Evaluating the Effectiveness Of Biogas Technology And Its Impact On The Environment, Human Health And Socioeconomic Conditions: A Case Study In Sialkot And Narowal District

By

Sadia Imran

Thesis submitted to the Lahore School of Economics

in partial fulfillment of the requirements for the degree of

M.Phil Environmental Sciences 2012

Words 21,308

Supervised by: Mr. Ali.S. Pracha

Abstract

The fast depleting supply of fossil fuels and growing global environmental degradation by potent greenhouse gases has pushed the World's economies towards the usage of alternate energy sources. Biogas energy accounts for a major chunk of the different alternate energies used globally. Pakistan being an agricultural economy and livestock being a major contributor has a great potential of biogas energy. This study evaluates the socioeconomic, environmental and health impacts of biogas technology in two villages, one in Narowal and one in Sahiwal district. All the biogas users from both the villages were given questionnaires during field survey and ten non-users were interviewed informally. It was found that all the plants in the villages were well functioning except for one digester. Each plant was $6m^3$ in size and required 45 kg – 50 kg of dung daily to produce enough gas to fulfill the cooking needs of the household. However, during the months of January and December due to low ambient temperature the gas produced is not sufficient and dung cakes and firewood are used to meet the daily cooking needs. The users' expenditure on chemical fertilizers decreased, 55% of respondents agreed that the bio-slurry completely fulfilled their fertilizer requirement. The consumption of dried dung cakes for cooking declined from 5,760 kg dung before biogas to 1,200 kg dung after the usage. The wood consumption in these villages after the biogas plant installation decreased from 28,080 kg to 2,520 kg annually. Wood was used during winters for heating purposes, also during the months of December and January fuel wood and dung cakes were used to fulfill cooking requirements as the gas produced was not sufficient to meet the requirements of the households. Biogas usage completely substituted the Liquefied petroleum gas (LPG) requirement of the respondents as the consumption and expenditure of LPG after biogas was nil. Women experienced time saving of two and half to three hours per day by using biogas stoves for cooking. It was estimated that nineteen functional plants altogether were saving nearly 125 ton of carbon dioxide per year. It can be concluded that many direct and indirect impacts of biogas on health and environment cannot be quantified. A greater public involvement is necessary for the large scale dissemination of the biogas technology throughout the country as an alternate energy source.

Document structure

Introduction and Objectives: This section explains the world's and Pakistan's energy consumption and the need for renewable energy technologies such as biogas. It highlights the main objective of the study and the research questions addressed in order to achieve the main objective

Literature Review: This section formally defines biogas and explains how the technology works. It goes on to explain benefits and outlines Pakistan's and other countries' experience with the technology**.**

Study Methodology and Case Study Information: This section provides information on data and its sources, and talks about the study area in Sialkot and Narowal**.**

Results and Discussion: This section presents results of the survey and discusses the key findings

Conclusion and Recommendations: This section summarizes the research findings and their implications and proposes recommendations for further development.

References: This section provides a complete list of data and information sources used in the document.

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List of Acronyms and Abbreviations

AEDB	Alternate Energy Development Board
AD	Anaerobic Digestion
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
Co_2	Carbon Dioxide
CH_4	Methane
CH_3COOH	Acetic Acid
EROI	Energy Return on Energy Invested
FY	Fiscal Year
GDP	Gross domestic product
GHG	Green House Gases
GoP	Government of Pakistan
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
GWEC	Global Wind Energy Council (Germany)
HDIP	Hydrocarbon Development Institute of Pakistan
H_2O	Water
IEA	International Energy Agency (France)

LPG	Liquefied Petroleum Gas
NEA	Net Energy Analysis
NEG	Net Energy Gain
NRSP	National Rural Support Programme (Pakistan)
OECD	Organization for Economic Co-operation and Development
PKR	Pakistani Rupee
PV	PhotoVoltaic
PVC	Poly Vinyl Chloride
PRSP	Punjab Rural Support Programme (Pakistan)
RE	Renewable Energy
RET	Renewable Energy Technologies
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organization)
UC	Union council
UK	United Kingdom
USA	United States of America
USD	United States Dollar

