

NORWEGIAN UNIVERSITY OF LIFE SCIENCES



Biogas Production from Municipal Organic Waste, A Process of Sustainable Development in Lahore, Pakistan (A Review)

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DECLARATION:

I Muhammad Abbas, declare that this thesis is a result of my research investigation and my own findings. All of sources other than my own knowledge have been acknowledged and a reference list has been attached at the end. This work has never been previously submitted to any other university for the award of any degree or diploma.

Signature _____

Place and Date _____

DEDICATION:

I dedicate this work to my beloved family and especially my wife and sweet daughter Eishal Abbas. God bless you for sacrificing to stay away during the days when I was working on my thesis. With the help of God and your constant encouragement to enable me to complete this task.

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In the name of Allah, the most merciful and the beneficent who blessed me with the potential to complete this task. The blessing of the Prophet Muhammad (PBUH) who is a torch of knowledge for all Muslims.

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ABSTRACT

Proper disposal of municipal solid waste of Lahore is one of the major challenges for responsible waste management authorities. Various studies reveal that about 50 to 70% of the generated waste is collected in Lahore while the rest of the waste lies in the street, walkways and in vacant plots. The collected waste is dumped in the open and uncontrolled landfills without any energy recovery. The present study is a literature review study where an attempt is made to find out sustainable solution for the disposal of municipal organic waste of Lahore. In the present study it is found out that biogas production from the municipal organic waste is a sustainable source of handling the waste. Hence, the biogas production will also help to achieve sustainable development in Lahore due to reducing the gap of demand and supply of electricity shortfall through renewable energy sources (biogas), greenhouse gas emission reduction substituting the fossil fuel and receiving the economic benefits from biogas.

Biogas production from municipal solid waste Lahore will improve environmental quality of the surrounding by reducing GHG emission and control the leachate pollution. A rough estimate of the study shows that if 100% of the generated municipal organic waste of Lahore is collected and utilized for biogas production this can produce 352,745.96 m³ biogas/ day. The produced biogas can be utilized for electricity production or upgraded biogas can be used in the vehicles which substitutes the fossil fuel. Of this produce biogas 884MWh electricity can be generated with 35% electric conversion efficiency while 50% of the biogas energy can be utilized for cooling or heating the buildings. In addition to these 18,234,387.4 tons CO₂ equivalent/year can be avoided due to changing of current improper waste disposal system to biogas and the substitution of electricity and chemical fertilizer. From the economic point of view biogas production from the municipal organic waste of Lahore can generate revenue of US\$ 844.34 billion /year due to the substitution of fossil fuel, chemical fertilizer replacement with digestates and through carbon credit scheme.

ABBREVIATION

FAO	Food and Agriculture Organization
MCL	Metropolitan Corporation of Lahore
PCRET	Pakistan Council of Renewable Energy Technology
BSP	Biogas Support Program
PDBP	Pakistan Domestic Biogas Program
RSPN	Rural Support Network Program
GGS	Greenhouse Gas
PDDC	Pakistan Dairy Development Company
NGOs	Non-Governmental Organization
NRSP	National Rural Support Program
ADP	Association for the Development of Pakistan
PCAT	Pakistan Council for Appropriate Technology
GoP	Government of Pakistan
ADB	Asian Development Bank
UNDP	United Nation Development Program
GTZ	German Technical Corporation
ARE	Alternative Renewable Energy
EPD	Environmental Protection Department
SWM	Solid Waste Management
CDA	Capital Development Authority
MSWM	Municipal Solid Waste Management
LWMC	Lahore Waste Management Company
CDM	Clean Development Mechanism
ESMAP	Energy Sector Management Assistance Program
UNFCCC	United Nation Framework Convention on Climate Change
BetaPak	Bio Energy Technology Application Pakistan
HDIP	Hydro Carbon Institute of Pakistan
NGV	Natural Gas Vehicles

EIA	U.S Energy Information Administration
WAPDA	Water and Power Development Authority
MTDF	Medium Term Development Framework
IEA	International Energy Agency
CHP	Combine Heat and Power
GMP	Global Warming Potential
GoPED	Government of Punjab Energy Department
SGC	Sweden Gas Center

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Chapter 1:

1.1 Introduction and Problem Statement

In Pakistan huge amount of municipal solid waste (MSW) is generated daily. Like other developing nations, MSW is highly neglected area in Pakistan pertaining to overall environmental management and energy recovery point of view (Batool and Ch, 2009). More specifically in Lahore about 6000 tons of municipal solid waste produce daily in 9 different towns (ESMAP, 2010) with approximately 0.84 kg per capita waste generation rate (Batool and Ch, 2009). The management of this enormous amount of MSW is a big challenge for responsible authorities and visible problem and harmful effects of improper waste handling has been reported in many studies. Currently, in Lahore 60% of the produced MSW is collected while the rest of the 40% waste remains uncollected and lies along roadsides, streets, railway lines, depressions, vacant plots, drains, storm drains and open sewers (Batool and Chuadhry, 2009). The collected waste even improperly managed, disposed off in open dumps and in unstandardized landfills. This contributes to unattractive environment, poor sanitation conditions, disease, pollution of water bodies and environmental degradation (ESMAP, 2010). The main problem concerning to proper disposal and treatment of MSW includes lack of reliable data and research, shortage of trained manpower, inadequate legal and regulatory cover, poor institutional and administrative arrangements, shortage of equipment, financial and technical difficulties and a serious shortage of competent private operators (Batool and Ch, 2009).

The municipal solid waste (MSW) is treated differently in different parts of the world. The waste is naturally degraded in unstandardized landfills, burnt the waste in dump sites and through controlled aerobic and anaerobic digestion process. The first two processes are widely in operation in developing countries and large volume of methane and carbon dioxide is released into the atmosphere. The release of these gases into the atmosphere becomes very harmful for the environment (Jingura and Matengaifa, 2009). The natural degradation of the organic matter is causing smell and spreading of diseases in the surroundings.

Natural biodegradation of organic matters contributes approximately 590-800 million tons of methane in the atmosphere (Bond and Templeton, 2011). Waste water and landfills constitute 90% of waste sector emissions and about 18% of global anthropogenic methane (CH₄) emissions

(Bogner et al., 2008). The methane (CH₄) which has high potential of global warming either can be taped or freely released into the atmosphere. The latter situation take place when the organic matters are illegal disposed of or thrown away in the vacant places. The taped methane (Biogas) used as a source of energy while un-taped methane is very harmful for the environment (Bond and Templeton, 2011).

Several researches have been conducted in the world to solve local, regional and global problems due to the improper disposal of MSW which are discussed in the previous sections. Most of these researches showed their reliance on renewable energy for sustainable development to meet their daily energy needs through waste to energy routes that cause less negative environmental and social impacts (Rao et al., 2010) as well as energy is recovered during the process. Several definitions of sustainable development have been put forth but the following is very common one 'the development that meets present generation needs without compromising on future generation needs' (Dincer, 2000). Environmental compatibility is a crucial asset of renewable energy. In line with other renewable resources waste to energy technology like biogas will become an attractive alternative of energy in near future (Kothari et al., 2010).

Biogas is a renewable source of energy which is produced in the bioreactor through anaerobic digestion process by using waste as feedstock. The waste includes municipal solid waste, industrial waste water, animal excreta and agricultural waste used for biogas production. Bond and Templeton (2011) illustrate that biogas is a holistic approach to get rid of from organic waste and producing energy through anaerobic digestion process which makes it a sustainable source of energy. Even though, in some cases biogas is preferred because of resource efficiency over other renewable energy sources like bioethanol and biodiesel as mitigation of GHG emissions (Börjesson and Mattiasson, 2008).

Typically biogas contains 50-70% methane and 30-50% carbon dioxide and small amount of other gases. It has a calorific value of 21-24 MJ/m³(Bond and Templeton, 2011). Anaerobic digestion is the process and technique of decomposition of organic matter by a microbial process in an oxygen-free environment (FAO, 1996). Controlled anaerobic digestion of organic wastes has multiple benefits. On one hand, it provides a renewable source of clean energy, while on the other side the digestates can be used as organic fertilizers in the agriculture sector. The electricity

and fuel production from the biogas might strengthen the national energy supply, as well as reduce greenhouse gases (GHG) emissions (Yadvika et al., 2004)

So far, Lahore compost plant is the only one plant in Pakistan which recycles only 20% of the total Lahore collected municipal solid waste into organic rich fertilizer without recovering the energy. This study is an attempt to find out biogas potential from organic municipal solid waste in Lahore district, Pakistan. The study proposes a large scale biogas plant in Lahore and demonstrates how it helps to achieve sustainable development in the city? The study also demonstrates biogas utilization and its benefits. .

1.2 Objectives

The overall aim of this study is to assess biogas potential from municipal solid waste in Lahore district, Pakistan.

The specific objectives are:

- 1 To identify the** technology and process required producing the biogas from the organic municipal waste?
- 2 To calculate** GHG emission reduction due to the implementation of biogas technology in Lahore. The emissions are calculated on the basis of current waste disposal system of open landfills and dumping sites

1.3 Research questions

The study has following research questions:

- How biogas plants can significantly play a role to energy crisis and reduce greenhouse gas (GHG) emissions in Pakistan?
- How much biogas can be produced from Municipal waste in Lahore?
- How much digestates can be produced and how much chemical fertilizers can be substituted in terms of mass volume and nutrients value?
- How much economic revenue can be generated through the production of biogas?

1.4 Thesis structure

This thesis is consists of 8 chapters. The first chapter gives the introduction of the title and problem statement of the study. It also includes the research objectives and questions of the present study. The second chapter explains about the historical development of manure based household biogas plant in Pakistan and on-going projects about waste management in Lahore. In addition to this 2nd chapter also gives a brief overview of renewable energy policies in Pakistan. Third chapter demonstrate the conceptual framework of the study and explains how internal and external factors and sectors influence on biogas system or vice a versa. Fourth chapter is about the literature review of the study. This chapter is divided in two parts. In the first part a critical review is made on the existing biogas potential studies from Pakistan. The second part explains about the environmental, economic, energy and health benefits of biogas reported in the literature. Fifth chapter demonstrate the methodology used in the present study. Sixth chapter provides findings and discussion. Moreover, in the 6th chapter biogas potential from organic municipal waste of Lahore and greenhouse gas emission calculation has been quantified. Discussion is included in the chapter 7th. Chapter 8th consists of conclusion and future research and development in this field.

Chapter 2 Background

2.1 Development of Biogas Plants in Pakistan

Pakistan is one of those many countries in the world where biogas technology was initiated many years ago, but has not yet been widely and successfully adopted. Biogas plant development history goes back 54 years ago when the first biogas plant was initiated. The conventional use of animal dung in the form of dung cake as a source of energy for cooking and lighting has been practiced for a long time in the villages of Pakistan. This mode of energy was not limited only in rural areas, but it was the major source in the urban areas until the natural gas was discovered in Pakistan. This section of the thesis will give a historical overview of biogas plants in Pakistan.

Based on biomass resource availability from livestock and crop residues for biogas production, the country has a potential to install 5 million biogas digesters. Until 2006, only six thousand small scale biogas plants are being installed (Ghimire, 2007a). The use of biomass resource in Pakistan is not very efficient for energy purposes and potential is wasted because of non-scientific conventional technologies (Sahir and Qureshi, 2008). Contrary to this, in China and India 6.8 million household and 1000 medium and big size biogas plants were installed by the end of 2007 (Amjid et al., 2011). Compared to these 1000 biogas plants in China and India, Pakistan Council for Renewable Energy Technology installed only 3 community based and one big thermophilic plants, but none of them is working (Ibid, 2011). In Nepal, the first biogas plant was installed in 1975 and 90,000 biogas units set up before 2003 (Pokharel, 2003).

In 1959, first biogas plant was installed in Pakistan under domestic biogas plant initiative in Sindh area (Sheikh, 2010). This was after the government took some important steps on national and community levels to promote biogas technology in the country. The government established Pakistan Council of Appropriate Technology (PCAT) in 1975 and National Institute of Silicon Technology in 1981. In 2001 both of these departments NIST and PCAT merged to Pakistan Council for Renewable Energy Technology (Sheikh, 2010). From 1974 to 1986 Pakistan Council for Appropriate Technology (PCAT which is now PCRET) launched a project to install 4,137 biogas plants in the rural areas of the country in three different phases (Ghimire, 2007a). In the first phase, 100 biogas plants were installed for free for publicity reasons. The second phase

included a 50% subsidy and the third phase included only technical support to the beneficiaries (Amjid et al., 2011).

In 2000, the Biogas Support Programme (BSP) was initiated. Under this scheme, 1,200 plants have been set up and there was a plan to install 10,000 more plants in the next five years. Through the installation of these planned plants, the target was to exploit 27% of the total biogas potential in the country (Amjid et al., 2011).

NGOs have also played a very important role in the installation of biogas plants in the country. Until 2007, Pakistan Council for Renewable Energy and Technology (PCRET) was at the leading position by setting up 1600 biogas plants (Bikash Panday, 2007). However, up to January 2013, a non-profit NGO Rural Support Network Programme (RSPN) installed 2,774 biogas plants in 12 different districts of Punjab under Pakistan domestic biogas plant (PDBP) programme. Rural support programme network (RSPN) success story in the biogas plant field is due to appropriate policies and practical knowledge of biogas technology. More than 250 technically trained masons were used to build biogas plants. RSPN has as a future policy to achieve carbon credits under CDM by installing 300,000 biogas plants in the country. Biogas plants help to reduce the use of firewood for cooking, which further assists to reduce CO₂ emission and deforestation. Rural Support Programme Network (RSPN) vision is highly appreciable in the reduction of GHG emissions and to fulfil the energy demand through renewable energy source. But probably this will get very low positive assistance from carbon credit scheme because the prices of per ton CO₂ emissions are gradually going down and especially in the future when RSPN will achieve its target of 300,000 biogas plant (RSPN, 2013).

Pakistan Dairy Development Company (PDDC) installed some biogas plants in 2009 and received very overwhelming public response. Due to this positive public response PDDC increased their number of biogas units from 450 to 556 (Amjid et al., 2011). The aim of PDDC is to provide low cost energy to the rural people by providing 50% subsidies to each unit. Similarly, with the help of New Zealand Aid the Alternative Energy Development Board (AEDB), installed biogas units in Karachi with the aim to produce 250KW electricity by using the manure of 400,000 cattle of the area (Sheikh, 2010). A NGO 'Koshis' in the Sialkot region installed 200 biogas plants. Similarly, another NGO (Initiative for Rural and Sustainable Development- IRSD), installed 150 biogas plants in the Maira Khurd area which is near to the

capital city (Islamabad). The previous mentioned plants were installed with the help of UNDP under Small Grants Programme. PRSP and NRSP also installed 200 biogas plants (Ghimire, 2007a).

Near Soon Valley in Punjab with the help of ADP, 15 new biogas plants were installed at three different stages. These plants are small farm scale units and provide the energy demand of approximately 360 residents of the area. Each plant serves 24 people to meet their needs with the respect of cooking and lights(ADP, 2011). Most of the existing biogas plants are in Punjab province.

2.1.1 Design of Existing Biogas Plant in Pakistan

The design of biogas plant in Pakistan is very simple. Mostly the plants are installed in the vicinity of home. This reduces transportation cost of substrate to feed biogas plant. The construction material is based on concrete, bricks and steel and traditional knowledge and local technology has been used. The cost is variable depending on the size of the biogas plants. For the average household biogas unit, the cost ranges from 35,000 to 50,000PKR which is around US\$500 (Ghimire, 2007a, ADP, 2011)

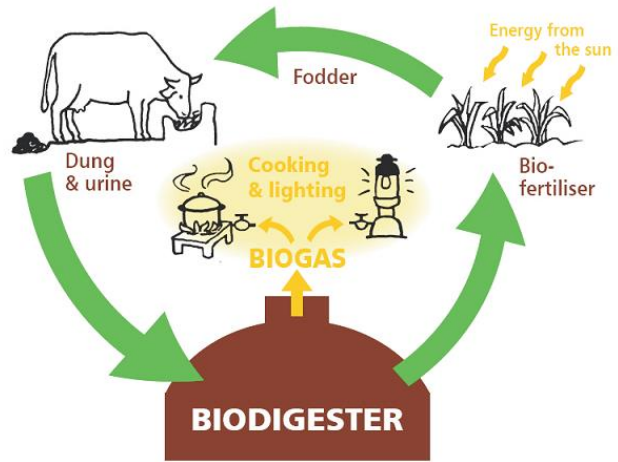


Figure 1 Household Biogas plants www.afrisolenergy.com

The floating drum is the most commonly used design in Pakistan. Twenty one Chinese fixed domes were installed on pilot basis, but failed because of consistent leakage from the Hair line, seepage, and low gas pressure. The floating drum design become popular over Chinese fixed dome because of its less leakage. Later on, Indian Dheenbandhu and Nepali design GCC 2047 6m3design was also introduced and being practiced in Pakistan. These designs are also widely used and are successful because of less leakage and high gas yield (Ghimire, 2007a).

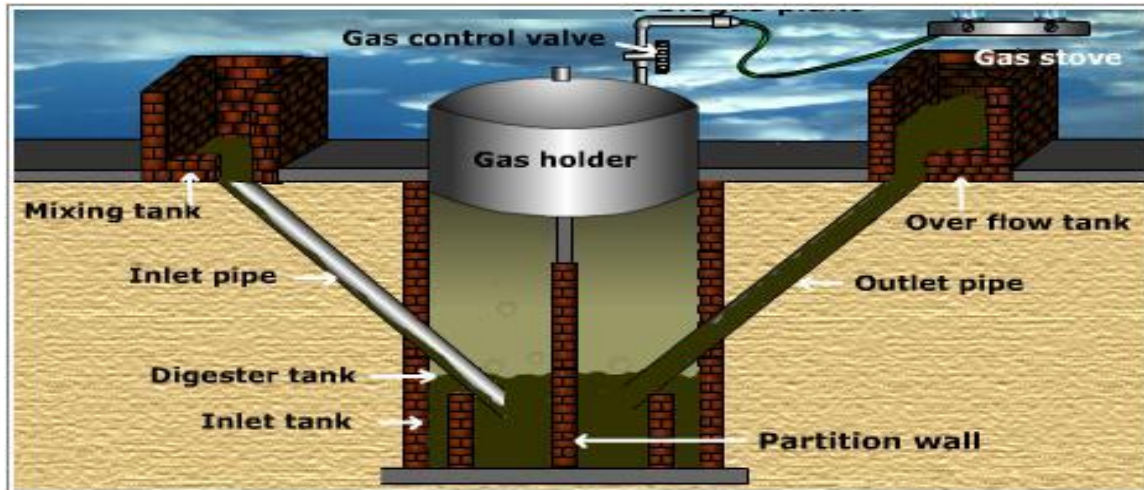


Figure 2 Floating Drum and Fixed dome biogas plant shape source: www.tutorvista.com



Figure 3 Nepali GCC Biogas Plant Design source: Bajgain, S. (1994)

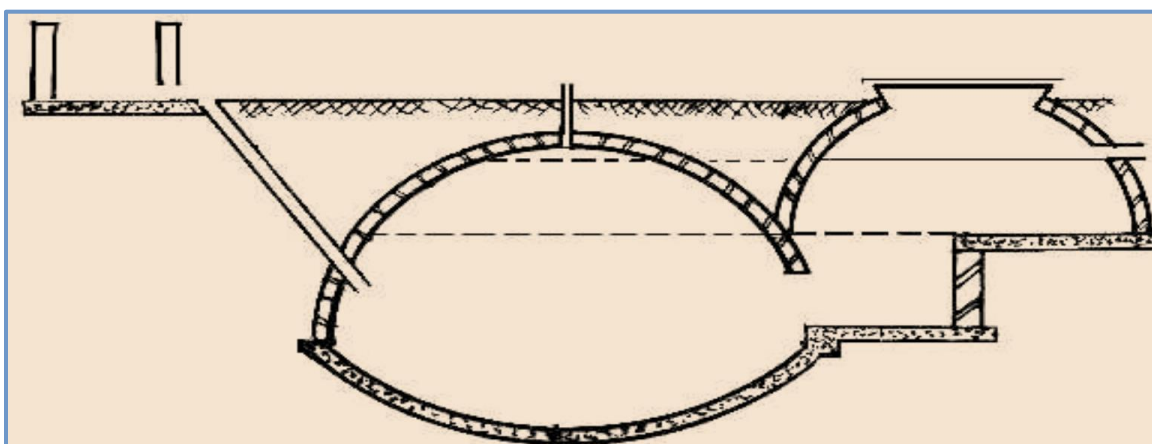


Figure 4 Indian Dheenbandu Biogas Plant Design Source: (Action for Food Production, can be found at www.afpro.org)

The installed biogas plants are small in scale with varying capacity of 5-15 m³ biogas production per day (Ghimire, 2007b). Organic waste which is a good substrate for biogas production is totally absent in Pakistan. The installed biogas plants in Pakistan are fed by animal dung with the same amount of water. These small scale biogas plants are designed to meet the energy demand at household level. Beside these small scale plants, only 2 medium size 20 and 35 m³ plants Nepali design GCC 2047 have been installed in Dera Ismail Khan by the Rural Support Programme Network with the financial help of Foundation for Integrated Development Action (Ghimire, 2007a)..

