}$$

For 3/4" metal:

$$\mathrm{CO_2\ emission\ \ for\ 3/4''\ metal} = \mathrm{Metal\ volume\ (m^3)} \times \mathrm{CO_2\ emission\ factor}\ \left(\frac{\mathrm{kg}}{\mathrm{ft^3}}\right) \times \mathrm{Conversion\ factor}\left(\frac{\mathrm{ft^3}}{\mathrm{m^3}}\right)$$

$$\mathrm{CO_2\ emission\ \ for\ 3/4"\ metal} = 4\ (\mathrm{m^3}) \times 0.0048\ \left(\frac{\mathrm{kg}}{\mathrm{ft^3}}\right) \times 0.0283\ \left(\frac{\mathrm{ft^3}}{\mathrm{m^3}}\right) = 0.0005\ \mathrm{kg}$$

For limestone:

$$\mathrm{CO_2\ emission\ \ for\ Limestone} = \mathrm{Limestome\ weight\ (kg)} \times \mathrm{CO_2\ emission\ factor} \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times \mathrm{Conversion\ factor}$$

$$\mathrm{CO_2\ emission\ \ for\ Limestone} = 50\ (\mathrm{kg}) \times 0.74 \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times 1 = 37\ \mathrm{kg}$$

For 10 mm Iron bar:

$$\mathrm{CO_2\ emission\ \ for\ 10\ mm\ Iron\ bar} = \mathrm{No\ of\ Iron\ bars\ (Ea)} \times \mathrm{CO_2\ emission\ factor} \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times \mathrm{Conversion\ factor} \left(\frac{\mathrm{kg}}{\mathrm{bar}}\right)$$

$$\mathrm{CO_2\ \ emission\ \ for\ 10\ mm\ Iron\ bar} = 2\ (\mathrm{Ea}) \times 1.91 \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times 7.32 \left(\frac{\mathrm{kg}}{\mathrm{bar}}\right) = 27.96\mathrm{kg}$$

For binding wire:

$$\mathrm{CO_2\ \ emission\ \ for\ binding\ wire} = \mathrm{Binding\ wire\ weight\ (g)} \times \mathrm{CO_2\ \ emission\ factor} \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times \mathrm{Conversion\ factor} \left(\frac{\mathrm{kg}}{\mathrm{g}}\right)$$

$$\mathrm{CO_2\ \ emission\ \ for\ binding\ wire} = 50\ (\mathrm{g}) \times 1.91 \left(\frac{\mathrm{kg}}{\mathrm{kg}}\right) \times 0.001 \left(\frac{\mathrm{kg}}{\mathrm{g}}\right) = 0.0955\ \mathrm{kg}$$

Total $\mathbf{CO_2}$ emission = $\sum \mathbf{m_i\ CF_i}$

$$\mathrm{Total\ CO_2\ \ emission\ } = \sum \mathrm{CO_2\ \ emission\ \ of\ Engineering\ bricks, Cement, metal, limestone, 10\ mm\ iron\ bar, binding\ wire}$$

$$\text{Total CO2 emission} = 927.5 + 258.8 + 0.005 + 37 + 27.96 + 0.0955 = 1252.36\ \text{kg}$$

Sample 02

No	**Items**	**8m³**	**10m³**	**12m³**	**30m³**
1	2*4*9 Engineering Bricks	636	795	954	1325
2	Cement	453	550	647	1682
3	3/4" metal	0	0	0	0
4	limestone	3.80	3.80	3.80	7.60
5	GI pipe	55.70	27.85	27.85	27.85
6	10mm steel bar	0	0	0	121
7	binding wire	0.48	0.48	0.48	2.87

Total CO_2 value	1148.87	1377.08	1633.13	3166.75	kg CO_2
CO_2/ m^3	143.61	137.71	136.09	105.56	kg CO_2/ m^3

Sample 03

No	Items	$8m^3$	$10m^3$	$12m^3$	$15m^3$	$22m^3$	$35m^3$	$65m^3$
1	2*4*9 Engineering Bricks	795	1060	1166	1219	1590	2120	2915
2	12mm steel	0	0	70	70	84	140	196
3	10mm steel	73	73	87	87	121	145	218
4	6mm steel	20	20	37	37	20	33	52
5	Cements (SLS)	388	582	647	809	1078	1725	2588
6	Binding wire	6	6	5	5	19	29	48
7	Polythene	8	8	22	22	0	0	0
8	3" Nails	1	1	2	2	2	2	4
9	2" Nails	1	1	2	2	4	4	6
10	1/2 GI pipe	0	0	14	14	0	0	0
11	¾" GI Pipe	11	11	0	0	0	0	0

Total CO_2 value	1301.75	1760.85	2051.40	2266.15	2917.90	4197.70	6026.58	kg CO_2
CO_2/ m^3	162.72	176.08	170.95	151.08	132.63	119.93	92.72	kg CO_2/ m^3

	Biogas plant capacity	**6m³**	**8m³**	**10m³**	**12m³**	**15m³**	**22m³**	**30m³**	**35m³**	**65m³**	**Unit**
Total CO2 emission	**Sample 1**	1,252	1,450	1,647	1,863						kg CO_2
	Sample 2		1,149	1,377	1,633			3,167			kg CO_2
	Sample 3		1,302	1,761	2,051	2,266	2,918		4,198	6,027	kg CO_2
	Avg	1,252	1,300	1,595	1,849	2,266	2,918	3,167	4,198	6,027	kg CO_2
CO2/m3	**Sample 1**	156.5	145.0	137.2	124.2						kg CO_2/ m^3
	Sample 2		143.6	137.7	136.1			105.6			kg CO_2/ m^3
	Sample 3		162.7	176.1	171.0	151.1	132.6		119.9	92.7	kg CO_2/ m^3
	Avg	156.5	150.4	150.3	143.7	151.1	132.6	105.6	119.9	92.7	kg CO_2/ m^3