List of Units of Measurement

BTU	British thermal unit
GW	Gigawatts
J	Joule
L.F	Lineal Foot
m^3	Cubic meter
MJ	MegaJoules
MW	MegaWatts
NRs	Nepalese Rupees
Kg Co_2 e/HH/year	Kilogram of carbon dioxide equivalence per household per year
Kg	Kilogram
Km	Kilometer
TOE	Tonnes of oil equivalence
kWh	Kilowatt hour
KCAL/m^3	Kilocalorie per meter cube
KCAL/Kg	Kilocalorie per kilogram
kWh/Kg	Kilowatt hour per kilogram
Kg/kWh	Kilogram per Kilowatt hour
kWh/m^3	Kilowatt hour per cubic meter

1. INTRODUCTION

1.1 Energy Consumption and Development

Energy is an absolute necessity of everyday life. It is used in the form of light, heat and electricity (Faroque and Hameed, 2012). Human 'development' and energy requirements go hand-in-hand. Increased energy consumption tends to result in economic development and higher living standards (Hall et al., 1986; Aqeel and Butt 2001; Murphy and Hall, 2011). The consumption and use of energy in the world is highly concentrated in the industrialized regions like North America, Japan,Europe and Australia. The tropical world uses less energy in the form of fossil fuel and electricity (Agarwal, 2012). The socio-economic prosperity in a society is measured by its per capita energy consumption. There is a strong relationship between the Human Development Index (HDI) of a country and its energy prosperity (Asif, 2011). Figure.1 shows a direct correlation between access to electricity and economic well-being in some countries (Asif , 2011).

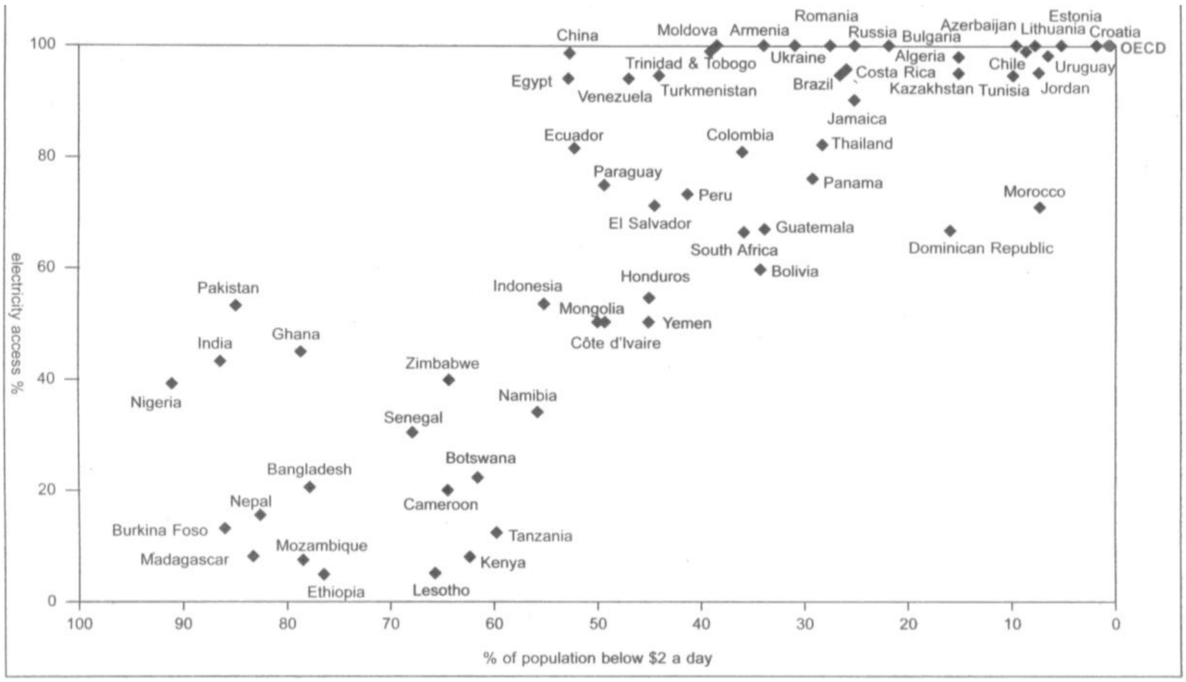

Figure1: Relationship between Economic Prosperity and Electricity Access (Asif, 2011)

According to the International Energy Outlook (IEO), 2005 worldwide energy demand is projected to grow exponentially by 2025, with emerging economies accounting for nearly two third of the increased energy use (Asif, 2011).