2.1.2 Problems with the Existing Biogas plants in Pakistan

It is not worth mentioning how many plants are installed in the country unless they are not functioning well or contributing in the national energy supply. The average reported life spans of the biogas plant in Pakistan are 5 year (Sheikh, 2010) and 15-20 years (Sahir, 2008). The average life span variation depends on the maintenance of the plant. As many of the biogas plants are reported non-functional because of technical faults and un-standardized model, lack of training to use and maintain the plant, climate issues and financial problems (Pandey, 2007). The government initiated biogas project has been failed because of financial problem, lack of technical support and lack of community training to maintain and adapt with the facility (Amjid et al., 2011). Similarly, 21 biogas installed by the Pakistan Council for Appropriate Technology (PCAT) plants were reported failed because of the un appropriate technology (Ghimire, 2007a).

We can easily claim that none of the biogas plants installed before 15 years is really currently working. No research has been done neither from government departments nor NGOs to find out the number of functional and non-functional biogas plants in the country.

In spite of the various efforts and promotion of biogas plants by PCRET, AEDB and other international and National NGOs, there is still an energy crisis in the rural area of the country. Pakistan Council for Renewable Energy (PCRET) and other departments have spent billions of rupees since the first biogas plant was demonstrated, but they are unable to fulfil the energy demand. For the year 2012-13, PCRET allocated 89 million PKR for biogas plants development and dissemination (PCRET, 2013). Considering the past and present performance of biogas units in Pakistan and associated problems with them, there is a need for better technology equipped

biogas plants which can give more gas yield and sustain in the winter temperature. There is no doubt that high technology equipped biogas plants would be more expensive compared to existing ones in the country, but they can be more beneficial and government can provide subsidies. There is a need for organized and revised policies and follow up services to maintain the biogas plants in the country.

2.2 Renewable Energy Policies in Pakistan

Pakistan has abundant renewable energy resources and so far these resources have not been employed for energy production except in hydroelectricity dams (GOP, 2006). About 99% of the supplied energy is produced from conventional sources such as oil, gas, hydro, and nuclear. On the other hand, only 1% of the energy is produced from micro renewable energy projects whereas the country has abundant of renewable resources (Sheikh, 2010).

To use the enormous renewable potential the Ministry of Water and Power initiated in 2005 and 2006 the development of renewable energy sector with a very comprehensive Alternative Renewable Energy Policy (AEDB, 2013). This policy was divided in three phases, short, medium and long term. Through this short term ARE 2006 Policy, the government started to offer strong incentives to attract local and international investor to the sector. Barrier to implementations was also removed (ibid, 2013). The ARE Policy 2006 ended in June, 2008, and this was replaced by medium term ARE Policy 2011. The experience and challenges in the short term policy provided the basis for the next medium term policy (GoP, ARE, 2011). The medium term policy 2011 includes more renewable resources, for example, waste to energy, geo thermal, biodiesel and ethanol. Hence these resources were not prioritized in the short term policy 2006. The government demonstrate in the Alternative Renewable Energy Policy 2011 document that;

The GoP's strategic objectives of Energy Security, Economic Benefits, Social Equity, Environmental Protection, Sustainable Growth and Gender Mainstreaming, now are further harnessed under the ARE Policy 2011, developed by the Ministry of Water and Power with the support of international agencies including Asian Development Bank (ADB), USAID, UNDP, German Technical Corporation (GTZ), Energia International and with consensus of all relevant stakeholder including provincial governments, private sector and academia. The ARE Policy 2011 will help to create a conducive environment for the growth of domestic ARE Sector.

The Medium Term policy is the Consolidation Phase for sustainable growth of the renewable energy sector (2010– Dec 2014) and the Long Term policy will be the Maturity Phase for competitive growth which will start from January, 2015 (AEDB, 2013).

2.3 Renewable energy institutions in Pakistan

In 1975, the government of Pakistan established Pakistan Council for Appropriate Technology (PCAT) and National Institute of Silicon Technology (NIST) in 1981(Sheikh, 2010). The aim of these institutions was to facilitate, promote and explore the renewable energy resources in the country. Then in 2001, PCAT and NIST merged to become Pakistan Council for Renewable Energy Technologies (PCRET). In 2003, the autonomous body Alternative Energy Development Board (AEDB) was established by the government of Pakistan. Since then, PCRET and AEDB are two government institutions working for the execution, promotion and implementation of renewable energy projects in Pakistan (Sheikh, 2010). Many national and international NGOs and UNs departments are also working on research and development (R&D) of renewable energy in Pakistan.

2.3.1 Barriers in the Renewable Energy Development

- Policy and regulatory barriers: Lack of well-defined policies for public and private partnership. Red trapezium? And delay in the projects allotments and payments. Inadequate incentives for the power producers from renewable resources
- Institutional barriers: lack of coordination between different ministries, organizations, agencies and stakeholders. Lack of proper legislation and sometimes government provided incentives are misused
- Financial barriers: insufficient funds to develop renewable energy projects
- Local market barriers: lack of local market infrastructure to promote sale of renewable energy technologies and the end products
- Technology barriers: minimum standards in terms of durability, performance and reliability are not followed. Lack of technical renewable energy experts
- Information and social barriers (Mirza et al., 2009).

2.4 Solid Waste Management policies in Pakistan

Environmental legislation is not well developed in Pakistan compared to other developed world. There are no National Quality Standards (NQS) for solid waste management (SWM). Due to recent past climatic catastrophes (floods and earthquakes), the government of Pakistan has taken some initiative to reform and regulate urban services in the country. The government established waste management agencies and facilitated technical assistant from international experts for the better management of solid waste in the country (EPD, 2012). The government also established solid waste management (SWM) rules under the Local Government Ordinance 2001(Mahar, 2012). But practically, neither at province nor city level solid waste management are not fully developed to include all aspect of municipal waste. These aspects include collection, transportation, recycling and energy recovery of the municipal solid waste. In Pakistan, only 60% generated municipal waste is collected and out of this 40% waste is disposed of in land filling, 3% compost, 3% waste as fuel and 5% recycled (ibid, 2012). Still there are no proper regulations about waste recycling in Pakistan and none of the formal sector (government department) is involved in this activity. In Lahore, some informal sectors are currently working in the recycling business at small scale level (Batool and Chuadhry, 2009).

2.4.1 National Institutional Mechanism of SWM

Generally in Pakistan; the solid waste management has been the responsibility of the local government. But high population growth rate led to an increase in the quantity of municipal waste which creates many environmental problems. Various institutions are now involved in different aspects of waste management services chain. Broadly, the involvement of these institutions is categories into two:

- Direct waste management service
- Indirect waste management service (support service)

The direct management services are provided by those institutions which are directly linked in the management, transportation, and recycling etc of the municipal solid waste like Environmental Protection Authority (EPA), Capital Development Authority (CDA) in Islamabad and Lahore Waste Management Company (LWMC) in Lahore. Indirect or support services are

provided by the academia, political department and officials, financial and technical institutions. The purpose of support services is to enhance efficiency and effectiveness of the waste management institutions through awareness raising campaigns, technical expertise and finance.

At institutional level Ministry of Environment, Local Government and Rural Development has played three important functions; as a regulatory agency, technical support agency and public health agency. Recently in Pakistan local government, the town/Tehsil Municipal Administration (TMAs) are the responsible for the solid waste management. There are some exceptions where the districts have this responsibility. Before the devolution of local government in 2003, municipal solid waste management (MSWM) was under the responsibility of Provincial Public Health Engineering Department (PHED) (UNEP, 2010)

2.4.2 Challenges and Issues of Solid Waste Management in Pakistan

- There is no proper waste collection system
- The waste is openly dumped on streets, in free residential plots, at barren lands. No controlled sanitary landfills sites are available
- No waste to energy project is functioning
- No waste separation (source separation) method is practiced neither at household and offices level nor at commercial (restaurant, hotel)
- No formal (large scale government project) recycling institution is working
- The citizens are unaware of infectious and non-infectious solid waste
- No policy and regulatory framework exist for SWM
- Financial constraints to buy transport for waste collection and industrial set up for recycling and waste to energy

(Mahar, 2012, EPD, 2012)

2.4.3 Solid Waste Management Agencies and Project in Lahore

The solid waste management system was formalized in Lahore when it became part of Lahore Urban Development Project (LUDP) which started in 1978. Then in 1980, in the pre-appraisal mission of the World Bank, a solid waste management (SWM) project was initiated in Lahore.

At that time, this solid waste management (SWM) was under the authority of Metropolitan Corporation of Lahore (MCL) (Batool et al., 2008).

Lahore Waste Management Company (LWMC) was established by the City District Government Lahore (CDGL) for the better management of solid waste in Lahore. The Company was established under section 42 of company ordinance 1984 Lahore Waste Management Company (LWMC, 2013). It is working under the mission '*to provide waste management program that contributes to maintain the health of the residents by ensuring that waste is removed from the city and disposed off in an environmentally acceptable manner*'(LWMC, 2013).The waste is collected and transported to three main dumping sites in Lahore. Recently the collection and transportation of household waste was outsourced to some international contractors. Some Turkish contractors are involved in the transportation of solid waste in Lahore. Batool and Chaudhry (2009) demonstrate that about 60% of total generated waste in Lahore is collected and brought to the dumping site while the rest of the waste lies along the roads, in streets, vacant plots, and garbage heaps in the Muhallahs. But Lahore Waste Management Company (LWMC) claimed that the outsourcing of solid waste to foreign contractors increased the waste collection efficiency up to 80% (LWMC, 2013).

Lahore Waste Management Company (LWMC) organized different awareness campaign in the recent year. In these campaigns well renowned political, academic, religious and administrative personality was involved, and the speakers emphasizes the importance of keeping the city clean.

2.4.4 Lahore Waste Management Company 'Waste to Energy' Project

Lahore Waste Management Company (LWMC) is a very active organization. LWMC ensures the solid waste management functions in Lahore and is encouraging public and private partnerships collaboration. Due to the energy shortage in Lahore and Pakistan at large Waste Management Company (LWMC) invited 'International Call for Expression of Interest Waste to Energy Project in Lahore, Pakistan. This will be a joint venture project (LWMC and International or national company) having the capacity to use 1500-2000 tons/day of municipal solid waste of the city of Lahore. The last date to submit the EOI (expression of interest) was August, 2013, and there is no updated information available at the moment (LWMC, 2013).

Lahore compost plant is established at Mehmood Boti dumping site in the outskirts of Lahore. At this site around 900 to 1000 tons daily waste is received and out of this total 350 to 450 tons organic waste is processed daily for composting in the plant(Wajid, 2011b). It is a 60 days aerobic digestion process plant which used windrow technology for composting the household waste to organic fertilizer with the capacity to utilize 1000 tons per day organic waste to compost, utilized for soil conditioning. The basic purpose of this project is to reduce greenhouse gas emissions from open dumping waste and produce organic fertilizer. Some of the experts are not agree with this treatment process of solid waste. According to Batool (2009) there is no doubt that waste composting (organic fertilizer) can enrich the soil conditioning and it is a simple and economical procedure but anaerobic digestion of organic material would have more nutrients value especially N which is lost in aerobic digestion. So this mean there is needs to process the waste on freshly basis. Otherwise if the waste dumped for long time and then used for composting may be it can lost nutrients like nitrogen, phosphorous and potassium through volatilization and leaching through soil? The project is now registered as a Clean Development Mechanism (CDM) project with UNFCCC(CDM, 2008). The rest of the waste is dumped alongside the plant.

This project is submitted on July, 07th 2008 by the Lahore Compost (Pvt). The project is sponsored by IBRD as trustees of the Danish Carbon Fund and Saif Holding Limited, and Lahore Compost (Pvt) limited itself. The total investment of this project is about US \$5.5 million. Through this project, 78,344 tons of CO₂ emission will be reduced annually (CDM, 2008).

Saif Group, through Lahore Compost (Pvt.) Ltd has set up its first composting plant at Mahmood Booti under an agreement with the City District Government Lahore (CDGL). The project has been setup on Build-Operate-Transfer basis, whereby the project will be transferred to CDGL after a period of 25 years. This is the first public-private project in Pakistan on such a large scale in the area of Municipal Solid Waste (MSW) recycling. The company is registered as a CDM project with UNFCCC (Lahore Compost Ltd, 2013)

The economic viability of this project with CDM is 18.38% while 13.18% without CDM. The total estimated annual revenues are US \$1.798 (0.858+0.94) by selling of Carbon Credits at US \$11 per ton of CO₂ and sales of 5591 Metric tonnes compost per year at US \$3 per 50 Kg bag respectively (ibid, 2008).

Because of this project; cheap organic fertilizer will be available in the market for farmers. The project will enhance the commercial activities of waste composting in Lahore, which further reduce the greenhouse gases and landfill. The produced organic fertilizers are quite cheap and have great significance. Pakistan is facing a energy shortage crisis and mostly during the wheat and rice season there is a shortage of locally and imported produced chemical fertilizers. So this is a safe alternative and more environmentally friendly than mineral fertilisers.

Chapter 3: Conceptual Framework of the Study

The Conceptual framework is a systematic structure of the meanings and variables that helps to the development of the study. The basic purpose of conceptual framework is to simplify and explain the relationship among different concepts in the study (Slideshare, 2012). This chapter is set out to explain the conceptual framework of the dissertation. First section explains the structure of the designed framework and second section explains the process of biogas system and how different factors influence on biogas production

3.1 Explaining the Structure of Conceptual Framework

Figure 5 shows the conceptual framework of the study. This framework is broadly categories in two systems 'internal' and 'external'. The internal system refers to, the procedure and functioning of a biogas plant system and the external system explains how it affects the internal system throughout (biogas plant construction to final product biogas). In other words, internal system provides an overview of how biogas plant works. The arrows from input to output show the sequence or flow of the system. System boundary separates the actors of internal and external system in the use cases. The 'internal system' (biogas production and process) is very complex but in this framework a very simple model is presented for easy understanding because this study is partly focusing on biogas plant technology. Biogas production procedure started from the input of various substrates like animal manure, municipal solid waste, industrial waste water and crop residues etc. The substrates should have some specific characteristics (composition of the substrates) and the absence of required nutrients in the substrates needs pretreatment (not for all substrates) before digestion in order to get optimum biogas production. Red color arrow cross the internal system boundary which explains that input substrates are produced outside in the external system and transported to internal system for biogas production. In the second phase the substrate is mixed in order for fermentation to take place. The third phase consists on anaerobic digestion which is the main part of biogas production. Anaerobic digestion has three different stages hydrolysis, acidification and methanization. Fourth and last procedure is the output which is in the form of biogas and digestate. The produced biogas can be used for energy production,

electricity, combined heat and power and if biogas is upgraded it can be used as vehicle fuel. The organic enrich digestates can be used as organic fertilizers in the farms.

The 'external system' is linked with internal and double edge arrows show simultaneous relations of both internal and external systems. The 'external system' is a design to explain how different stakeholders and institutions like government, environment, community, health sector, the agriculture sector, energy sector and economy are influenced by the biogas plant? More detail is available in the next section. This conceptual framework is designed with the aim to investigate two things (1) how different stakeholders get benefits from biogas and how this leads to the sustainable development of the city and (2) how different stakeholders like government, community and financial institutions play their role for the development of biogas technology.

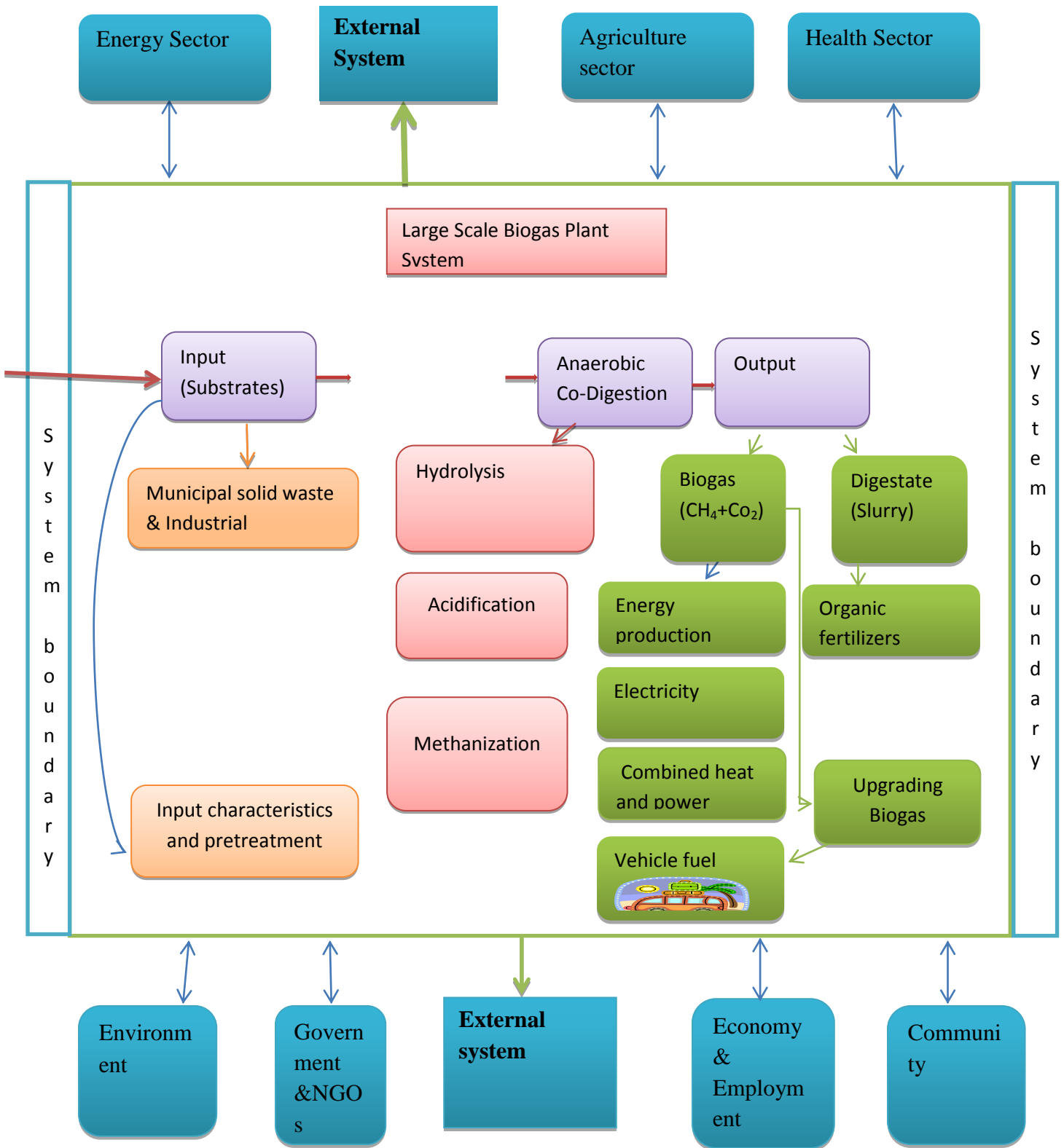


Figure 5. Conceptual Framework of the Study prepared by Muhammad Abbas

3.2 Internal Biogas Plant System

3.2.1 Substrates (Feedstock)

Theoretically all organic matters can be used for biogas production (Bond and Templeton, 2011). But practically animal manure, municipal solid waste, industrial waste water, crop residues and energy crops are the substrates which are normally used for biogas production across the world. These substrates can be solid, slurry, and the mixture of both. However, some of the organic materials are preferred more than others because of their easy degradability, economical suitability, high gas yield and technological (FAO, 1996).

Animal manure is the most common substrate used for biogas production. Manure is a combination of animal feces, urine, feed waste and bedding in the yards. So the composition of manure is different depending on yard management (AgSTAR, 2012). Municipal solid waste (MSW) is a potential substrate for anaerobic digestion mainly consists on household waste, restaurants and hotel waste, fruits and vegetable market waste etc. Due to increase biogas yield and resource efficiency of biogas plant, in Europe there is also a growing interest to cultivate energy crops like sugar beet and barley (Bond and Templeton, 2011).

3.2.2 Co-digestion

Co-digestion refers to anaerobic digestion of multiple organic wastes in one digester. Normally this method is used to increase methane production by digesting low yield and difficult digestible materials with high methane yield substrates (AgSTAR, 2012). Normally agriculture residues are co-digested with animal manure. Álvarez et al., (2013) demonstrated that manures co-digestion with other substrates can increase methane (CH₄) yield 50 to 200% depending on operating conditions and co-substrates.

3.2.3 C/N Ratio

The presence of carbon and nitrogen in organic material is called C/N ratio. For anaerobic digestion 20:1 to 30:1 is the optimum carbon nitrogen ratio (FAO, 1996). High and low C/N ratio in the organic

materials leads to low biogas yield. Some of the crop residues like rice, maize, and wheat straw and saw dust contains high C/N. Single anaerobic digestion of these straw gives very low biogas yield that's why they are co-digested with animal manure (FAO, 1996). Furthermore, low or high C/N ratio in the substrates can contribute to the poor performance of bioreactor (Bond and Templeton, 2011). Such substrates require further pretreatment or co-digestion with other substrates.

3.2.4 Pretreatment

A fraction of lignocellulose polymers is comprised in municipal solid waste animal manure and agriculture waste. These lignocellulose polymers and inorganic wastes are resistant to biological degradation. As Taherzadeh and Karimi (2008) explain, *Lignocelluloses are composed of cellulose, hemicellulose, lignin, extractives, and several inorganic materials. Natural materials such as starch, lipids, glycogen, elastin, collagen, keratin, chitin and lignocellulose, as well as synthetic polymers such as polyesters, polyethylene and polypropylene, are among these polymers. However, enzymatic hydrolysis of lignocellulose with no pretreatment is usually not so effective because of high stability of the materials to enzymatic or bacterial attacks. The aim of pretreatment is to change these properties in order to prepare the materials for enzymatic degradation.*

Poschl (2010) said that the feedstock is pre-treated to speed up the digestion process and where regulations demand. The feedstock is sterilized, or harmful sediments discharged from digesters without damaging the digestion process.

3.2.5 Volatile solids

The weight of organic solids burned off when heated to about 538'' C is define as volatile solids(FAO, 1996). Biogas production potential from different organic materials can also be calculated through volatile solids contents of various organic materials have.

3.2.6 Anaerobic Digestion

Simply ‘digestion’ is a process of reaction and interaction of different methanogens and substrates in the digester. Anaerobic digestion is a biological degradation process of organic matters in the absence of oxygen. Organic digestion is very complex process and requires specific temperature and various bacterial populations (Lastella et al., 2002). The anaerobic digestion has three stages (FAO, 1996 and Jingura and Matengaifa, 2009) which are discuss below.

3.2.7 Hydrolysis

Plant and animal feedstock consist on carbohydrates, lipid, protein and inorganic materials. The extracellular enzymes which are released by bacteria during anaerobic digestion process helps to solubilize large molecular complex substance into more simple ones. This also called polymer breakdown stage where the polymerized glucose broke down to dimeric and then it converts into monomeric with the help of cellulolytic bacteria. This process is called hydrolysis (Lastella et al., 2002, FAO, 1996).

3.2.8 Acidification

In this stage the acid forming bacteria usually ‘glucose’ breaks down into fewer atoms of carbon ‘acids’. In this process, various acids are produced like acetic acid; propionic acid butyric acid and ethanol (FAO, 1996). This stage also called fermentation of organic matters where the complex organic compounds are converted into simpler organic compounds (Rao et al., 2010).

3.2.9 Methanization

The acidification finally ends up with methane (CH₄) production by methanogenic bacteria’s which are highly sensitive to O₂ concentration in the system (Lastella et al., 2002). During this process, many by-products are produced before the final product methane (CH₄) like water,

hydrogen and carbon dioxide (FAO, 1996). Many factors facilitate this inhibition process and some of these are discussed here.

3.2.10 pH value

The pH value of the input mixture varies with time in the digester. In the initial stage of fermentation acid forming bacteria are produced, and this can reduce the pH value in the digester below to 5 which stop the fermentation process. To achieve optimum yield the pH value of the input mixture in the digester should be between 6 and 7. In the later stage fermentation process continues, and nitrogen digestion increases the concentration of NH_4 , which further increase pH value above 8. At last stage when methane production becomes stable pH value remains between 7.2 and 8.2 (FAO, 1996, Lastella et al., 2002).

3.2.11 Temperature

Optimum biogas production can be achieved in two temperature ranges 35C mesophilic and 49-60 C in thermophilic technology (Pen state Extension, 2010). The gas production decrease when the ambient temperature reached below 10 C or high than 60 C because the methanogens become inactive at extreme temperature (FAO, 1996).

3.2.12 Loading rate

Loading rate is the amount of the material fed per unit of volume in a day. It is the weight of volatile solids fed to the digester daily (FAO, 1996). The amount of the total solids in the digester determines the yield of biogas from different substrates. Furthermore, the loading rate also keeps the stability of anaerobic digestion process (Rao et al., 2010). Overfeeding and underfeeding of the substrates in the digester leads to inhibition of methane and low biogas yield respectively (FAO, 1996).

3.2.13 Hydraulic Retention Time

Retention time is the average time of a given input remains in the digester in order to methanization. It is calculated by dividing total volume of the digester by the input volume added daily.

Retention time = $\frac{\text{volume of the digester}}{\text{volume of the input fed daily}}$. Retention time is also dependent on temperature.

Higher the temperature lowers the retention time. But the temperature should not be so highly so that the methanogens are killed (FAO, 1996).

3.2.14 Toxicity

Toxicity means the presence of toxic materials in the digester which inhibit healthy growth of pathogens. High concentration of sodium, potassium, calcium, magnesium, ammonium and sulphur in the material produce toxic effect on methanogens in the digester.

3.2.15 Biogas

Biogas is an end product of anaerobic digestion which mainly consists on methane (CH₄) and carbon dioxide (CO₂). Other gases like H₂S and nitrogen are also available but they are very minimal. Methane (CH₄) is a principal combustible component from biogas composition.

Biogas is different from other energies in two ways. It's a methane fuel which is considered a clean fuel, and secondly it is the best way of controlling and collecting the organic waste and producing organic fertilizers (Ghimire, 2013).

3.3 External Biogas Plant System and their influence

Apart from the internal anaerobic digestion system there are some external institutions like Government, financial department and community which play their part for the development of biogas technology in the city. For example the Government play an important role in the

dissemination of biogas plant all over the world. Different government in different countries play various roles for the development of biogas of biogas technology. *Worldwide effective and widespread implementation of domestic biogas technology has occurred in countries where government was fully involved in the subsidy, planning, design, construction, operation and maintenance of biogas plants (Dincer, 2000)*. Millions of small scale biogas plants in India and China are a repercussion of government involvement. Between 1974 and 1987 the Ministry of Petroleum and Natural Resource Management installed 4137 plants in Pakistan (Mirza et al., 2008). This programme was failed when the government withdrew the financial assistance (Bond and Templeton, 2011). Moreover, Dincer (2000) put great emphasizes on the role of government for environmental problem solution through promoting public transport, introducing renewable energy technologies, alternative energy dissemination for transport, energy source switching from fossil fuels to environmentally benign energy options, recycling, carbon or fuel taxes, policy integration and acceleration of forestation.

In addition to this some of the external institutions will be strengthen due to the development of biogas technology for example health improvement, environmental pollution control, employment increase and the agriculture development due to provision of organic fertilizer. All of these sectors will discuss briefly in the chapter 4th and 5th.

Chapter 4: Literature Review

The previous chapter demonstrates the conceptual framework of the study. According to present study's objectives and research questions the researcher emphasize on the input and output phase of biogas technology in the conceptual framework. Similarly in this chapter the literature review focus on input (part 1) and output (part 2) phase of biogas technology. This literature review is a best of my abilities where many scientific articles from different parts of the world focusing on biogas technology are reviewed and the critical discussion is presented at the end of the chapter. This chapter is divided into two parts. The first part gives a critical review on biogas potential studies from Pakistan and second part explains the significance and utilization of biogas. Latter part highlights the issues and demonstrates the examples how biogas plants can help to address the energy crisis and GHG emissions. The second part further divided in different subsections. In the first subsection the main concern is to discuss energy issues as a whole. Road traffic issues are discussed briefly as a background of GHG emissions in the transport sector. Furthermore, environmental, health and economic benefits are discussed. These sections present an overview of how biogas can provide benefits in the respective fields. By reviewing different studies from Europe an attempt is made to determine how Pakistan can benefit from biogas as European countries have done.

4.1 Part 1 Biogas potential from biomass and municipal solid waste (MSW)

4.1.1 Previous studies about biogas potential in Pakistan

Being an agriculture and sixth largest population country in the world, Pakistan has great potential to produce biogas from biomass and waste. But there are very few research papers and limited research activities about biogas both from state and private institutions. The existing research papers about biogas potential in Pakistan are descriptive and mainly focus on biogas potential from biomass resources and present a very beautiful and optimistic picture for the future of biogas technology in the country. There are no research studies which deals with technical aspect of biogas production for example effect of temperature on biogas production, co-digestion of animal manure, design consideration plant residues. No one can disagree about

the bright future of biogas technology in Pakistan. However, there are so many considerations and uncertainties in the biogas potential estimation. In order to popularize biogas technology there is a need to remove such kinds of constraints.

Biogas potential from manure is not simply number of animal (cattle and buffaloes) and their dung but there are some other factors which effect on the total potential. For instance the quantity of the dung from animals totally depends on the type and quantity of the feed given to the animals. Feed also furthermore affects the biogas yield from the dung. As the dairy milk products demand increase and becoming very profitable business in the country the numbers of big dairy farms also increasing. Consequently big giant companies like Nestle and politicians are being heard and personally observed to invest in the dairy farm business. In order to achieve maximum milk yield from the buffaloes and cows, relatively high nutritional feed is used. This is not the practice for normal herd holder because of its low income In this way it is technically not wise able to make generalization about the biogas potential only based on the number of animals.

A literature review study conducted by Amjad et al, (2011) demonstrates that Pakistan has a daily potential to produced 16.3 million m³ biogas from cattle and buffaloes. He also reported that Sugarcane residues (bagasse) which is a good source of renewable energy, has the potential to produce 3000 MW energy (use the same units)in Pakistan.

Bio Energy Technology Application (BetaPak, 2009-10) publish on its home page that there are 63 million cattle and buffaloes in Pakistan which can produce 150 million m³ biogas per day. The estimate is based on average dung dropping rate of 15 kg per animal/per day. In the same literature it is mentioned that 6 kg dung can produce 1m³ of biogas. First of all, number of animals presented in the previous study is very high. In another study Sheikh (2009) mentioned that there are 57 million cattle and buffaloes. The annual increase is 8%. BetaPak (2009-10) and Sheikh (2009) estimated number animals, but there was a difference of 8 million animals between the assessments. Sheikh (2010) calculated that Pakistan has total potential to produce 14.25 million m³ biogas from 57 million cattle and buffaloes by assuming 50% dung collection. He says that the average dung dropping rate in Pakistan is 10 kg and 20 kg wet manure. This can produce 1m³ biogas. This again is confusing and gives different amount of total biogas

potential. For instance Amjid et al (2011) and Sheikh (2010) using the same number of animals and other parameters like dung dropping rate and biogas potential m³/kg, calculated a potential of 14.24 million m³ and 16.3 million m³. The reason for the difference is not explained. Sheikh (2010) cited to (Ghaffar, 1995) who reported that one kg dung (using 20% dry mass) produces 0.19 m³ biogas. Sheikh (2010) mentioned that Pakistan Council for Renewable Energy Technology (PCRET) installed about 1600 of 5m³ biogas plants and almost the same numbers of plants were commissioned by the NGOs from last three years. This means that total 3200 biogas plants were installed. Further, he says that in response to these 3200 installed plants 0.016 millions m³/day biogas energy was tapped from last three year. I show how Sheikh (2010) estimate this potential (Number of total plant installed × total capacity of each plant (5m³ × 3200 = 16000m³/day which is equal to 0.016 million m³/day).

But 5m³ biogas plant means that the plant is running at full capacity. The factor that may reduce this potential is improper feeding, maintenance and other factor like leaking, temperature. (Nazir, 1991) calculated that the 5m³ installed vertical biogas plant produces 2.8 m³/day in summer while 1.6m³/day in winter and 5m³ horizontal biogas plant produces 2.4m³ in summers less than the vertical. Despite of its many advantages, biogas potential cannot be harnessed at full level because of certain constraints linked with and especially at small scale level plants (Yadvika et al., 2004)

Pandey (2007) in their domestic biogas feasibility report conducted interview in different parts of Punjab, Pakistan and reported that the respondent needed 4-5 hours daily gas for cooking three time meal. So in order to meet previous energy demand through biogas, 40 to 45 kg dung required to feed the biogas plant. Furthermore, in Pakistan there are 10 million household which has cattle and buffaloes and out of these 5 million household has practical potential to install biogas plants in their vicinity. The reason of unsuitability of 5 million household is, of 2 million household has only 1- 2 animals while 3 million household unsuitable for biogas plants because they already have natural gas supply or likely to be low temperature and insufficient water rewrite. Their field study was carried out in Punjab where the animals are stall fed and such animals produce 15 to 20 kg dung/day. So pertaining to meet 40-45 dung needs more than 2-3 animals are required in each household in the country rewrite (ibid, 2007).

4.1.2 Factors influencing on biogas potential

Biogas production and yield is a very complex matter and it is not only dependent on the type of substrates and numbers of animals as it is mentioned in the previous studies. There are many other factors and variables like temperature, volume of digester, space requirement, organic loading rate and hydraulic retention time (HRT) which directly influence on biogas yield (Berg and Kennedy, 1983 in Yadvika 2004). Hydraulic retention time is the average time of a given input remains in the digester in order to methanization. Another farm scale pilot study was conducted by (Mussoline et al., 2012) where two digester of 1m^3 were filled and prepared for co-digestion of untreated rice straw and pig wastewater with hydraulic retention time 189 days. Both of the digester A and B were filled with 50 kg dry rice straw diluted with pig wastewater to create dry digestion condition 20% total solids (Kastner et al.) and each of them is heated with different temperature. Digester A treated with mesophilic while digester B in ambient mesophilic temperature condition. Furthermore, both of the digester where designed for different optimum input capacity. For instance digester A, optimum input capacity was 150L of pig wastewater while digester B was design for only 60L minimum input. From digester A 22,859L and from digester B 1420L total biogas yield was obtained during this time period. This study conclude that temperature and digester input capacity positively correlate with biogas yield.

A study was conducted by (Pognani et al., 2009) in a full scale anaerobic digested plant to evaluate the possibilities of replacing the energy crops with organic fraction of municipal solid waste. This full scale study continued for 8 months and 55 samples were tested with hydraulic retention time (HRT) of 40 days and for post digestate HRT of 10 days. The samples were analysed in thermophillic condition and total solids (Kastner et al.) was 150g/kg. The result of the study shows that the mixture of organic fraction municipal solid waste (OFMSW) with cow slurry produced almost same amount of biogas yield as an energy crop (EC). Similarly, a batch digestion of municipal garbage study was conducted by (Rao et al., 2000) in India for 240 days under 26C temperature condition. The result shows that ultimate biogas production of municipal garbage is $0.661\text{m}^3/\text{kg}$ volatile solids (VS) and the ultimate bioenergy is 18,145kJ/kg volatile solids (VS). The experiment of ultimate biogas yield of municipal garbage is also compared with other substrates like cow dung. The experiment shows that municipal garbage yield (m^3/kg dry

municipal waste) was 2.50 times more than cow dung. It was concluded that municipal garbage has a high bioenergy potential which can be used for biogasification.

Crop residues have great potential of biogas production and it can be co-digested with animal manure and waste water as well as single substrate in an anaerobic process. A small scale batch study was conducted by (Isci and Demirer, 2007) in Turkey for 23 days to find out biogas production potential from cotton wastes. Three different cotton residues cotton stalks, cotton seed hull and cotton oil cake were analyzed in batch reactor. Trace metal supplementation and nutrients effects were also part of the study analysis and the experiments were investigated with two different waste concentrations 30 and 60g/L. The result of the study shows that in the presence of basal medium 1g of cotton stalks, cotton seed hull and cotton cake produce 65, 86 and 78 ml CH₄. Finally it is concluded that cotton waste can be treated anaerobically and basal medium co-digestion has a very positive effect on biogas potential production.

Methane productivity of manure, straw and solid fraction of manure study was conducted by (Møller et al., 2004) in Denmark. The manure of pig, sow and dairy cattle were analysed in order to get methane potential in terms of VS. The sow is a female pig. It was observed in the results that ultimate biogas yield is very high in pig (356 l kg VS⁻¹) sow manure (275 l kgVS⁻¹) compare to dairy cattle (148 l kg VS⁻¹). Low methane productivity was found in sow and other dairy cattle livestock compared to pig. Because of higher volatile solids (VS) content in straw it was concluded that the use of straw as bedding material can increase the volumetric and methane productivity from the livestock source.

The anaerobic fermentation of food waste: a comparison of two bioreactor system study was conducted by (Kastner et al., 2012) in Austria. This study was carried out with the intention to find out efficient fermentation method in order to get high biogas yield from organic (fruit and vegetables, animal feedstuff, leftover, waste from industrial kitchen, biological residues, manure and contents of fat separators) waste. For this purpose, two bioreactor systems named Continuous Stirred Tank Reactor (CSTR) and Fluidized Bed Reactor (FBR) were analysed. The result of the experiments show that CSTR produced 670 NL/kg VS while FBR 550 NL/kg VS. Moreover, CSTR productivity was 3.9 NL/(L/d) and 3.4 NL/(L/d) in FBR system was obtained. But finally

it was observed FBR has more stable process at high loading rate compare to CSTR which has limited organic loading rate.

4.2 Part 2 Energy Crisis in Pakistan and Learning the Experience of Biogas Plants from Europe

Energy plays an important role in the development of any country. It strengthens the economy and brings changes in the consumption pattern and socio-economic status of people. Currently, Pakistan is facing the worst energy crisis in its history (Burki, 2010), and the average shortfall is crossing 5000 MW mark (Nawab, 2013). In 2008-9, power outages went up by 30%, while in 2010 it increased up to 18 hours in some areas of the country (Alahdad, 2012). There is a strong correlation between GDP growth rate and energy consumption. (Alahdad, 2012), (referring to Aziz et al. 2010) reported that the Pakistani economy lost \$3.8 billion in 2009 because of the energy crisis. Industries have shut down and about half a million jobs were lost.

The duration of power outages varies, depending on the political atmosphere, public protests against energy crisis, weather conditions, debt payment to oil supply companies, and whether a residential area is urban or rural. Energy misery continues and policy makers have framed no feasible plans to alleviate it.

Pakistan has always been dependent on oil, natural gas, and water for hydroelectricity in order to produce energy. Of the total energy supply, about 81.2% comes from oil and natural gas, 12.5% from hydroelectricity, and 6.3% from coal (Nawab, 2013). More specifically, in the year 2010-11, 94,635 GWh of electricity were produced, the production being based on 35% oil, 34% hydro and 27% natural gas (HDIP, 2012). There is an annual 10% increase in electricity demand, while supply doesn't increase at the same rate (Nawab, 2013), and this also leads to power outages in the country. This state of energy threatens future generations. Pakistan, for instance, is an oil-deficient country. In order to import petroleum, Pakistan spends \$14.5 billion annually, amounting to nearly 36% and 50% of total annual import and export earnings, respectively (Nawab, 2013). Secondly, Pakistan had 55.103 trillion cubic feet (TCF) of natural gas reserves, but half of these have been used by now, and it is estimated that if natural gas is consumed at the

same rate, within 18 years these reserves will be exhausted (HDIP, 2012). The use of natural gas resources has moved from the domestic sector to industry and then to transport in Pakistan. As stated in the newspaper (Dawn, 2011) the daily production of natural gas in the country is about 4 billion cubic feet, whereas consumption is about 6 billion cubic feet per day. In order to meet existing requirements, therefore, natural gas shortages amount to 2 billion cubic feet per day in Pakistan.