1.2. Non- Renewable Energy

Energy conversion and efficiency are the two principles that brought change in the energy trend, introduced by the industrial revolution in the 18^{th} century. Energy resources maybe categorized as renewable and non- renewable resources. Non-renewable resources are natural resources that are limited in supply and cannot be replenished more quickly than they are consumed. Fossil fuels are a common example of non-renewable resources. These are formed by decomposition of dead organic matter, and include coal, petroleum, natural gas, oil shale and tar sands (Kelly, 2010)

1.3 Renewable Energy Sources

Renewable resources include energy from the sun, biological and biogeochemical cycles such as solar power, wind power, biogas/biomass and hydropower (Omer, 2012; Waiser, 2008).Supporters of renewable energy sources believe that as these are obtained from natural processes, thus are more reliable in terms of supply and cost effective in some cases to and may offer attractive benefits to meet energy crisis. Renewable energy is clean and carbon dioxide free. Globally, 16% of total energy consumption comes from renewable sources, with 10% coming from biomass, and 3.4% from hydroelectricity. The renewable power capacity globally has now reached 200 GW and by 2030, the overall demand is predicted to almost double the current levels (Faroque and Hameed, 2012).

1.4 Environmental Threats linked with Fossil Fuel Consumption

Burning fossil fuels releases greenhouse gases(GHG) such as carbon dioxide (CO_2), methane, water vapour, and sulphur dioxide into the atmosphere, resulting in serious environmental threats such as air pollution, deforestation, global warming, climate change, water and groundwater contamination, soil erosion and increased risk of diseases (Pieprzyk et al., 2009). Natural gas being the cleanest is preferred over the others because of its higher calorific value and lower carbon dioxide emission as shown in the Table. 1 (Asif, 2011).

Table 1.Comparison of different types of fossil fuels in terms of energy content and carbon dioxide emission (Asif, 2011)

Fuel	Specific energy content (kWh/Kg)	Specific CO_2 emissions (Kg/kWh)
Coal	6.7	0.37
Crude oil	12.7	0.26
Natural gas(at N.T.P - 0^0C and 1bar)	15.3	0.19

Despite serious environmental threats, increasing prices and resource depletion, fossil fuels still account for 83-85% of the world's energy mix against the 15- 17% for renewable sources (International Energy Agency [IEA] and Organization for Economic Co-operation and Development [OECD], 2011). Figure 2 shows the continued global reliance on fossil fuels, and how little renewable sources (not counting hydropower) contribute to world energy usage.

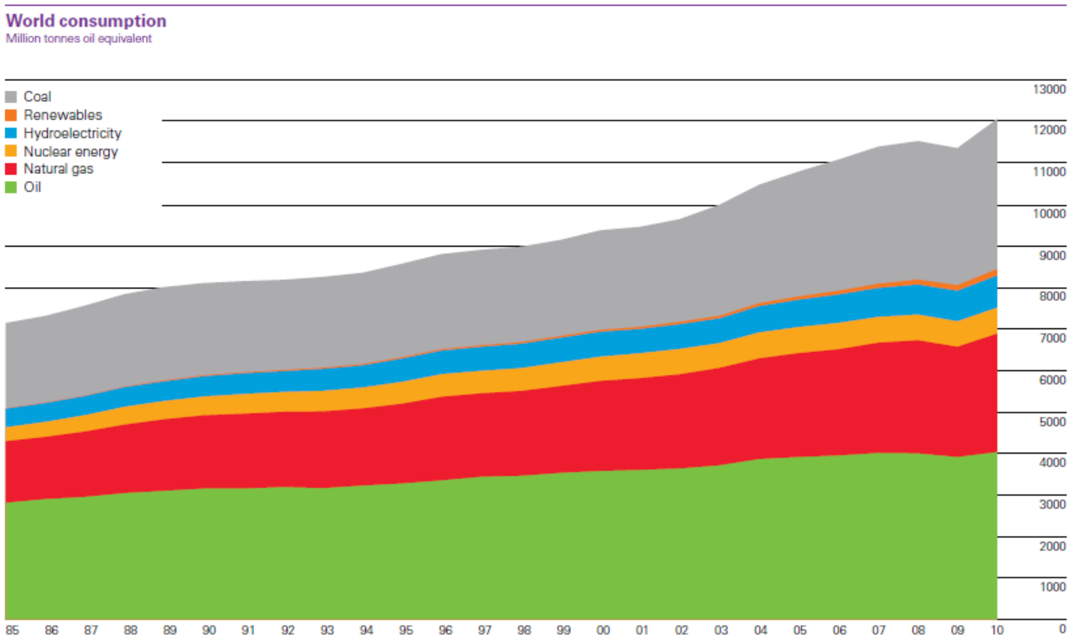

Figure: 2 World Energy Consumption by fuel, 1985-2010 (BP, 2011)