Pakistan is a leading country in the world in CNG vehicles, with 2,740,000 CNG cars and 3,285 refueling stations, followed by Iran, Argentina, Brazil, India and Italy (NGV, webpage) and (Gallery, 2011). However, according to United States Energy Information Administration findings in terms of total natural gas reserve Pakistan hold 28th position in the world with 29.67 trillion cubic feet. Russia has the most natural gas deposits with 1680.0 trillion cubic feet, followed by Iran's 1045.67 trillion cubic feet (EIA, 2012). Currently, CNG vehicles comprise 61.14% of the total car market in Pakistan. The use of CNG vehicles worldwide has increased significantly, with an average growth of 30.6% since the year 2000 (Gallery, 2011). CNG transportation was also a main priority area under the CDM projects but until now the government was unable to formulate any transport project under the CDM as did in some of the other countries like India, China and Colombia etc (UNFCCC, 2013). There is very low public budget for the transport sector. This allows private commercial transporters to drive small and heavy vehicles on the roads which become more and more air polluted. These transport operators compete with each other in the urge to earn more daily profit which some time result in live loss of the passengers and other commuters.

Thirdly, due to population increase, per capita water capacity has decreased from 5650 m³ in 1951 to 1000 m³ in 2010. In the last century an annual temperature increase of 0.6 C has been observed in Pakistan, and Indus river (which is a main fresh water source in the country) inflow from the melting of ice and snow increased from 70 to 80% (WAPDA, 2013). No doubt hydroelectricity is economically viable (Nawab, 2013), and some of the new hydropower dams are in the government pipeline; but the scarcity of water, ice melting from glaciers, increase in temperature and catastrophic floods every year all warn us to reduce our dependency on fossil fuel and hydropower in order to cope with the energy crisis in the future.

Pakistan has the 6th largest population in the World. More than 67 million of the country population living in urban areas which characterized it in the most urbanized country in the region. Along with so many internal and external issues, the country is facing challenges like climate change and droughts, energy crisis, traffic pollution and congestion, terrorism, high rate of migration, urbanization and lack of cities development policies. Most of the industrial sectors are located close to big cities like Karachi, Lahore, Faisalabad, and Rawalpindi and this lead towards rural to urban migration. Rapid urbanization and migration needs better roads mobility for the commuters.

High population growth put the burden on road traffic and obviously fossil fuel demand increase tremendously. But there are no strong initiatives to improve or widen the roads, to find renewable source of energy to replace fossil fuel and traffic situation in the country. Having crisis in Pakistan International Airline (PIA) and Railway there is more burdens on road traffic and it is estimated the roads carrying 92% of the total passenger's traffic (GoP, 2012).

Table 1. Road Traffic development in Pakistan, Source: National Transport Research Centre (NTRC) and Pakistan Bureau of Statistics

Year	Road Length in KM	Population (million)	Registered Motor vehicles
2007/08	258350	162.38	6,201,755
2008/09	258350	169.94	6,559,364
2009/10	260760	173.51	7,853,022
2010/11	259463	177.1	9,080,437
2011/12	261595	180.71	11,000,357

There is a significant increase in the roads network from 1990 to 2000, 170000km to 260760km respectively, but after that the roads extensions are very minimal. The above table represent the huge difference between population growth and total road length and road length with registered vehicles in the country. As it shows from 2007 to 2011 there is 46% increase in the registered vehicles while the road length increase with 1.26% with 11% increases in the population. Because of this traffic congestion in Lahore, there are 1,250 annual deaths related to air pollution (Daily Time, 2006). The traffic situation is serious and needs for proper policies and legislation.

(Barth and Boriboonsomsin, 2008), illustrate that carbon dioxide (CO₂) can also be reduced by improving traffic congestion in the cities. The latter is possible when the road length increases with population growth. Traffic congestion means more burning of fossil fuel which is further associated with more carbon dioxide (CO₂) emissions. In Pakistan overall carbon dioxide (CO₂) emissions have increased 84.75% from 2003 to 2008. There is a 39% increase in the GHG emissions from the transport sector since 2003 to 2008. If the growth rate of these GHG emissions remains the same then the figures reach around 66 million metric tons CO₂ emissions in 2020 (MTDF, 2011).

Even though the energy and traffic situation is still worsening, Pakistan can recover from this crisis. The increasing energy deficit in spite of the abundance of unexploited resources is a clear example of policy failure in the country. Energy solvency can be achieved through the abundant availability of renewable energy resources, especially biogas and solar energy. According to (Amigun et al., 2008), biogas is important and distinct from other renewable energy sources like solar, wind, thermal and hydro, because it manages organic waste material which if untreated can cause pollution and many health problems. Furthermore, it converts waste into energy and valuable organic fertilizers which definitely help to reduce GHG emissions. Biogas directly or indirectly reduces deforestation, soil degradation, soil erosion, and natural catastrophes like floods. A biogas plant dissemination study was conducted by (Bhat et al., 2001) in eight different villages of the Sirsi block of Karnataka State in the south of India. This study investigated the performance of existing biogas plants in the area. The results show that 100% of operating plants are meeting 85% of cooking energy demand. The reason for this success story is, first, large cattle holding, because cattle provide adequate manure to feed the biogas plants. Guarantees and warranties and follow-up service from entrepreneurs have also contributed to success. These entrepreneurs are financed by society and private growers. The high income and high literacy rate in the sites studied have also played a part. From this study we can conclude that the absence of some or all of the above factors contribute to the story of failed biogas plants in Pakistan.

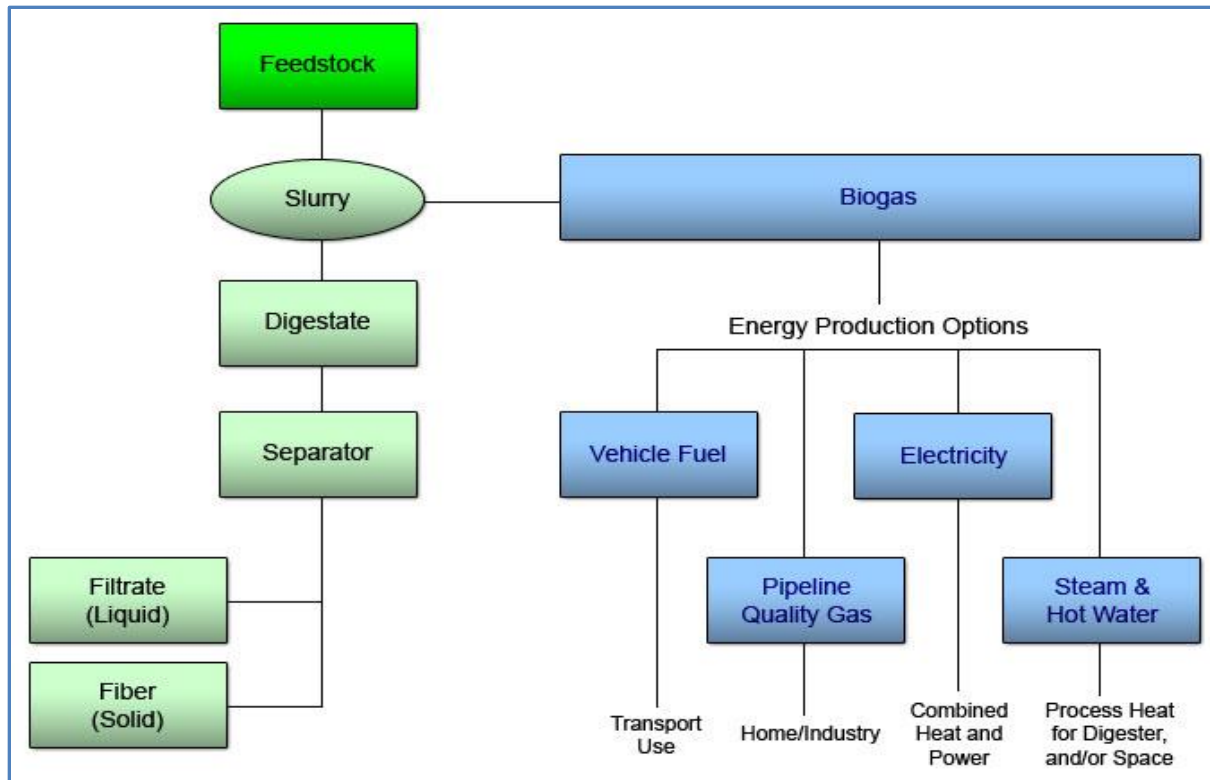


Figure 6 Process of Biogas Energy System source: (Phase 3 Renewables, 2008)

According to (IEA, 2013), bioenergy a renewable source can contribute 25 to 33% (up to 250 EJ) in global energy demand through replacing fossil fuels by 2050. In Europe many plants have been installed. The feedstock used is sewage sludge, crop residues and municipal solid waste. In 2007 it estimated that in European Union 69 TWh biogas was produced (Pettersson and WeLLInGer, 2009) Germany, UK, Sweden and Poland are the biggest producer and have the highest number of biogas plants 7100, 229, 124 respectively (Seindenberg, 2011). Most developed agriculture biogas plants are in Germany, Denmark, Austria, Sweden, Netherland, France, Spain, Italy and United Kingdom (Holm-Nielsen et al., 2009). European policies concerning to energy has fixed the goal to meet 20% of the total energy through renewable energy source by 2020 (Holm-Nielsen et al., 2009, Pertl et al., 2010)

“produced biogas use for combined heating, power generation, and upgrading and utilization as fuel in the vehicles. The produced power is sold to the grid and heat is distributed through district heating system” (Holm-Nielsen et al., 2009).

In Sweden 1.4 Twh biogas is produced every year from 230 digestion plants and it was plan to reach at 3 Twh until 2012. These 230 biogas plants further divided into 135 waste water treatment, 18 co-digestion, 14 farm scale, 5 industrial waste and 57 landfills(SGC, 2012). Of the produced energy 49% was used for heating, 5% for electricity production, 36% biogas up graded and used as fuel in the vehicles and 10% was flared off. The transport sector in Sweden consumed about 80% of the total country fossil fuels (SGC, 2012). In order to reduce fossil fuel dependency in the transport sector Sweden developed biogas upgrading technologies to use it as a fuel in the transport. At the end of 2009 there were 23000 biogas vehicles (heavy and light vehicles) operating and 104 public filling station has been established in Sweden (NGV, 2010)

Germany is a market leader in developing biogas technology (Pöschl et al., 2010)) and also largest biogas producer in the world because of agriculture based biogas plants (Weiland, 2010). United Kingdom (U.K) and Germany both produce 2/3 of the total biogas production in EU (Birgit Balkenhoff, 2011). Germany produces 10 TWh electricity from biogas sources per year which is about 1.6% of the total electricity demand in the country. The biogas is most commonly used for combined heat and power (CHP). The electricity is fed into the power grid and heat is used for district heating (Pöschl et al., 2010)). Still the struggles are going to harness technically available potential which is about 60 TWh per year.

In Norway until 2010 internet sources shows that are 35 biogas plants (24 sewage, 5 organic waste, 5 manure and 1 is co-digestion) producing approximately 192 GWh energy (Rojas, 2012) and it is estimated that in future biogas production will increase about 69% and figure will touch 324 GWh(Govasmark, 2011). The existed plants are not utilized up to their maximum capacity which is about 300 KWh. Ten more plants are planned and will be completed soon. Sludge from waste water, food waste and animal manure are the main resource of biogas production in Norway(Rojas, 2012).

Norwegian government established ENOVA and TRANSNOVA program in 2011. The basic purpose of the later project is to reduce carbon dioxide (CO₂) emissions from fossil fuels through introducing environmental friendly transport in the country. Biogas in Norway is used for following purposes: in the transport is 2%, for heating 53%, for flaring 19%, for electricity 18% whereas 9% is unknown(Govasmark, 2011). In the near future it is planned to upgrade the biogas in order to use it for transport and especially in the public buses. At the moment, there are 65

biogas fuelled buses working in Oslo and 135 buses will be added very soon by the completion of new biogas plant in Oslo in 2013 (Kommune, 2012). Currently upgraded biogas is the most environmental friendly fuel in the market because of it's a CO₂ neutral.

Denmark is one of the pioneers in implementing CHP (Lund, 2007) and developing agriculture biogas plants from animal manure and organic waste co-digestion plants (Holm-Nielsen et al., 2009). The development of agriculture biogas plants was due to the energy crisis and high energy prices in 1973 in Denmark (Raven and Gregersen, 2007). In 2002, there were 20 centralized biogas plant and 35 farm scale plants in Denmark which harness 3% of the total manure. About 2.6 PJ renewable energy was being produced which replaced 14% of the fossil fuels in the country ((Raven, 2007;Lund, 2007). The dependency on oil has been decreased from 92% to 41% in 1972 and 2007 respectively (Lund, 2007).

To conclude this, the current energy crisis and high energy prices in Pakistan present similar situation of Denmark in 1973. So there is need to follow the examples from European countries to combat the energy crisis in Pakistan. The country has substantial biomass resources and climate conditions are very favorable for anaerobic digestion. The government should create infrastructure to installed large biogas plants (like Nordic countries) in different cities in order to produce energy. Even though, if the government is not interested to help public, these biogas plants can help to reduce imports of petroleum.

4.3 The Environmental Impact of Biogas

Biogas is an environmentally friendly (especially when CO₂ is removed from it composition) tool for reducing greenhouse gas emissions. It is a very effective means of addressing issues like indoor air pollution, deforestation and reducing greenhouse gas emission through manure and solid waste as feedstock for biogas production (Arthur et al., 2011). Indoor air pollution and deforestation mainly related to developing countries where biomass resources like firewood are used for cooking and lightning. The raw biogas which is normally used in Europe for heating, cooling and electricity generation comprises 60% methane and 40% CO₂. H₂S and NH₃ are also available in the tanks but their use is minimal (Berglund and Börjesson, 2006). The previous ratio can vary depending on the raw material used for biogas production. The upgraded biogas ($\leq 95\%$ methane) in which CO₂ is removed through an upgrading process is used in the transport

as fuel. Consequently, Berglund's (2006) analysis shows that by replacing fossil fuels with biogas, greenhouse gas emissions can be reduced by up to 75-90% from heating and by 50-85% from vehicle fuel. It can also reduce the emission particles of POCP, EP and AP.

4.3.1 Greenhouse Gas Emission Reduction through Substituting Biomass Burning with Biogas

The traditional use of this biomass for cooking and heating associated with the increase of greenhouse gas emissions, deforestation and health related issues especially among women and children (see health section). There is need to find out better alternative clean fuel to meet our needs. Biomass (animal dung and crop residues), if used for biogas production in a anaerobic digestion process, can be a major source of renewable energy and reduce greenhouse gas emissions by reducing the smoke from traditional energy sources of cooking and improving management of manure and biogas residues.

Biogas technology beside of its many other usage has a great potential to reduce greenhouse gas emissions (GHG) through substituting firewood for cooking, Kerosene oil for lightning and cooking and chemical fertilizers (Pathak et al., 2009). Since Pakistan is an agricultural country, more than 70% of the population live in rural areas where traditional methods of using wood, dung cake and crop waste is a normal and feasible source of cooking heat (Sahir and Qureshi, 2008, Amjid et al., 2011).

The Pakistan biogas feasibility report prepared by (Pandey and Bajgain, 2007), claimed that a 6m³ biogas plant has the capacity to save 2.0 tons of biomass annually in Pakistan, while Katuwal (2009) reported that biogas reduced consumption of 250 kg of firewood per month (3 tons per year) in Nepal. The use of biogas can reduce the demand on firewood and other biomass, further reducing deforestation in Pakistan. As in Nepal, the deforestation and fuel wood crises are very closely linked with each other. Fuel wood is a major source of cooking, lighting and heating in the rural area of developing countries which further causes deforestation. On the other hand, deforestation caused a fuel wood crisis in Nepal (Katuwal and Bohara, 2009). The report demonstrated that the use of biogas plants can result in better management of farmyards, further improving the surrounding environment and eliminating odors.

Furthermore, Katuwal (2009) illustrated that as a result of household biogas plants, there is a tremendous reduction in the firewood, dung cake and sawdust, amounting to approximately 53%, 63% and 99% respectively, as reported by respondents. This is clearly a satisfactory and significant step to reducing GHG emissions in Nepal through the installation of biogas plants.

A family size biogas plant in India has a capacity of 9.7t of CO₂ e/year Global Warming Potential (GWP). This is further estimated that a family size biogas plant can achieve carbon credit of US \$ 97/year by reducing greenhouse emissions under clean development (CDM) project (Pathak et al., 2009). A family size biogas plant has a potential to substitute 316 L of Kerosene, 5535kg of firewood or 4400 kg of cattle dung/year which are otherwise emit NO_x, SO₂ and CO₂ in the atmosphere. Very similar to the previous study a biogas plant impact evaluation was conducted by (Agoramoorthy and Hsu, 2008) in three different states in India: Gujrat, Rajasthan, and Madya Pradesh. This study was done during January and July of 2007, and 125 biogas plants were analyzed. The study demonstrates that biogas plants ease ecological stress in the remote villages of India. This is explained by annual reduction of firewood use from 1048.9 to 410.6 kg after the installation of a biogas unit in a family comprising 5 to 6 members. They further estimate that the 125 households studied reported that they can each save 79.79 tons of firewood annually. The use of kerosene was reduced about 62%.

Amigun (2008) focused on the UNDP biogas initiative program in Bamako region of Mali and its success story of eradicating poverty through energy discourse. From this experience he concludes that an increase in the number of biogas plants in Africa would reduce the use of firewood and help to achieve Millennium Development Goals by eradicating poverty and child mortality, empowering women, controlling disease and improving environmental sustainability.

4.3.2 Mitigation of Greenhouse gas emissions from replacing fossil fuel to Biogas in the vehicles

Biogas can be used as vehicle fuel when it has been cleaned and upgraded. The cleaning of biogas comprises on the separation of water and hydrogen sulphide (H₂S) while up- gradation means separation of carbon dioxide from normal biogas (60% CH₄ and 40% CO₂) content(Petersson and WeLLInGer, 2009). Substituting fossil fuel with biogas leads to the reduction of greenhouse emissions. Biogas production from energy crops (ley, maize and sugar beet) is the most resource efficient compare with other renewable fuel like bioethanol because it

gives high energy yield per hector (Börjesson and Mattiasson, 2008). However, the fuels which produced from energy crop either biogas or bioethanol are not totally emissions free because it required fossil fuels for cultivation.

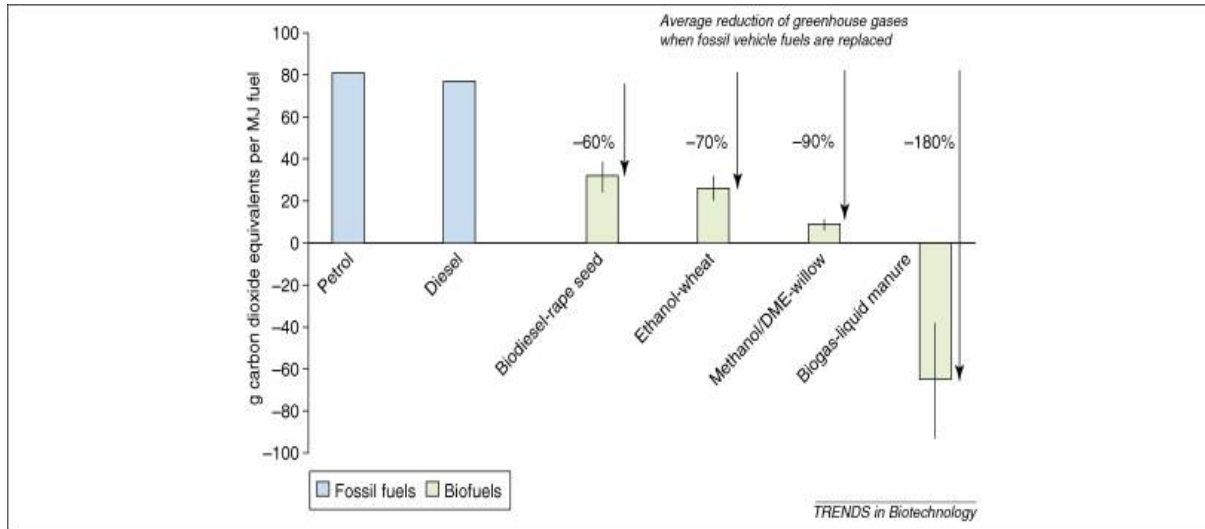


Figure 7Life cycle emissions of greenhouse gas from fossil fuel and other biofuels source: (Börjesson and Mattiasson, 2008)

From a greenhouse gas perspective biogas production from liquid manure is the most favorable because of avoiding methane emissions from manure storage and carbon dioxide emissions reduction through replacing biogas with fossil fuel. Figure 7 shows the diesel and petrol substitution in the vehicles with biodiesel based on rape seed reduce 60% of the greenhouse gas emission while biogas based on liquid manure reduce 180% of the emissions. Liquid manure based biogas fuel in the vehicles has the highest capacity (180%) of reducing carbon dioxide (CO₂) because if manure is stored and not utilized it cause methane emissions. Natural degradation of manure during storage leads to methane (CH₄) which is very high potential greenhouse gas (Møller et al., 2004). Replacing the fossil fuels with biogas and if manure is used for biogas production reduce similar percentage of greenhouse gas emissions. According to (Börjesson and Berglund, 2007), substituting biogas fuel with petrol and diesel in the light duty and heavy duty vehicles has potential to reduce global warming potential (GWP) about 50 and 80% respectively. The variation in the global warming potential 80% and 180% which is stated in the above is explained through the type of substrate used for biogas production. The intensity of greenhouse gas reduction is dependent on the type of the substrate used for biogas production (Petersson and WeLLInGer, 2009). For example, energy crops like ley and sugar beets are not as

effective as manure to reduce greenhouse gas emissions because the energy crops required fossil fuels for cultivation.

Currently Ruter has started biogas fuel buses in Norway and this biogas is produced from sewage sludge. A new biogas plant using food waste in Oslo (Nes) started functioning and in the winter 2013 about 100 more biogas fuel buses will float on the roads. It is estimated that new biogas fuel buses will reduce 40% NO_x, particulate matter 80% and CO₂ emissions up to 90% (www.Ruter.no). Sweden has leading position to use biogas as a vehicle fuel followed by Switzerland with the aim to reduce greenhouse house gas emission by replacing fossil fuels (Börjesson and Mattiasson, 2008). The concentration of POCP will reduce 50-70% and 20-65% when biogas is used in the light-duty vehicles and heavy duty vehicles respectively and this reduction reached at 80% when manure is used as feedstock for biogas production (Börjesson, 2007).

4.3.3 Greenhouse Gas Emissions Reduction through Manure and Solid Waste as Feedstock in the Biogas Plant

As it is described before biogas can be produced through different organic materials like animal manure, agriculture residues, waste water and municipal organic waste etc. If this organic matter is not properly treated or well-handled, it will cause major greenhouse gas emissions. In Pakistan where urban waste management is poorly developed because of financial resources, lack of transport facilities and non-standardized disposal sites, organic waste is a big threat for local and global environment (Batool et al., 2008). Natural degradation of animal manure during its storage leads to methane CH₄ emission which further adds to increase in the greenhouse gas emissions (Møller et al., 2004). Methane (CH₄) is a strong greenhouse gas and has 21 times more global warming potential compared to carbon dioxide CO₂ (IPCC, 2007). Biogas production from anaerobic digestion of animal manure, slurry and organic waste is an effective way to reduce greenhouse gas emission specifically ammonia and methane (Holm-Nielsen et al., 2009).

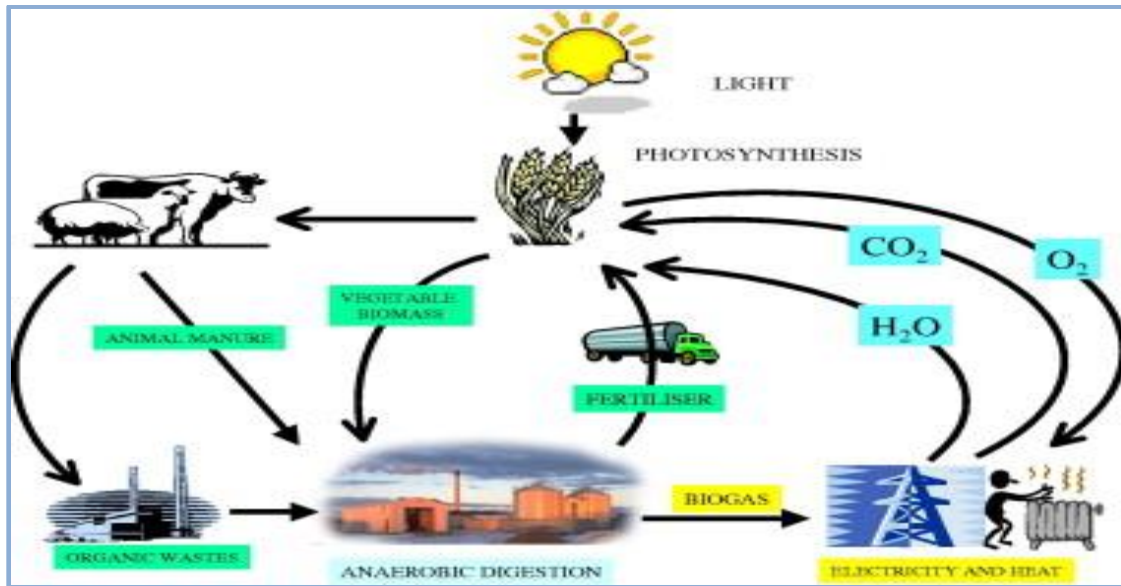


Figure 8 sustainable cycles of Anaerobic Co-Digestion of Animal Manure and Organic Waste, source: (Al Saedi, 2002 cited in (Holm-Nielsen et al., 2009))

According to Danish environmental conditions, methane (CH_4) emission can be reduced about 1.6 kg CH_4 /ton of pig slurry if manure is digested for biogas production and the storage timing was assumed to be 15 days in the reference system. In addition to this the introduction of biogas production, NH_3 emission is reduced about 20% from uncovered storage tank while 70 to 85% NH_3 emission reduction estimated from the conventional storage tank using semi permeable cover sheet in Sweden (Börjesson and Berglund, 2007). Similarly from the crop residues context, one hectare agriculture land contains 100-160kg N from the top and leave of sugar beets and approximately 20-40% of the nitrogen lost in the next cropping seasons in the form of ammonia and nitrogen gas in the atmosphere and nitrate leakage into the ground water (Börjesson and Berglund, 2007). Without considering the reference system into account biogas production and upgradation from animal manure has the potential to reduce methane CH_4 emissions up to 22-26%, organic waste 12-17% from grass, straw beet tops 8-16% (Börjesson, 2003 cited in (Petersson and WeLLInGer, 2009)).

Composting of organic waste is another technology which is being practiced in Pakistan, Lahore in order to reduce greenhouse gas emissions and to provide organic enrich fertilizers for farmers. But composting is not efficient technologies to reduce greenhouse emissions compare to biogas because composting recycle the waste but no energy is produced from the waste and nitrogen

lost. The produce energy from organic waste as through biogas can be used to alternate fossil fuel. So considering the associated problem with composting technology one can easily prefer biogas technology in order to reduce greenhouse gas emissions and for energy production. Beside of its many other usage biogas production from animal manure and organic waste indirectly also play an important role in order to achieve food security, animal and human health (Holm-Nielsen et al., 2009).

In Pakistan either practically or in the literature the introduction of biogas technology is always thought in the energy production context. Whereas, biogas is a great source to reduce greenhouse gas (GHG) emission as it described above. Unfortunately, the significance of biogas in terms of reducing GHG emissions is still neglected in Pakistani literature. According to 2008 figures Pakistan total greenhouse emissions were 309 million tons of CO₂ equivalent. Energy and agriculture sector are the biggest contributor with 50 and 39% respectively (Gardezi). Pakistan is highly vulnerable to climate change which can be assessed through floods, earthquakes, melting the glacier on the Himalaya, food and energy security, water scarcity, temperature rise and loss of soil fertility (Chaudhry, 2013). Floods and earthquake very often occurs in the country which causing millions of deaths and billions dollars economic loss in the form of unemployment, rehabilitation, agricultural damage and drought etc. So there is dire need to focus our attention on the two major GHG contributors; energy and agriculture sector. Pakistan should start to use alternative renewable energy solution like biogas at large scale which can substitute fossil fuel energy and agriculture residue can be used for biogas production.

4.4 Biogas Plants and Health Benefits

The use of biomass energy for cooking, heating and lighting has been common throughout and is still practiced in developing and underdeveloped countries. In such countries the success of biogas cannot identify solely in terms of how many plants are installed? But other indicators including whether or what extent biogas plant contribute to the quality of the users (Ghimire, 2012). In Pakistan, biomass fuel like firewood, dung cake and crop residues contributes major share of daily energy consumption in rural low income areas (Umar. K, et al. 2007). Po JY et al. 2011 conducted a study titled “Respiratory disease associated with solid biomass fuel exposure in rural women and children”. The results of the study show a significant relationship between

acute respiratory infections in children and chronic bronchitis and chronic obstructive pulmonary disease in women. The study concluded that by minimizing exposure to smoke and improving stove design, respiratory disease can be reduced. Similarly, Bruce et al (2000) in Katuwal (2009) reported that the traditional use of biomass for cooking energy increases the risk of respiratory diseases like bronchitis, asthma, tuberculosis, lungs cancer and ear infections. In Nepal the biogas plants are smoke-free and improve the health especially of women and children, who are more vulnerable to smoke disease in the kitchen (Katuwal, 2009). He further explains that stoves specially prepared for biogas burning prove to be more smokeless, up to 60.5% compared with traditional biogas stoves. Similar health benefits by installing biogas plants are reported by Pandey (2007) in the “Feasibility Study of Domestic Biogas Plants in Pakistan.”

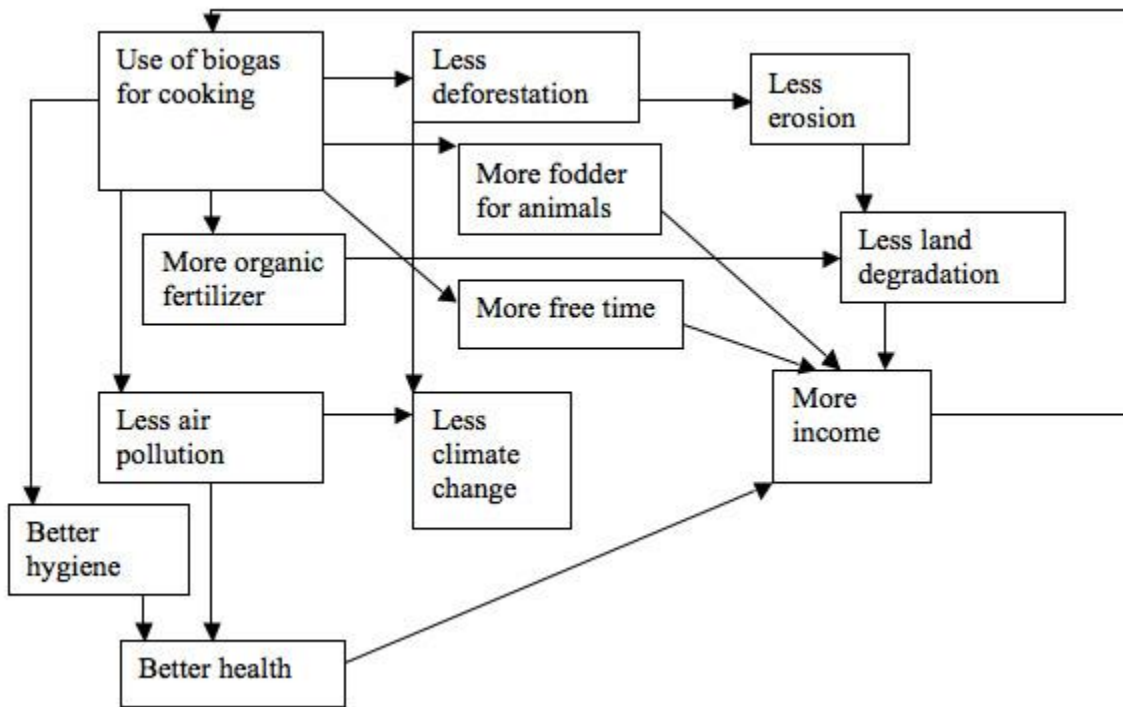


Figure 9 Effects of Cooking with Biogas source: (The EcoTipping Points Project, 2010)

Biogas plants proved to be very effective in the case where it linked with public toilets or where the human excreta are no more store openly. Furthermore, better health benefits can be achieved through switching fuel woods to clean cooking fuel (biogas). In Guatemala in born babies 19.9% low weight was found in families who were using firewood compared with 16.0% for those using electricity and gas for cooking and lightning (Bond and Templeton, 2011).

In Pakistan about 6.4 million people per annum suffer from diseases related to air pollution and have to be hospitalized. Air pollutant particles are observed more in Lahore than in other cities of Pakistan like Karachi, Quetta and Rawalpindi. These particles are six times more numerous than the permissible limit of WHO and three times more than U.S. EPA limits. An average of 10,092 buses per hour have been counted from seven surveyed sites in Lahore, without taking into account the number of automobiles and other vehicles (Majid et al.). The use of upgraded biogas as fuel can reduce GHG emissions as it is stated in many studies which further can also improve the environment.

4.5 Economic benefits of Biogas

The economic feasibility of biogas plants can be investigated with different factors, such as output (biogas) substitution of fuel, slurry (the use of residues and nutrients ratio), health benefit and pollution abatement (CDM). The health benefits are explained in the previous section. There are several studies which explain the economic benefit of biogas with fossil fuel, digestate as organic fertilizer and to achieve carbon credits under clean development mechanism (CDM) through biogas plants.

Biogas is a clean renewable resource for energy production. Renewable energy ensures environmental sustainability, economic profitability through a cheap source of energy and the creation of job opportunities for people all over the world (Isci, 2006). That is the reason why renewable energy has become popular in recent times. As reported, the use of biogas for vehicles has gained in popularity not only because of the high price of alternative fuels but also due to the great concern for the impact on global warming as a result of burning fossil fuels (Richard, A. 2010) and (Umar, K 2007). Berglund (2006) estimates that biogas generates SEK 0.40 per kWh, while petrol generates approximately SEK 1.20 per kWh. Moreover, a study conducted in Georgia demonstrates that biogas plants are economically feasible and their internal rate of return is more than 20%, while the payback timing is reported as less than seven years. Biogas contains CH_4 and CO_2 , and after the decomposition process the remaining residues contain plant nutrients and are used as fertilizer.

Amjad et al. (2011) demonstrates that the substitution of biogas and its residues for conventional cooking sources and chemical fertilizer can save 5150 PKR (almost equal to US \$100). Biogas

production from biomass resources needs less capital investment per unit cost compare with other renewable energy sources like hydro, wind and solar (Rao et al., 2010) in small scale biogas plant.

Table 2. Economic benefits of biogas. (After BetaPak, 2009-10)

Items	Cost without biogas plant (PKR)	Cost with biogas plant
LPG (2 cylinder)	2500	0
Fuel wood (3 mound)	1000	0
Dung cake	1000	0
Chemical Fertilizer	650	0
Total	5150	0

Table 4.2

Assessing economic impact of biogas system is very complex in developing countries where the biomass fuels are not well marketed. Nevertheless, there is one main driver that is reduces the pressure on woodland through which we can make economic assessment (Bond and Templeton, 2011).

The above table is adapted from the Biogas Energy Technology Application (BetaPak, 2009-10) web page, where they mention that by installing 5m³ biogas plants, a rural family can save 5,150 PKR (almost equal to US \$100) monthly in Pakistan. There is no doubt that manure-based biogas plants can be a good alternative and an economical source of energy in Pakistan because of the high price of petroleum goods and power outages of electricity and compressed natural gas (CNG). However, no research has been done yet to investigate the economic evaluation of installed biogas plants in Pakistan. The above economic savings estimate was also cited by Amjid et al., (2011) in his published article. Hence, these estimates are too optimistic.

By contrast, a study of ‘relative cost analysis of cooking fuel in Pakistan’ conducted by (Pandey and Bajgain, 2007)demonstrates that electricity is the most expensive and natural gas the cheapest source of cooking fuel in Pakistan. They further illustrate that domestic biogas plants generate 5 to 7 times more expensive energy as compared with natural gas. However, there is no doubt that the natural gas is a cheaper source of energy but it is not available everywhere, and reserves are very limited in the country. In order to cope with the energy crisis and make biogas technology affordable for rural communities where there is limited access to other energy

sources, the government provides a 25% subsidy to install biogas plants. The Pakistan Council for Renewable Energy Technology (PCRET, 2013) allocated Rs 89.2 million for development and promotion of biogas technology in order to meet the domestic fuel needs of rural areas and promote the production of bio-fertilizer.

In Nepal two biogas projects are registered under the Clean Development Mechanism (CDM), and these sell the carbon emissions under VER at the rate of 7 USD/ton. This was due to the fact that biogas reduces the burning of biomass, which in turn reduces GHG emissions (Katuwal, 2009).

Pandey (2007) demonstrates that biogas plants would help to achieve the following Millennium Development Goals (MDGs): 1) Eradication of extreme poverty and hunger by reducing fuel expenses; improving agricultural production by using more nutrients containing residues; and, with the development of the biogas sector, opening up more jobs in the country. 2) Achieving universal primary education by providing proper lighting in schools and homes for children to study by. 3) Promoting gender equality and empowerment of women by reducing women's workload and the time spent in firewood collection; and improving the health of women by reducing the smoke from cooking. 4) Reducing child mortality from indoor air pollution. 5) Ensuring environmental sustainability through reducing deforestation, GHG emissions and improvement of soil nutrients.

In conclusion, biogas is an economical source of energy for countries like Pakistan where power outages present a big challenge for government. Despite the availability of enormous biomass resources, the absence of good understanding and the use of key concepts of cost estimation may affect project profitability and technical solutions for the commercialization of biogas plants in Pakistan. The profitability of biogas would result from reducing the dependency on fossil fuels, since Pakistan spends half of its export earnings to import petroleum. Furthermore, installation of biogas plants will reduce GHG emissions (as is proven in many studies all over the world) and income will be generated by registering such projects under CDM projects. Examples of these benefits are available from Nepal and India. Bio-slurry, which is a by-product of biogas, can reduce the dependency on chemical fertilizers in Pakistan. It has proven to be the best alternative to chemical fertilizers which significantly increase agricultural production. Biogas plants will

reduce the use of firewood in rural areas, and it will save women the time involved in searching for firewood in the forest and make cooking easier for them.

4.6 Discussion of the literature review

4.6.1 Slow Development of Biogas Technology all over the World

The history of anaerobic digestion (biogas) goes back more than two centuries (Marchaim, 1992). But the oil crisis in 1973 and harmful effects of fossil fuels on environment and health and negative impacts of waste (including municipal and agriculture waste) enhanced the interest of biogas technology around the world and especially in industrialized countries (Arthur et al., 2011, Bond and Templeton, 2011);(Dincer, 2000). Several studies about biogas technology came after this oil crisis and environmental sensitivity which is widely recognized in the Kyoto Protocol 1992. Theoretically, anaerobic digestion of waste (biogas) present very fancy picture concerning to its utilization as a source of energy and multidimensional benefits and ways of reducing greenhouse gases emissions (GHG). However, in the ground reality it gives another insight and still biogas technology is not widely operationalized (except some sewage biogas plant in EUs and small household plants in developing countries) which can alternate the fossil fuel neither in developed nor in developing countries (Marchaim, 1992, P:13).

In developed countries, biogas technology development hindered because of the operational difficulties high technology cost and low prices of the conventional source of energy (oil, gas, electricity). Slow pace of economic development, lack of organized policies and supervision, inadequate foreign direct investment (FDI) and inexpensive non-commercial fuel such as firewood has been reported the main hindrance of biogas program in developing countries (Marchaim, 1992, P:13). Many studies are available across the world which only emphasizes on abundant resource availability for biogas production but still this field did not get its full potential.