1.5 Renewable Energy Technologies Global Scenario

The growing energy crisis due to increased consumption, continuous depletion and rising prices of fossil fuels has led many countries to explore alternative energy sources that are sustainable, safe for the environment, and economically feasible (Iwaro and Mwasha, 2010). International treaties and protocols such as the Copenhagen Summit and Kyoto Protocol have attempted to raise awareness of resource depletion and climate change. Promoting alternative energies is said to be an important step towards reducing carbon footprints (Linares et al., 2008).

Many new renewable energy technologies are being explored, with rapid technological advances in biomass in future, especially in relation to improved agricultural and municipal solid waste and production of different kinds of biodiesel. Sugar cane ethanol production in Brazil, geothermal energy in the Philippines, agricultural waste-to energy in India, thermal solar energy in China, and improved wood-fuel cook stoves in some African countries are some successful examples (Goldemberg and Lucon, 2010).

Germany has led the innovation in renewable energy technologies for years. Bioenergy plays a key role in the country's future energy mix. Biomass is currently growing at the fastest pace of all the renewables, and has overtaken hydropower as a source of electricity. In 2008, biomass supplied 3.7% of the electricity consumed in Germany, up from 3.1% in 2007, while wind power's share increased by 0.1% up from 6.4% in 2007 to 6.5 % in 2008 (Burgermeister,2009).

China leads the world in wind power with an approximate installed capacity of nearly 63 gigawatts (GW) in 2011 (Global Wind Energy Council [GWEC], 2012). China has also become the world's largest producer of hydropower with an installed capacity of 230 (GW) (Interfax China, 2012).

In Sri Lanka with the collaboration of World Bank and Global Environmental Facility lot of efforts have been made to provide electricity and socioeconomic improvements in the rural areas through solar photovoltaic PV, hydro, wind and biomass renewable energy technologies (www.energyservices.lk).

Hydropower is a major contributor to World energy supplies. With a gross installed capacity of 740 GW, it fulfils almost 17% of the World's total electricity demand. In Norway 99% of the electricity is produced from hydropower, Brazil produces 99% and Canada 92% of its electricity from hydropower. A number of developing countries like Egypt, Morocco, India and Mexico are focusing on solar thermal power. There are seven projects of over 17,000 MW of collective capacity in the pipeline (Asif 2011).

1.6 Developing Countries and Energy Crisis.

Lack of efficient and affordable energy technologies are a major constraints in development of emerging and developing economies. These countries face two-fold energy challenge:

Meeting the needs of billions of people who still lack access to basic, modern energy services while simultaneously participating in a global transition to clean, low-carbon energy systems. Over 1.6 billion people in the world have no electricity which translates into limited access to radio and modern communication, and inadequate health and education facilities. Nearly three billion people in the world depend on dirty fuels to meet their most basic energy needs: 2.5 billion people cook with biomass (wood, dung, and agricultural residues), and over half a billion people cook with coal (Ahuja and Tatsutani, 2009).

1.7 Energy situation in Pakistan

Pakistan is no exception to the other developing nations, thus is an energy-deficient country. With much of the consumption coming from oil and gas, the indigenous reserves of oil and gas are limited and the country depends on the fragile supply of imported oil that is subjected to disruptions and price volatility (Harijan et al., 2009). Nearly 31% of the country's energy requirement is met through imports (Asif, 2011). The oil import bill of Pakistan increased from about $7 billion in 2007 to over $ 12 billion in 2011. The aggregate energy supplies in the country amounted to 64.5 million tonnes of oil (TOE) equivalent and registered a growth of 2.3 % over the previous year (HDIP, 2010-2011).

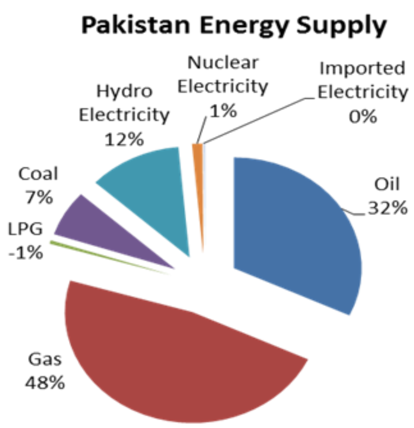

Figure:3 Pakistan energy supply by source (HDIP, 2010-2011)

More than 99% of the energy is supplied through conventional energy sources and renewable sources supply only one percent (Sheikh, 2010). Figure 3 clearly shows that the major chunk of energy is coming from fossil fuels mainly gas 47.6% and oil 32.0% .The aggregate energy consumption during the year 2010-2011 was 38.8 million TOE, of which 38.5% was consumed by the industrial sector, followed by transport which consumed 30.9% as given in figure 4, agriculture only accounted for 2% of the total consumption (HDIP, 2011).

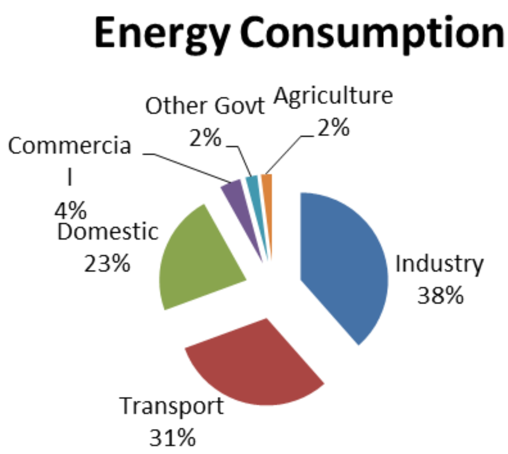

Figure 4: Pakistan energy consumption by sector (HDIP, 2010-2011)

Increased demand for electricity and fluctuating oil prices have resulted in an increased reliance on natural gas, especially for transport fuel and power generation. Despite efforts by the Government and various donor agencies, the gap between energy demand and supply continues to increase (Shah et al., 2010). Statistics suggest that over the last thirty six years gap between energy demand and supply in Pakistan has increased six times, from 3 million (TOE) in 1971-72 to around 18 million (TOE) in 2008-2009. Figure 5 shows the increasing gap between electricity demand and supply in Pakistan from 1981-2009, figure 6 shows the difference between the oil consumption and production in Pakistan, the indigenous oil production is low and cannot meet up the with the country's consumption requirement ,to meet this demand of oil is imported from abroad (Asif, 2011).

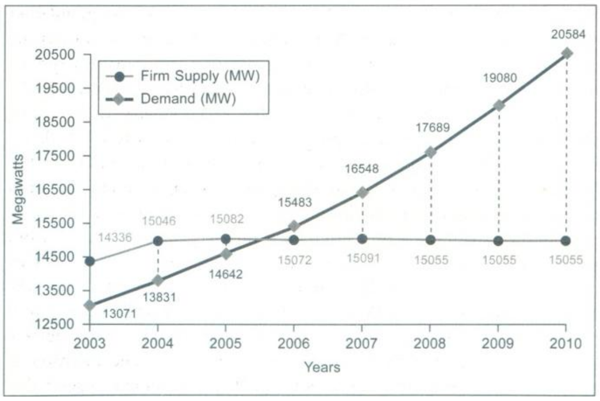

Figure 5: Growing gap between electricity demand and supply in Pakistan (Asif, 2011)

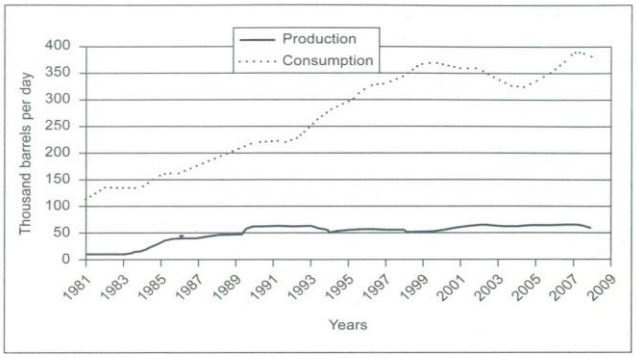

Figure 6: Gap between demand and supply of Oil (Asif, 2011)

According to World Energy Outlook 2011, 64 million people in Pakistan do not have access to electricity and 112 million still use biomass for cooking (Hussain, 2012). Fuel poverty, a situation where the household spends more than 10% of its income on fuel to heat or cool the home environment in order to bring to a moderate temperature, is a major issue of rich and energy affluent societies besides the developing economies. The per capita energy consumption which is an indicator to the socioeconomic prosperity of a country is 4,391 kilowatt hour KWh for Pakistan against 44,245 KWh for the United Kingdom UK and

108,424 KWh for United States of America USA. Figure 7 gives a comparison of Pakistan's energy consumption with a few countries (Asif, 2011).