Biogas production and its conversion into energy is very complex process especially in the developed countries where high energy required for biogas plant operation, integration with electricity, long transportation distance to brought feedstock and digestate back to farms, and limited availability of organic waste and arable land. In Denmark, the development of biogas technology is hindered due to following reasons. First, the price paid for per kilo watt hour of biogas electricity was € 0.06 to 0.075 which was relatively high compare to conventional

electricity. Second, the construction of new centralized biogas plants was stopped because of unavailability of organic waste. The shortage of organic waste in Denmark was because of many centralized biogas plant were installed in a short period and used the organic waste as feedstock (Raven and Gregersen, 2007). There was a supply shortage of organic waste for biogas plant. The transportation of organic waste very far away from regional plant made it economically and environmentally unfeasible. Thirdly, in 2001 a coalition Liberal/Conservative political party came into power and they emphasized less on environmental issues and more on cost effective energy supply in Denmark. Moreover, renewable energy policies were shifted and revised. Fourth, Danish Biogas Action Program was stopped by the government in 2002 and many R&D and funds scheme were also cancelled (Raven and Gregersen, 2007).

In Germany, currently, operation of majority of biogas plants is suboptimal, mostly to 80% capacity, which is partly attributed to lack of specialized training for technical plant operators on biological process control. The complexity of process engineering for the range of feedstock used is such that optimization, in most part, is possible only in laboratory scale studies. Their adoption for full-scale operations is still afflicted with uncertainties (Poeschl et al., 2010). In addition to this he further elaborates that, the conversion of biogas to electric power through fuel cell technology makes it four time more expensive and this restricts it to only at pilot scale. One of the outputs of biogas is a digestate which has potential utilization as organic fertilizer. The excessive digestate required arable land in the vicinity of the biogas plant. A biogas plant having capacity of 500 KWh requires 350 hectares of arable land to remain within the acceptable nitrogen contents range according to EUs regulation (Poeschl et al., 2010). If there is insufficient arable land close to biogas plant then the digestate has to be transported to long distance for disposal. This long transportation of digestate can turn into negative for environment and economic point of view if it across the define parameters. For example Poeschl (2010) conduct a study in Germany and illustrates that, the net energy output turns into negative when feed stock and digestate transportation distances exceed to 22 km and 425 km for manure and municipal solid waste (MSW) respectively. It is possible that large variations can exist in energy efficiency among the biogas systems studied. These variations depend both on the type and properties of the raw materials studied and on the system design and allocation methods chosen (Berglund and Börjesson, 2006). Alternatively, the digestate can be transformed into solid and liquid form

which again required high energy and huge investment for pretreatment prior to its usage in the agriculture (Poeschl et al., 2010).

Similarly, in Sweden around 200 large and small scale biogas plants have been installed, producing 5 PJ/year of biogas (SCB, 2005 cited in (Börjesson and Berglund, 2006)). Despite of these 200 biogas plants and many economic initiatives and the technological advancement of biogas in Sweden, the produce biogas contribute only 0.3% of the total energy consumed (Lantz et al., 2007). If the total biogas potential is harnessed (which is about 50 PJ/year) then this will correspond to only 3-4% of the total energy consumption in Sweden (Börjesson and Berglund, 2007). In spite of the aforementioned environmental and socio-economic benefits in this chapter, the economic feasibility of biogas production is limited under current Swedish conditions (Lantz et al., 2007). The review of literature and biogas technology development across the world shows that, it seems to be very difficult to achieve full potential in near future years unless some very strong initiatives and policies reform should not be undertaken in the country.

Apart from previous mentioned problem with biogas which hindered its development, there are some internal barriers which also contribute. These internal barriers are associated with the fermentation of the substrates. Biogas production is a process of microorganisms and depends on various factors like pH, temperature, hydraulic retention time (HRT), carbon nitrogen (C/N) ratio, etc., which is a relatively slow process (Yadvika et al., 2004). Anaerobic fermentation being a slow process, a large HRT of 30–50 days is used in conventional large scale biogas plants under mesophilic condition. This leads to a large volume of the digester and also increased the cost of the system. The decrease in gas production during winter season in small scale household biogas plant has been reported which, poses a serious problem in the practical application of this technology (Yadvika et al., 2004) Lack of process stability, low loading rates, slow recovery after failure and specific requirements for waste composition are some of the other limitations associated with biogas production.

Lack of good understanding and application of key concepts of cost estimation, a key to successful project which impacts both on project profitability and influences the technical solutions is a foremost barrier of biogas development and commercialization in Africa, despite

the availability of biomass resources (Amigun et al., 2008). Pokharel (2003) demonstrate that in Nepal the biogas technology is not well recognized because of technical, financial, policy, institutional and subsidies barriers. Similar barriers hindered the development of biogas technology in Pakistan, India and china. In India and China four and 27 millions of biogas plants have been installed respectively (Bond and Templeton, 2011). Beside of these 4 millions of biogas plant in India, waste to energy constitute 0.42% of the total energy supplied in the country (Rao et al., 2010). In many developing countries 50% of the installed plants are non-functional (Bond and Templeton, 2011).

In Pakistan two public departments, Pakistan Council for Renewable Energy Technology (PCRET) and Alternative Energy Development Board (AEDB) along with many other international and national NGOs are working for the promotion and execution of the biogas plants. These two departments spend millions of Pakistani rupees in the form of salaries of the employees, subsidies for small biogas units and promotional activities for biogas technology in the country. The poor economy of Pakistan cannot afford such expenditure if the output of biogas project is nearly to zero. Apart from small and large hydro projects, the renewable energy sector including solar, wind, thermal and biogas contributes less than 1% of the total energy supplied in the country (Sheikh, 2010).

Referring to the conceptual framework of the study, here the role of the government and financial institution brought into the action to formulate and regulate relevant and affective policies and provide incentives to the relevant agencies. The development and implementation of biogas systems is being stimulated by both existing and coming governmental incentives. For example, in Sweden the government exempted the taxes from biogas energy which improves the competitiveness of biogas compared with fossil fuels. Several on-going and planned biogas projects in Sweden have obtained governmental investment grants that aim at speeding up the transition to an ecologically sustainable society. In addition to this the Swedish government has also reformed the national waste handling policy including a ban on landfilling with organic waste from the year 2005 and an obligation to use biological treatment methods (e.g. anaerobic digestion or composting) of wet organic waste (Börjesson and Berglund, 2007).

To conclude this biogas energy is not in a pace which can alternate the conventional energy (oil, gas, hydro) in the recent future years. Many efforts and R&D activities are going on to promote and eliminate the technological barriers. The 'efforts' refer to developing countries where the relevant institutions organize campaigns, workshops; seminars and government induce incentives to promote biogas technology. While 'Research and Development' (R&D) refers to developed countries where they try to minimize the energy intensification and price compatibility with conventional source of energy. Present study find out biogas potential from animal manure and municipal solid waste and proposed a co-digestion biogas plant in Lahore. The literature review as a whole and more specifically discussion section of the thesis highlights some problems associated with biogas technology across the world which is a great learning experience in order to design the biogas plant in Lahore. The design of this biogas plant would be an art where all of these barriers (internal and external) are possibly avoided.

4.6.2 Summary

Biogas is a renewable and clean source of energy which has multidimensional ways to enhance the sustainable development of any country. It reduces GHG emissions through waste management and provides clean energy, improve the health condition of the peoples, increased the employment opportunities for peoples. Biogas system is not simply a matter of input availability for its production but many other factors play important roles. These factors are broadly categories in internal and external factors. Both of these factors are really important for the development of biogas technology in any country. The internal factors refer to the maturity and advancement of biogas technology while external refer to the institutional and economic development of all stakeholders. Low prices of alternative fuels, lack of maturity and advancement of biogas technology like high energy requirement and complexity of biogas plant design deprived its development in industrialized countries. Whereas lack of finance, organized policy failure and inadequate technological knowledge of biogas technology, are the major obstacles for biogas development in developing countries.

Chapter 5 Research Methodology

Generally the word research methodology meaning ‘‘ scientific way of gathering and processing required information’’. Keep these meanings in mind present study has been accomplished.

5.1 Research Method

In the present study mix method research has been used. As name reflect ‘mixed method is a combination of qualitative and quantitative’ research. As Creswell (2008) explain *mixed method procedures employ both of quantitative and qualitative*. Quantitative research is not very much apparent in the study as normally it is defined in the literature. Anyhow this study is a mixture of quantitative and qualitative method.

5.2 Type of Data

Generally two types of data are use in all the researches, primary and secondary. Data which is already collected and used for other purposes irrespective to current study is called secondary for instance publish books, journal articles, census report and government published documents. On the contrary to this primary data is obtained directly from first hand source by the research (Creswell, 2008, Bryman, 2012). It is collected through interview, questionnaires, tape recordings and observations etc.

Ongoing study focused on both secondary data and partially primary data a source of information. The secondary data which is used are relevant research papers from different online journals, web pages of relevant organization and books. Bunch of research papers have been read pertaining to complete this dissertation.

5.3 Data collection

Primary data was collected within 2 weeks in January 2012. Later on some photographs about municipal solid waste and biogas plants were captured.

5.4 Limitation

Like other studies this study also has some limitations. First of all there is no lab research has been done until now to examine the real potential of biogas from animal manure and municipal solid waste in Pakistan. For this reason it was my plan to import food and animal waste samples in order to perform lab experiment here in UMB. I applied to Mattilsynet for the permission to import samples in April, 2013. But unfortunately they refused after two months by saying that ‘food and animal waste from Pakistan can contain harmful pathogens which will be diffused in the environment here’. I respect their authority and changed my plan to do literature review based study. To some extent this restricts my experimental knowledge about biogas potential which might reflect somewhere in thesis. Even though Mattilsynet reject my application but still I had strong wishes to work in biogas lab. I join to my Norwegian friend who was also working on biogas potential from animal manure along with other substrates for his Phd dissertation. After three days as I started my work in the Volleybeck biogas lab suddenly in the night fire hit and half of the lab damage badly. Renovation of the lab took long time and quit my plan again.

5.5 Study Area:

This study is focus on the MSW of Lahore. Lahore is a capital and second largest city of Pakistan in terms of population after Karachi. The expected population is about 10 million (Majid et al., 2012) which makes it amongst 40 largest cities in the world(Worlдатlas, 2013). Moreover it is a most growing economy in Pakistan and contributing significantly to the National GDP of US\$395 billion. Lahore is a business hub after Karachi, having 9000 industrial plants (ESMAP, 2010). Due to many business activities (including manufacturing and services), the city is witness of rural migration from all parts of the country. This fast pace of urbanization due to rural migration and indigenous population growth there has been increase in the consumption

pattern which put immense pressure on the social and physical structure of the city (ibid, 2010). Out of many other issues, solid waste management and energy shortfall is a big challenge for the government officials.

Lahore is located on River Ravi bank with Latitude 31° 32'N; Long 74° 22'E. The climate is hot and average temperature varies between 36 and 46 °C winter and summer respectively(Majid et al., 2012).The city of Lahore has 9 towns name Shalimar, Nishtar, Gulberg, Ravi, Data Ganjbuksh, Iqbal, Aziz Bhatti, Samna Abad, and Wahga town(LDA, 2013). The city has three main municipal dumping sites Mehmood Boti in Shalimar town, Saggian in Ravi town and Baggarian in Nishtar town.

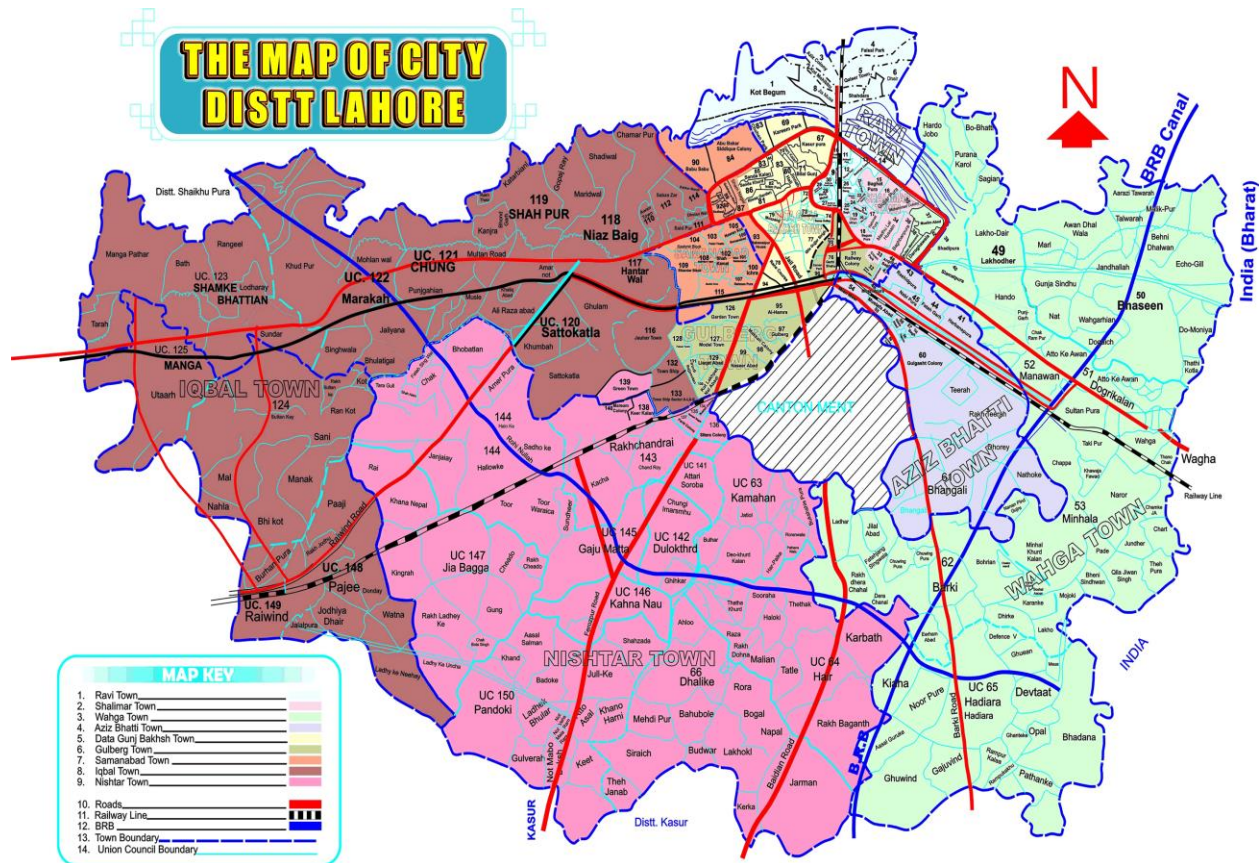


Figure 10 Map of Lahore source: <http://www.mappery.com>

Chapter 6 Situational Analysis

6.1 The current situation of Municipal Solid Waste in Lahore

Lahore Waste Management Company (LWMC) of the City District Government Lahore (CDGL) is the sole responsible authority to handle the solid waste in Lahore. In the city district Lahore, 6,000 tons of municipal waste is produced daily (ESMAP, 2010) with approximately 0.5 to 0.65 kg/per capita generation rate (Batool and Chuadhry, 2009). Of this total generated municipal solid waste, 60% is collected daily while the rest of 40% municipal solid waste is uncollected and lies in the streets, walkways, on the roads, vacant plots and in the drains (Ibid, 2009). Lahore Waste Management Company (LWMC) claims that the outsourcing of waste collection to international companies like Al-Burak (A Turkish company) increase the municipal waste collection percentage and now 80% of the total generated waste is collected daily in Lahore (LWMC, webpage). But still these numbers are neither well documented nor widely recognized in the scientifically published literature.

The collected municipal waste (60%) in Lahore is disposed of in the uncontrolled landfills and dumping sites at MehmoodBoti, Saggian, Baggarran and KahnaKacha (ESMAP, 2010). Apart from these official dumping sites in Lahore, there are number of illegal deposits of waste which are far from environmentally acceptable standards. The collected waste is dumped in the open dumping sites and burned in the open air to reduce its volume which contributes to air pollution. “At present, there are no landfill regulations or standards that provide a basis for compliance and monitoring, but national guideline for these standards are being prepared by the consultant under the National Environmental Act Plan Support Program (NEAPSP)” which are normally not followed. Almost all dumping sites in Lahore do not have collection and treatment of leachate and also the same case with landfill gas excavation. It is widely accepted that the uncontrolled dumping and landfills sites and the municipal waste in the open places may cause serious threat to ground water quality, soil quality and directly or indirectly influence on human health (Haydar and Masood, 2011).

The solid waste treatment and disposal technologies (like incineration, composting and sanitary landfills and waste combustion technology) are relatively new in Pakistan but now such

technologies are getting attention of the concerning departments. Currently, a MSW composting plant is functioning at Mehmood Boti landfill site in Lahore. It processes only 350-450 tons of organic waste and convert it into enrich organic fertilizers (Wajid, 2011a, Batool and Ch, 2009)but no energy is recovered in this process. The detail of this MSW compost plant is available in the background chapter 2.

In Lahore and Pakistan at large, the separation of organic and inorganic waste is not practiced at any level (house, restaurant, offices, commercial places, fruit markets). The unsorted (mixed) waste transported to nearby landfill sites through Lahore Waste Management Company's (LWMC) vehicles where it is dispose of without taking any precautionary measures. The composition of MSW in Lahore is presented in the following table.

Table 3 Composition of the Municipal Waste in in Lahore

Waste Component	Overall percentage %
1. Biodegradable	67.02
2. Nylon	8.99
3. Textile	6.95
4. Diapers (Pampers)	5.07
5. Combustible	3.21
6. Paper card	2.87
7. Non combustible	2.50
8. Tettrapak	0.90
9. Hazardous waste	0.87
10. Glass	0.68
11. Plastics	0.61
12. Pet	0.14
13. E-waste	0.11
14. Metals	0.07
Total	100.00

Source: (SEZER, 2012)

The above table is adapted from (SEZER, 2012), study of “Consulting Services Project for Integrated Solid Waste Management of Lahore City, the State of Punjab Pakistan”. There are some variations in the composition of MSW in Lahore among Sezer’s study and Batool and Chaudhry (2009), ESMAP, (2010) Haydar and Masood (2011) but biodegradable waste’s percentage is similar in all studies.

The above table shows that biodegradable waste has the most significant amount (67%) in the municipal waste in Lahore. This biodegradable waste contains household waste including fruit & vegetable residues 31%, wood bones, leaves and grass 25%, animal waste 2.53%(Haydar and Masood, 2011)and rest of the biodegradable percentage comprises on ash and dust. The presence of animal manure (see picture 5) is very good sign for biogas production from the municipal solid waste. This balances the carbon nitrogen ratio of the feedstock.



Figure 11A view of Municipal Waste Composition and Handling Practices at Mehmood Boti landfill Site in Lahore (Muhammad Abbas)

6.2 Anaerobic Digestion of MSW

The management of the municipal solid waste has been a great challenge for local authorities in all parts of the world. Much progress and efforts have been made for the sustainable treatment of MSW to avoid related harmful effects and energy recovery its sources. Despite of many alternatives available for MSW treatment now days, the anaerobic digestion is very successful and innovative technology developments have been seen so far (Mattheeuws, 2010). The EU policy to increases the production of renewable energy trigged anaerobic digestion of organic waste and make it very popular in the region (Pognani et al., 2009). Anaerobic digestion is one of the effective sources to reduce volume, decrease the harmful effects of municipal waste and produce energy from biodegradable waste of the municipalities (Jingura and Matengaifa, 2009) and emit lesser greenhouse emissions (Pognani et al., 2009). In addition to this, the anaerobic digestion of MSW can be used to enhance waste management practices by meeting the legal demands such as banning the organic land fillings, production of renewable resources, and improved the management of plant nutrients through organic fertilizers (Berglund, 2011(Pognani et al., 2009).

The alternative treatment technologies like composting process a small percentage of organic waste and it started to decline because of major quality challenges due to heavy metals and inert materials in the final products (Mattheeuws, 2010) and no energy is recovered in the composting process. Approximately 80% of the composting plants in Netherland and Belgium will be shifted to anaerobic digestion. The multidimensional benefits of anaerobic digestion over conventional aerobic processes are a low energy requirement for operation, a low initial investment cost and a low sludge production (Kim et al., 2006). Similarly, the recycling of MSW is also limited to easily recoverable material like glass, papers and plastic (Mattheeuws, 2010). For example in Lahore only 21.2% of the total generated waste such as plastic, paper, glass and metal can be recycled (Batool et al., 2008). The other alternative technologies like gasification, pyrolysis, plasma and biological drying are not as widely implemented as anaerobic digestion (Mattheeuws, 2010). The number of anaerobic digestion plants are increasing in Europe (Pognani et al., 2009). In 2014, the number of total anaerobic digestion plants in Europe will touch the figure of 244 with annual processing capacity of 8 million tons of organic fraction of MSW (Mattheeuws, 2010). With the passage of time and growing demand of anaerobic digestion

plants, several advancement have been made in the design and volume of the digester and now up to 60,000 ton of volumes anaerobic digesters are available in the market (Ibid, 2010).

Municipal solid waste contains both biodegradable and non-biodegradable components. However, the biodegradable fraction of MSW is digested to produce biogas (Rao et al., 2010). Biodegradable fraction of Municipal Solid Waste (MSW) is highly potential feedstock in the anaerobic digestion process to produced biogas (Jingura and Matengaifa, 2009). The chemical composition of the biodegradable waste comprises of cellulose, hemicellulose and lignocellulose. Both, cellulose and hemicellulose (carbohydrates composed of hexoses and mainly pentose) are available in the food waste, agricultural residues and animal manure which are easily degraded in the anaerobic digestion (Bruni et al., 2010).

A fraction of MSW such as woods, cardboards, textile, papers and baby pampers contains more lignocellulosic content which is very resilient in the anaerobic digestion and gives low biogas yield (Møller et al., 2004). Basically, lignocellulose is very complex and rigid matrix of plant cells and the tight binding between lignin, cellulose and hemicellulose resist the enzymatic attack of bacteria in the anaerobic digestion (Bruni et al., 2010). Few mechanical and thermal treatments of lignocellulosic substrates is available now in the market which increase its degradability and methane yield up to 25% (Hartmann et al., 2000). But in most cases pretreatment of such substrates increase the capital cost and energy input to output ratio turn to negative which makes it unsuitable for anaerobic digestion. Raposo et al. (2012) demonstrate that, “the organic substance can be subdivided into: fats, proteins, carbohydrates and lignin. Proteins, lipids and extracted fractions of carbohydrates are usually the soluble parts, while the fibrous components represent the structural lignocellulosic content, in which case solubilization is very difficult. So, biodegradability is limited by the crystallinity of the cellulose and the lignin content”.

Germany is a market leader to provide modern anaerobic digestion technologies. There are different anaerobic technologies available. In principal there are two main methods for treating organic household wastes. This is dry and wet fermentation. In a dry fermentation process the content of total solids (Kastner et al.) are between 25 and 45 percent (Steinhauser, 2008)while for the wet process a dry matter content of below 25 percent is required. Wet processes are often easier to operate and produce more methane per ton dry matter than dry processes. On the other

had do wet processes require substantial amounts of water if the waste is relatively dry. Anaerobic processes may further be divided by operational temperature. Higher temperatures give faster digestion. The thermophilic technology normally required 55 to 60°C, mesophilic 30 to 37°C while psychrophilic less than 20°C (Kim et al., 2006). For large scale reactors 37°C or 55°C are preferred. Thermophilic reactors may have some higher production rate and may also contribute to hygenisation of the substrate. On the other hand mesophilic reactors are more robust due to changes in the substrate composition and less vulnerable to ammonia inhibition.

For wet processes continuous stirred tank reactors (CSTR) are the most common technology. These are formed like large tanks, up to several thousand cubic meters, provided with heating and stirring equipment. Dimensioning the size of the reactor is done by multiplying the daily volume of substrates with the preferred average storage time in the reactor, and added five to ten percent extra volume in the top in case of foaming. If for example the plant is daily receiving 100 cubic meters of wastes, and preferred storage time is 25 days, a reactor size of 2500 cubic meters plus 125 to 250 cubic meters extra, is required.

6.3 Biogas Potential from biodegradable fraction of municipal solid waste (MSW) in Lahore

Table 5.1 shows that municipal solid waste of Lahore contains 67% of biodegradable waste. Along with the physical characteristics of the MSW, the chemical composition such as quantification of moisture content (MC), biodegradability, total solids (Kastner et al.), volatile solids (VS), nutrients contents (C:N) and particle size of the biodegradable waste are some of the fundamental parameters to find out biogas potential from the municipal waste (Raposo et al., 2012, Zhang et al., 2007). These parameter are not only restricted to obtain biogas yield from the substrate but also gives important information for designing and operating anaerobic digesters, because they affect biogas production and process stability during anaerobic digestion (Zhang et al., 2007). The information about the physical composition of the municipal solid waste in Lahore is well documented by different researchers (SEZER, 2012, Batool et al., 2008, Haydar and Masood, 2011, Rafiq Khan and Tanveer, 2011)but very limited information available about the chemical composition. Consequently the latter situation presents a degree of uncertainty of

the waste's properties, manifesting itself as financial risk in the investment of new treatment or disposal plant.

Lahore's municipal waste characterization study was conducted by SEZER (2012), and demonstrated that on average 47% of the moisture content was found in the municipal solid waste in Lahore with 29.52% organic matter content, 45.9% volatile substance and 1.67 Kcal/kg. The Lahore Waste Management Company (LWMC) gave financial support for this study and using this study to provide basic information about physical and chemical composition of the solid waste in Lahore to national and international investors who wants to involve in the waste management business. The problem with this study is that, it gives average moisture content of the overall municipal waste (including biodegradable and non-biodegradable).

The percentage of MC, TS and VS can be different if biodegradable and non-biodegradable waste is separately analysed. The reason is non-biodegradable waste for example glass, plastic, rubbers, pet and metal contains less moisture percentage compare to biodegradable waste. For example the moisture content in the non-biodegradable waste like glass, rubber, leather, plastic and tin cans was found to be 2, 2, 10, 2 and 3% respectively ([msw.cecs.ucf.edu/Exercise-Estimation of the Moisture](http://msw.cecs.ucf.edu/Exercise-Estimation%20of%20the%20Moisture)). The biodegradable municipal waste can contains high moisture content about 60 to 90% of the municipal waste (García et al., 2005).

Table 5.2 shows difference in the MC, TS and VS of the biodegradable and non-biodegradable if they are analysed separately. The table also indicates high moisture content in the biodegradable waste compared it with SEZER (2012), study. Due to relatively high moisture content of food waste, bioconversion technologies, such as anaerobic digestion, are more suitable compared to thermochemical conversion technologies, such as combustion and gasification (Zhang et al., 2007).

The moisture content (MC) of the biodegradable waste effect on the TS which further effect on VS. The VS is normally used as a basic indicator to find out methane potential from the feedstock (Raposo et al., 2012) . Zhang et al. (2007) reported that the methane yield obtained from their study is lower than Cho and park (1995) because of lower VS/TS. Moreover,

biomethanization from the waste is also subject to the concentration of three main organic components: protein, lipids and carbohydrates in the digested feedstock (Álvarez et al., 2010). It is also important to note that, not all VS are equal and therefore they exhibit different rates and extent of biodegradation during anaerobic digestion. (Raposo et al., 2012).

As I mentioned earlier there is limited literature available about the chemical composition of the biodegradable waste of Lahore. So in order to assess biogas potential from the municipal solid waste of Lahore we will rely on (Rao et al., 2000) and (Rao et al., 2010) estimates. Both of these studies are conducted in India to find out biogas potential from the organic municipal waste. The reported physical and chemical composition such as organic component, moisture content, VS and TS in the latter mentioned studies are more or less similar to Azhar and Baig (2011) study about the biogas potential from the food waste, conducted in Islamabad, Pakistan. Moreover, waste handling practices and food habits of Indian peoples are also similar to Pakistani people. In such cases we can rely on Indian studies if the required data is not available from Pakistan. This makes me quite confident with biogas potential results from biodegradable waste of Lahore.

6.3.1 Biogas potential calculation

The biogas or methane yield is measured by the amount of biogas or methane that can be produced per unit of volatile solids contained in the feedstock after subjecting it to anaerobic digestion for a sufficient amount of time under a given temperature (Zhang et al., 2007, Møller et al., 2004). Here I make biogas potential calculation from the biodegradable municipal solid (MSW) of Lahore under two biogas yields reported by Rao et al. (2000) and Rao et al. (2010). Each scenario uses same basic facts about MSW of Lahore.

Scenario 1: Biogas potential based on (Rao et al., 2000) analysis 0.661 m³/kg volatile solids

Some basic facts of Lahore's MSW

- Total generated municipal solid waste in Lahore = 6000tons /day¹
- Total Biodegradable (67%) municipal waste in Lahore = $6000 \div 100 \times 67 = 4020^2$ tons which correspond to 402000 Kg/day

Biogas potential calculations

Moisture content 85% and VS is 88.5%³

- Total Solids = Total weight of BD – Moisture content = $4,020,000 - 4,020,000 \div 100 \times 85 = 603,000$
- VS /TS = $603,000 \div 100 \times 88.5 = 533,655\text{kg}$
- Biogas potential from biodegradable fraction of MSW = $0.661 \text{ m}^3/\text{kg VS}^3$
- Total biogas potential from biodegradable waste in Lahore = $533,655 \times 0.661 = 352,745.96 \text{ m}^3$ biogas/ day. This biogas contains 70% (CH₄)³
- 1 m^3 biogas (70% CH₄) = approximate 7.0 KWh energy⁴
- So this correspond to $352,745.96 \times 7.0 = 2,469,221.7$ KWh calorific energy/day

Electricity production potential

- Biogas electricity conversion efficiency is 35%⁵ therefore
- Total daily electricity potential from biodegradable waste in Lahore = $2,469,221.7 \div 100 \times 35 = 884,227.6$ KWh electricity/day
- MWh = KWh $\div 1000$
- MWh = $884,227.6 \div 1000 = 884$ MWh electricity
- This correspond to 3183219360 KJ/second

1. (ESMAP, 2010)
2. (SEZER, 2012)
3. (Rao et al., 2000)
4. (SGC, 2011)
5. (Banks, 2009)

Scenario 2: Biogas potential based on (Rao et al., 2010) analysis 95m³/ ton of biodegradable waste

Some basic facts of Lahore's MSW

- Total generated municipal solid waste in Lahore = 6000tons /day¹
- Total Biodegradable (67%) municipal waste in Lahore = $6000 \div 100 \times 67 = 4020^2$ tons which correspond to 402000 Kg/day

Biogas potential calculations

- Biogas potential from biodegradable fraction of MSW = 95m³/ ton³
- Total biogas potential from biodegradable waste in Lahore = $4020 \times 95 = 381,900$ m³ biogas daily

This biogas contains 60% of methane (CH₄)³

- 1 m³ biogas (60% CH₄) = 6.0 KWh energy⁴
- So 381,900 m³ biogas = $381,900 \times 6.0 = 2,291,400$ KWh calorific energy/day

Electricity production potential

- Biogas electricity conversion efficiency is 35% ⁵therefore
- Total daily electricity potential from biodegradable waste in Lahore = $2,291,400 \div 100 \times 35 = 801,990$ KWh electricity/day
- MWh = KWh \div 1000
- MWh = $801,990 \div 1000 = 802$ MWh electricity/day
- This correspond to 2887164000 KJ/second

1. (ESMAP, 2010)
2. (SEZER, 2012)
3. (Rao et al., 2010)
4. (SGC, 2011)
5. (Banks, 2009)

The above calculation is a rough estimate and it shows small variation in the total biogas potential. Higher biogas yield is obtained from (Rao et al., 2000) analysis which is well explain by long digestion time of 240 days and overall bioprocess conversion efficiency of the substrate was reported to 95.44%.

6.3.2 Energy consumption and efficiency of biogas production system

The biogas production requires energy at four stages such as collection and transportation of the substrates, operation of the biogas plant, upgrading the biogas and finally spreading the digestate (Berglund and Börjesson, 2006). Moreover, she explains that normally it required 20-40% of the energy content of the biogas produced. Mechanical operation of biogas plant is the most energy demanding process in the whole biogas system and approximately it required 40-80% of the primary energy input. The energy efficiency of biogas production is evaluated through primary energy input to output (PEIO) ratio. The energy input highly dependent on the type of feedstock digested in the anaerobic digestion. The PEIO ranged from 10.5 to 64% depending on the type feedstock and its transportation (Pöschl et al., 2010).

The current study is a biogas potential study from municipal waste of Lahore. The Lahore is a densely populated and the outer edges of the city are approximately 40 km away from the city centre which reduce transportation energy. The annual average temperature remains between 30 to 35 C°. This will reduce enormous amount of primary energy input to biogas system.

6.3.3 Utilization of Biogas Energy

The scenario 1 shows that 2,469,221.7 KWh calorific energy/day can be produced from biodegradable waste of Lahore. The produce biogas energy can be used for different purpose but in the present study, the generated biogas energy proposed to use either for combine heat and power (CHP) or as vehicle fuel. The combined heat and power (CHP) production gives higher profitability than stand-alone power production because of maximum utilization of the produce energy and high total conversion efficiency (Börjesson and Berglund, 2007). As it shows in the figure 10, in the CHP 35% of the produce energy converted into electricity while 50% for heat generation and rest of the 15% energy is lost during the conversion process (Banks, 2009)

The produce electricity is fed to nearby national electric grid and cooling can be used to nearby food cold storage or for buildings. A part of generated heat is used for anaerobic digestion control process and the remaining heat can be used for district heating network, organic rankine cycle process (ORC) and cooling the buildings. The upgraded biogas substitutes the natural gas and also can be used as transportation fuel. The upgraded biogas (biomethane) is injected into the natural gas grid in an efficient way (Pöschl et al., 2010).

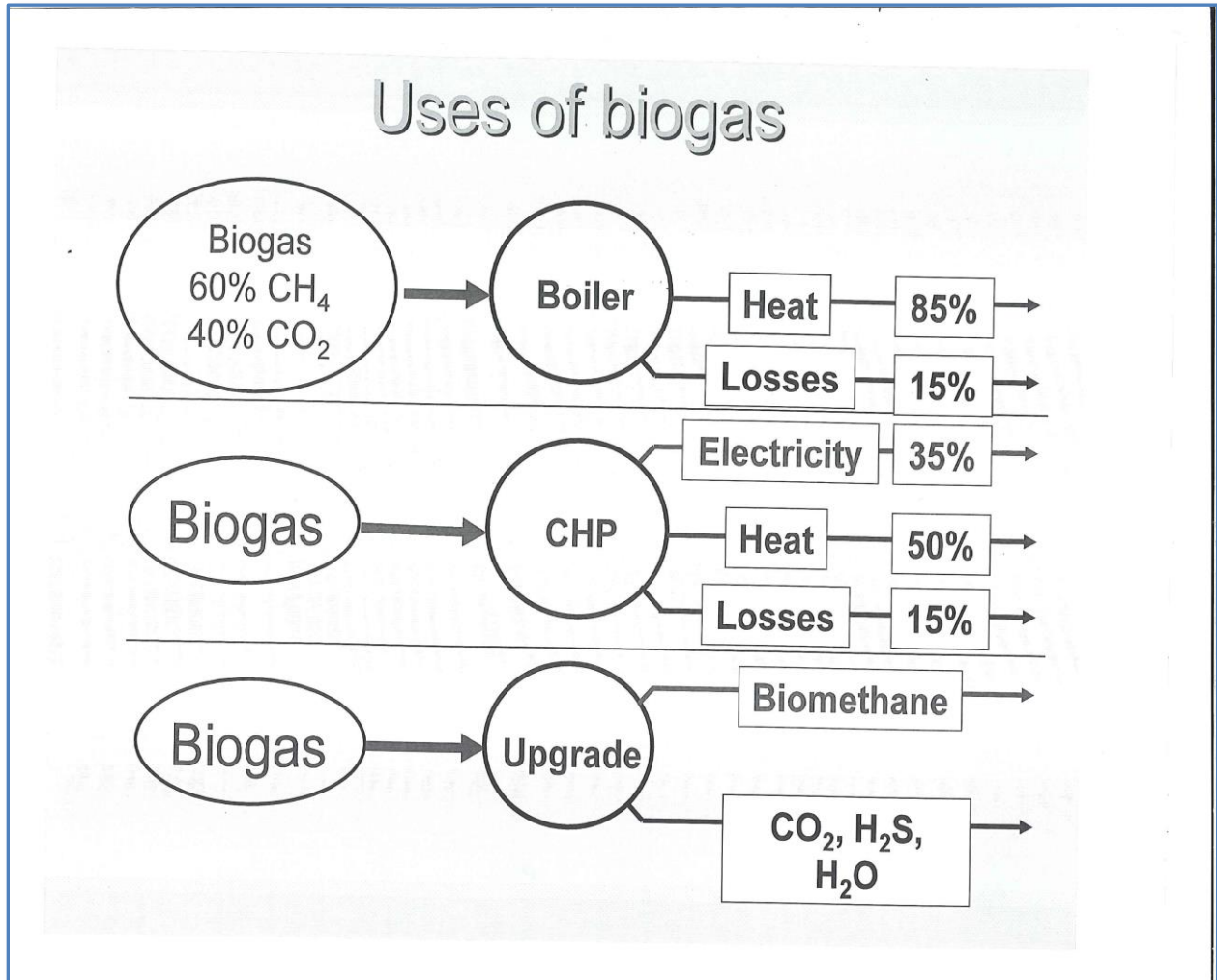


Figure 12 Conversion efficiency of different Usage of Biogas source: (Banks, 2009)

6.3.4 Up-gradation of Biogas

The up gradation or liquefying of biogas comprises on the extraction of CO₂, H₂S and other pollutants available in the biogas (Hullu et al., 2008). This enhanced the concentration of methane in the biogas which gives it more calorific value to biogas to make it use for fuel in the vehicles (ibid, 2008). Persson (2003), demonstrate that the separation of water and H₂S from the biogas is purification process while, the removal of CO₂ is up-gradation of the biogas. At the moment there are five techniques which normally discuss in the literature to upgrade the biogas. These are (1) chemical absorption of CO₂ and H₂S (2) High pressure water scrubbing (3) Pressure swing adsorption (4) cryogenic separation (5) membrane separation. The up gradation of the biogas is expensive procedure and only possible at large scale biogas plants where more than 10,000 tons waste process per year (Hullu et al., 2008).

High pressure water scrubbing is relatively cheap technique to upgrade the biogas. This technique gives 98% purity and 94% yield. On the other hand cryogenic technique is the most expensive and gives highest yield 98% but less purity 91% (Hullu et al, 2008).

H₂S can be removed either in the digester or from the upgrading process. H₂S is poisonous gas and in the presence of water it becomes H₂SO₄ which is even worse if it is inhaled (Hullu et al, 2008). In the Anaerobic process the raw material that contains sulphur produce hydrogen sulphide H₂S through transformation while ammonium produced due to nitrogen concentration (Hagen et al, 2001). The concentration of the H₂S can vary in the reactor depending on the raw material used. Biogas, sewage plant and landfills contain 10 to 2000, 10 to 40 and 50 to 300 respectively (Persson, 2003). A study conducted by Fiesinger et al. (2006) suggest that the addition of food waste with animal manure helps to reduce H₂S concentration in the biogas reactor. The H₂S concentration found very high in the reactor about 1500 to 4000ppm where the food waste not added.

The upgraded biogas is used in the vehicles as fuel. To use it as fuel in the vehicles required approximately 97% methane concentration in the biogas. In order to make calculations about the total potential of up-graded biogas here I used the biogas values from scenario 1.

Total biogas potential from biodegradable waste in Lahore = 352,745.96 m³ biogas/ day. This biogas contains 70% (CH₄)

Upgraded biogas 97% methane = 257,504.3m³/day

The above calculation shows that the organic municipal waste of Lahore has the potential to produce approximately 257,504m³ upgraded biogas/day. This potential is correspond to 257,504 litre diesel/day because the upgraded biogas (97% CH₄) has the same amount of energy value as diesel. See the table,

The energy content of different fuels (SGC, 2012)

- 1 m³ biogas (97% methane) 9.67kWh
- 1 m³ natural gas 11.0 kWh
- 1 liter petrol 9.06 kWh
- 1 liter diesel 9.8 kWh
- 1 liter E85 (Ethanol) 6.6 kWh

6.4 Digestate (Slurry)

Along with Biogas, the digestate is another by product of anaerobic digestion (FAO, 1992). The digestate is a nutrients rich substance of anaerobic digestion which can be used as organic fertilizer in the agriculture sector (AnaerobicDigestion, 2013). One of the features of anaerobic digestion is to reduce the odor up to 80% comparing it with feedstock to end product digestate. Moreover, it reduces the presence of weed seeds, bacteria, viruses, fungi and parasites available in the feedstock which is very important if the digestate is used as fertilizers. The deterioration of latter mentioned pathogens depends on temperature, treatment time, pH, and fatty acids availability. The best decay results of pathogens can be obtained with thermophilic temperature (Weiland, 2010). Digestate can be in liquid or solid form depends on either the feedstock is digested in a dry or wet fermenter. The liquid digestates is dried up to specific requirement in the biogas plant to reduce its volume and easy transportation.

It is quite evident that all of the biodegradable waste is not converted into biogas and digestates. Some of the waste is consumed by the microorganisms during their reproduction and growth and

some is lost during the anaerobic process (Rao et al., 2000). It is reported that the weight of the digestate will be around 90-95% of what was fed in the digester and the availability of the nutrients such as nitrogen, Potassium and Phosphorous will remain same in the digestate (AnaerobicDigestion, 2013).

Azhar and Baig (2011) conduct a study of biogas potential from vegetable and fruits waste and successfully set up a co-digestion (fruits and vegetable waste with animal manure) biogas plant of 1.2 m³ at National University of Science and Technology Islamabad, Pakistan. Two batch experiments were conducted, batch 1 contains only food waste and batch 2 contains food waste and animal manure. In addition, they found 17:1 C/N ratio for batch 1 and 30:1 for batch 2. This ratio is within the standard range to use the digestate as fertilizer. So on the basis of this study we can assume same nutrients values in the municipal biodegradable waste of Lahore

We assume the digestate weight 95% of the added feedstock

- Total biodegradable waste fed = 4020 tons/day
- Digestates Quantity = $4020 \div 100 \times 95 = 3819$ tons/day

This digestate contains 85% moisture content

- We required 20% moisture content to sale it in the market as the compost fertilizer has a market mechanism in Pakistan with 20% moisture content. So in this case
- Digestate with required moisture content = $3819 \div 100 \times 20 = 763$ tons/ day
- This correspond to 763000 kg/day
- This correspond to 15260 bags/day (50kg dry digestate in each bag)

The digestate is not compost but has similar characteristics (AnaerobicDigestion, 2013). According to available composting technology 35% of the nitrogen content is lost in the organic waste during the composting process (U. Sonesson, 1996 cited in Börjesson, 2007). The availability of nutrient contents in the biodegradable MSW of Lahore, the Lahore Compost Limited (LWMC) estimates that 100 kg composted organic fertilizer's bag contains following percentage of the nutrients. So I also assume same nutrients in the

digestate bag.

Table 4 Nutrients in the Digestate source: Lahore Compost Limited.

Macro Nutrients	
Nitrogen (N):	1.5-2.5%
Phosphorus (P):	1%
Potash (K):	1%

Micro Nutrients	
Zinc:	253 ppb
Ferrous:	388 ppb
Maganese:	18 ppb
Copper:	255 ppb
Magnesium:	3.9 ppm
Sodium:	3.9 ppm
Bulk Density:	560 kg/m ³

6.5 GHG emissions Reduction Potential of a Biogas System

It is widely recognized that biogas is a clean renewable source of energy (Börjesson and Berglund, 2007, Berglund and Börjesson, 2006, Holm-Nielsen et al., 2009, Katuwal and Bohara, 2009, Kothari et al., 2010, Pandey and Bajgain, 2007). The anaerobic digestion of municipal organic waste might reduce significant negative environmental impacts which are normally produce from waste handling practices as well as burning of fossil fuel. The extent of the emission reduction depends on the type of substrates and their usage and storage practices before to biogas production and technology applied for biogas production (Börjesson and Berglund, 2006). In addition to this, the total environmental impacts due to the introduction of a biogas system largely depends on the reference system replaced, concerning to energy supply and waste handling (Börjesson and Berglund, 2007). The reference system is refers to the existing system which will replace by the biogas system. In our case, biogas will replace fossil fuel used in the energy production and the waste which is dumped in the uncontrolled landfill without landfill gas collection and leachate control into the organic rich digestate and biogas. The

reference system produces large amount of emissions without producing any energy out of it. In the present study the GHG emission mitigation from the biogas can be investigated in three ways (1) substituting fossil fuel in the energy sector (2) mitigation of GHG from uncontrolled landfills as in the case of Lahore municipal waste (3) substituting the chemical fertilizers with digestate.

Batool and Chuadhry (2009) conducted a IWM 2 LCI model based study “The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan” and the baseline scenario demonstrate that the municipal waste of DTGB town emit 838,116 tons of CO₂ equivalent/year with an average of 1.68 tons of CO₂ equivalent/tons of waste. These emissions included the collection and transportation of the waste to dump site and the landfill gas emissions and leachates. The study further indicates different waste treatment possibilities and claimed that the production of biogas from organic waste and the substitution with electricity and digestate substitution with chemical fertilizer can reduce approximately 1.23 tons of CO₂ equivalent / ton of biodegradable waste compare to the baseline scenario. This corresponds to 74% emission reduction through uncontrolled landfills, transportation of the waste and substitution with electricity and chemical fertilizers. These results are very similar to Arnold (2009) and (Börjesson and Berglund, 2007) studies where it is mentioned that biomethane produce from municipal waste can save 73% and 50 to 80% GHG emissions respectively when the biogas is substituted with fossil fuels. So based on Batool and Chuadhry (2009) present study estimates GHG reduction potential from the biodegradable waste of Lahore.

In the present study, the baseline scenario (the existing waste collection and disposal system) shows that 14,667,300 (4020×365) tons of biodegradable waste is generated per year in Lahore which corresponds to 24,641,064 (14,667,300×1.68) tons of CO₂ emissions equivalent/year. These emissions include collection and transportation of the waste and landfill emissions. Based on our reference study of Batool and Chaudhry (2009), in our case if all the generated biodegradable waste of Lahore is utilized for biogas production and is substituted with electricity and digestate with chemical fertilizer

this can reduce 18,234,387.4 tons CO₂ equivalent per year with the rate of 74% emission reduction. So if the produce biogas is upgraded and substitute with diesel in the vehicles then this can reduce 73% of the baseline emission which correspond to 17,987,976.7 tons of CO₂ equivalent per year. In these entire cases, 100% baseline emissions are not avoided because some of the emissions are emitted during the transportation, processing and upgrading of the biogas.

Hence, the present study reveals that 18,234,387.4 tons CO₂ equivalent per year can be avoided if the produce biogas will be substituted with electricity and chemical fertilizer. The substitution of electricity also means the substitution of fossil fuel because in Pakistan almost more than 80% of the energy is met through fossil fuel(Nawab, 2013).

6.6 Economic Potential of Biogas from Organic waste of Lahore

The economic potential of biogas from biodegradable waste of Lahore can be investigated in three ways.

1. Total revenue from replacing the fossil that use in the electricity production or in the vehicles
2. Total revenue from the digestate which substitute chemical fertilizer
3. Total revenue from the carbon credit scheme (CDM) by reducing per ton of CO₂ equivalent/year

Fossil fuel replacement (**F**): in the present the study we assume the upgraded biogas will replace the diesel in the buses. So as it is calculated that 257,504.3m³/day upgraded biogas can obtain from biodegradable waste of Lahore. This upgraded biogas is corresponds to 93,988,960 m³natural gas/year. The prices of natural gas fluctuate but currently in Pakistan the consumer sale price of compress natural gas (CNG) at fuel station is Rs. 66.75/kg (PakBiz, 2013). So the total revenue from the substitution of fossil fuel corresponds to Rs. 62,737,588,080/year.

Benefits from Digestate (**D**): The nutrient rich digestates are normally used as organic fertilizer. It is very good that in Lahore there is acceptance of bio-rest and the market mechanism of

digestate is already exist. While making a phone call to Lahore Compost Limited marketing manager, informed me that there is high demand of digestate in Pakistan and at the moment the organic compost is used in the agriculture lands, plant nurseries, parks and horticulture and in the chemical fertilizer. Currently, Lahore Compost Limited selling a 50kg compost bag at the price of Rs. 250. The present study estimates that 5,569,900 digestate bags (50kg in each) can be produce per year if all the biodegradable waste of Lahore utilized for biogas production. So in the present study the economic value of the produces digestate corresponds to Rs. 1,392,475,000/year ($5,569,900 \times 250$).

Benefits from Carbon Credit Scheme (CDM)(C): The avoided GHG emissions from open landfilling substitution of fossil fuel and chemical fertilizers can earn money by registering such project under Clean Development Mechanism (CDM). There is already one biogas project “Pakistan Domestic Biogas Program” which Sales Carbon Credits (@ 13.74 US\$/tones of CO₂eq) (CDM, 2008). At current exchange rate 1 US dollar is equal to Rs.108 (dollareast.com) and I ton CO₂ emission reduction correspond to Rs.1483.92. Hence, the nature of emission reduction in the present study is different from already registered biogas program with CDM but we assume same carbon credit price per ton CO₂ eq to make an estimate. In the present study it is estimated that the substitution of upgraded biogas will reduce 18,234,387.4 tons CO₂ equivalent/year. So the monetary value of these emissions corresponds to Rs.27, 058,372,150.6 at the rate of Rs.1483.92 per ton of CO₂ eq.

So here I put all these benefits in the design equation.

All of these prices are in Pakistani rupees and determine from the local market condition

$$E_p = \sum_{y=n}^3 (F + D + C)$$

Where E_p is a total economic potential of produce biogas, $y = n$ is number of year

$$E_p = \sum_{y=n}^3 (F + D + C)$$

$$E_p = \sum_{y=1}^3 (62,737,588,080 + 1,392,475,000 + 27,058,372,150.6)$$

$$E_p = \text{Rs. } 91,188 \text{ billion/year approximately}$$

This corresponds to US\$ 844.34 Billion /year

Remember that this is very rough estimate and does not include the cost of production. There are some other indirect benefits which can be achieved by the introduction of municipal solid waste base biogas plant in Lahore which are not consider in the analysis. These include economic opportunities for peoples, technology advancement and health benefits.

Chapter 7 Discussion:

7.1 Why there is need of MSW based biogas plant in Lahore?

7.1.1 Climate change mitigation through proper waste disposal

The environmental impact of biogas can be assessed through pre management of the feedstock and substituting biogas with source of energy. In another words the environmental impact of biogas system is mainly dependent on the reference system replaced (Börjesson and Berglund, 2007). For example if we substitute fossil fuel with upgraded biogas as vehicle fuel then there is great reduction of greenhouse gas emission in the biogas life cycle assessment because of the reference system (fossil fuels) has very strong negative environmental impacts. In developing countries, where biomass burning (firewood, dung cake, crop residues etc) is used as a source of cooking also present a similar example. For instance here in Norway the cooking stoves are powered by hydroelectricity which is already produced from renewable source (means hydroelectricity) comparing it with rural areas of the developing countries where the stoves are powered by firewood. So this means that if the produce biogas is replaced by biomass or Kerosene oil based stove in developing countries has more potential to reduce GHG compare to Norwegian situation. Hence, it is very difficult to make generalization about the extent of environmental impact of different biogas system from different parts of the world because of the variation in the reference system and waste management handling practices (Börjesson and Berglund, 2007).

Similarly, in the context of Lahore, the substantial amount of generated biodegradable waste and the existing unscientific waste disposal system in the open dumping without taking any precautionary controls cause major environmental problem in Lahore. There is no proper official dumpsite in Lahore (Batool and Ch, 2009). The natural degradation of this biodegradable waste in the open dumping sites releases enormous amount of GHGs. Apart from this improper waste handling the combustion of fossil fuel as a source of energy release toxic pollutants in the atmosphere which has great threat to global warming. The transport sector makes a major contribution to overall greenhouse gas emissions (GHG). In Pakistan, in the IEA 2011 report it is highlighted that from 1990 to 2009 there was an estimated increase of 48.7 % in CO₂ emissions. The economic development in Pakistan is highly energy driven which contribute to increase the carbon dioxide (CO₂) emissions and increases the international debt to import the petroleum.

Many studies show that the future will be negatively affected if we keep degrading our environment like this.

Hence, from the previous section it shows that the reference system of waste disposal and transport sector release great amount of GHG in Pakistan. The production of biogas provides a versatile carrier of renewable energy and substantial amount of GHGs emissions can be reduced from this poorly managed waste and biogas substitution with fossil fuel. The biogas production from MSW allows to reduce GHGs through (1) as methane can be used for replacement of fossil fuels in both heat and power generation and as a vehicle fuel (2) the digestate which is organic fertilizer and soil conditioner replace the chemical fertilizers (3) direct emission reduction from improper waste disposal system. In the present study it is estimated that biogas production from municipal solid waste of Lahore can reduce 18,234,387.4 tons CO₂ equivalent per year through three previous mentioned applications. Waste management and GHG emissions reduction will also help to eliminate other environmental hazards and associated problems from the waste.

Generally biogas has been used for a long time for heating, cooling and generation of electricity, and is considered to be the best fuel for such purposes (Nawab, 2013), but there is also a growing interest of biogas to use it as fuel in the vehicles, as it has been observed and documented in Europe (new biogas plant in Oslo and biogas vehicles in Sweden is a good example of this). In the present study it is estimated that biogas production from MSW of Lahore has the potential to produce 257,504.3m³/day upgraded biogas which can substitute same amount of natural gas, a fossil fuel. This substitution of fossil fuel can potentially reduce the amount of GHG release from the combustion of the fuel and many biogas projects are now initiated in the world. Baltic Biogas Bus project is an example to reduce greenhouse gas emission by switching fossil fuel buses into biogas fuel. This is a one step to achieve EU's climate goal. The project claims that biogas buses are the best options for public transport to lower greenhouse gas emissions and improving the inner city air quality (Hallgren, 2012)

7.1.2 Reducing Energy Shortage and its benefits

There are many factors which contribute to achieve development of a society but a secure and sustainable energy supply is a key denominator of sustainable development. Secure and sustainable energy refers to the effective, efficient, long term and readily availability, reasonable

cost and has less deleterious environmental effects. This makes a connection between renewable and sustainable development of country (Dincer, 2000, Kothari et al., 2010).

Unfortunately Pakistan is energy deficient country. The per capita energy consumption is one of the indexes to measure the prosperity of a country. In Pakistan average per capita electricity consumption is 425 KWh, while world average per capita electricity consumption is 2516 KWh in 2004-2005 (Asif, 2009). Pakistan has been faced 4500 MW electricity demand and supply shortfall in 2008 which constitute 40% of the total supply (Asif, 2009). The similar situation also prevails in Lahore as well. According to GoPED (2012) there is 1000 MW electricity shortfall in Lahore.

The electricity shortfall hindered many economic and social activities in country. The extent of this problem can be investigated from Kugelman (2013) phrase “According to some estimates, energy shortages have cost the country up to 4% of GDP over the past few years. They have also forced the closure of hundreds of factories (including more than five hundred alone in the industrial hub city of Faisalabad), paralyzing production and exacerbating unemployment. Additionally, they imperil much-needed investments in development and infrastructure.

The biogas production from MSW can contribute to energy mix supply as it has been practiced in Europe. In the present study it is estimated that if 100% of the generated waste is collected and anaerobically digested this can produce 352,745.96 m³ biogas/ day. The produce energy can be utilized in CHP and it is estimated that 884 MWh electricity with 35% conversion efficiency. The rest of the energy can be utilized for cooling or heating the buildings or in the industrial processes. Hence this shows that the production of biogas from municipal solid waste of Lahore can substantially reduce the energy crisis in Lahore and economic development can flourish due to this energy recovery.

There can different economic drivers which can promote MSW based biogas technology in Lahore and Pakistan at large. These can be government incentives and operational profit by selling the byproduct of the biogas.

Chapter 8: Conclusion:

In Lahore substantial amount of municipal solid waste is generated daily which is a big challenge for local authorities. Tons of daily generated waste is not managed appropriately which further associated with major environmental problems in the city. The aim of this study is to find out biogas potential from organic waste and to what extent produce biogas can overcome the current energy shortfall in Lahore. In addition to this, GHG emissions reduction from the municipal waste of Lahore is also a main concern of this study. Altogether of this the basic purpose is to achieve sustainable development in Lahore.

Sustainable development requires sustainable source of energy that has minimal negative environmental and societal impacts Kothari et al. (2010) and one of the option is anaerobic digestion of municipal waste. At the moment the anaerobic digestion of municipal solid waste has got great attention in order to reduce greenhouse gas emissions from the waste and provide sustainable source of energy (Weiland, 2010).

The literature review of the study gives a very holistic picture of biogas production and its associated benefits. Many studies have been reviewed from all parts of the world. Unfortunately, there is no research paper has been published in Pakistan which focus on biogas production from the MSW. All of the reviewed studies showed very positive picture of biogas technology and its bright future.

The results of present study are very significant and useful to meet the demand of electricity and GHG emissions reduction from municipal solid waste of Lahore. Biogas production from municipal solid waste can help to achieve sustainable development by reducing the gap between demand and supply of electricity, GHG gas emission reduction from the municipal waste by changing the current practice of open dumping of waste to anaerobic digestion and providing economic benefits through energy supply, carbon credit scheme and substitution of digestate with chemical fertilizers.

In the energy context the statistics from the Government of Punjab, Energy Department reveals that there is 1000MW shortfall between supply and demand of the electricity in Lahore. In the

present study it is estimated that approximately 884 MWh electricity can be produced with 35% energy conversion efficiency while rest of the 50% energy can be used for cooling the buildings. Cooling of building also mean the substitution of electricity because in Pakistan the electricity is used for cooling the buildings. The upgraded biogas energy can be used in vehicles which substitute the fossil fuels.

From the environmental point of view municipal solid waste which is highly potential source of GHG emission and this challenged can be managed through biogas production. At present all of the collected municipal solid waste in Lahore is dispose off in the open dumping sites except some of the value able material is recycled. Such disposal practices have negative environmental effects and in the current situation it is necessary to use alternative waste handling treatments. In this study it is estimated that municipal solid waste treatment through biogas technology can reduce approximately 18,234,387.4 tons CO₂ equivalent per year. These emissions can be avoided from leaching and direct environmental emission from the degradation of organic waste in the open dumping sites. If the produced biogas will substitute with fossil fuel almost similar amount of CO₂ can be avoided. In addition to this in the present study scenario biogas production from the existing inappropriate waste management will also reduce the odour, improve air and water quality and nutrients management flexibility. All of these will contribute to improve local environment, health impacts, reduce GHG emissions and promote the development of the metropolitan area of Lahore.

In the study it is estimated that if all the produce biodegradable waste is utilized for biogas production this can achieve economic benefit of US\$ 844.34 Billion /year.

Beside of so many economic, social, energy and environmental benefits biogas technology has potential barriers. The barriers which hindered the development of biogas technology development are internal and external. The prior refers to the technological problems associated with biogas technology like high energy requirement and complexity of biogas plant design. The external barriers refer to the interest of the government and community for such technologies and lack of information and policy failure. Another barrier is the political instability and lack of financial resources as well as low pace of foreign direct investment.

8.1 Future Research and &Development

Being a 6th largest population country, enormous amount of waste is generated which is inappropriately handle and dispose of in the open dumping sites in Pakistan at large. This increase the risk of environmental hazards, air pollution, water contamination, negative impact on public health and increase the greenhouse gas concentration. Unfortunately, very limited researches have been done yet for the better disposal of municipal solid waste of Lahore and Pakistan at large. Biogas production from municipal solid waste is not only sustainable solution of waste handling but energy can be produced from waste which can help to meet current energy crisis in the country. But none of the research has been done to find out biogas potential and energy recovery from the municipal solid waste neither in Lahore nor in Pakistan. So there is a need of some potential researches which can produce quality of data in this field. Federal and Provincial government of Pakistan doing many efforts to collaborate with international consultancy companies and advertising many tenders to launch some biogas and solar projects in Pakistan in order to combat the energy crisis. Beside of political and economic instability in the country, the international companies will not show any interest unless there are some very good biogas potential scientific studies.

The benefits of anaerobic digestion over other waste treatment technologies like incineration, combustion, plasma and composting makes it very popular in Europe and other region. Present study is a first step of biogas potential from MSW of Lahore. This opens various new dimensions where further researchers can be established in the field of biogas. For example the critical review of different studies shows that there are many possibilities to enhance biogas production manifold through co-digestion of different substrates and through some other consideration like design of the digester and impact of temperature etc. So studies can be done to optimize biogas production through co-digestion of different substrates with organic fraction of municipal waste in Lahore. Moreover, this study highlights the possible solution for the better treatment of municipal solid waste of Lahore. Due to the time limitation and thesis requirement this study and biogas technology as well focuses only on biodegradable fraction of the municipal waste of Lahore. Various other studies can be done to find out the sustainable disposal of non-biodegradable fraction of the municipal waste of Lahore and the energy potential from it. Furthermore, there can some studies to find out the feasibility of biogas plant in Lahore where for instances the cost of production and geographical location can be investigates.

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