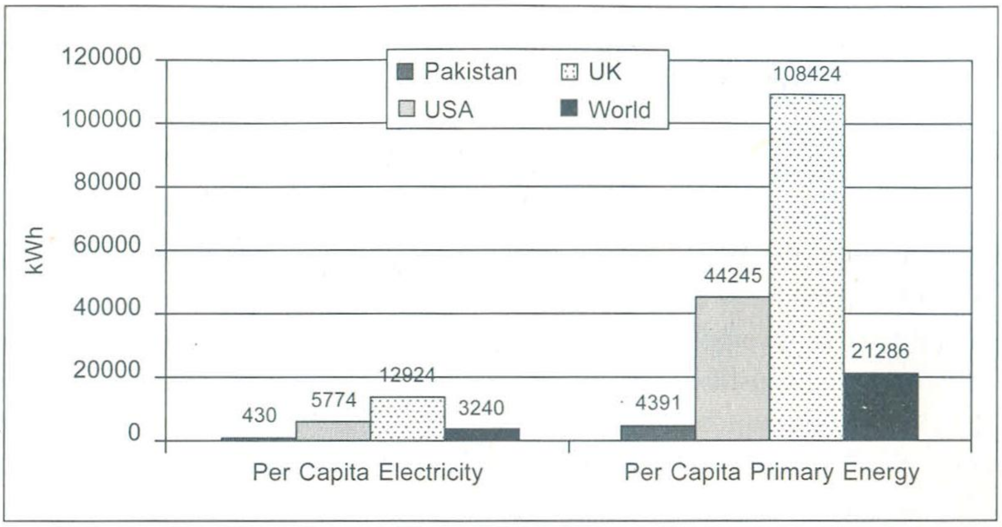

Figure 7: Comparison of per capita electricity and primary energy consumption (Asif, 2011)

1.8 Renewable Energy Potential and Technologies in Pakistan

Pakistan possess a great potential of renewable resources because of its geological setup, geographical position, climatological cycles and agricultural activities, which if utilized effectively can play a great role in achieving energy security and sustainability in the country (Ibrahim, 2009). The Alternative Energy Development Board (AEDB), established in 2003 is working for the development, promotion and facilitation of renewable energy technologies and aims that by 2030, 5% of the energy consumption of the country will be met through renewable energy. Currently only 40MW of energy is produced through renewable energy (RE) technologies, which forms only 0.21% of the total installed generation capacity. RE has a significant potential to bridge the gap between energy demand and supply in the country (Javaid et al, 2011; Sheikh, 2010 and Amjid et al, 2011).

1.8.1 Potential of Water Energy (Hydropower)

Pakistan's total identified potential for hydropower is 42 GW out of which 6.2 GW, nearly 15%, has been exploited so far. The northern areas of the country are rich with hydropower resources. The development of hydropower as an alternate energy resource requires secure supply of water from the Eastern Rivers (Ibrahim, 2009; Asif, 2011 and Sheikh, 2010).

1.8.2 Solar Energy

The use of solar energy for heating promises a more rapid pay off than other energy alternatives because the basic technology already exists and needs only minor refinements. The South Western province of Baluchistan and North Eastern part of Sindh offer excellent conditions for harnessing solar energy where sun shines between seven to eight hours daily or approximately more than 2300–2700 hours per annum. Despite the favourable conditions, use of solar energy for generating electricity or heating is still in its inception. Mostly photovoltaic systems of generation capacity 100–500 Watt/unit have been used for producing electricity in a few areas. AEDB has electrified nearly 3000 households with total PV power generation of 200 kW in districts of Kohat, D.G. Khan, Punjab, Sindh and Baluchistan (Skeikh, 2010).

1.8.3 Biomass (Biogas/Biofuel) Energy

Biomass energy plays an important role in the energy mix of Pakistan contributing nearly 35% of the total RE production. Biogas, one of the most significant types of biomass energy, makes optimal utilization of dung. It provides (soot-free) clean gas for meeting cooking and energy needs as well as enriched bio-fertilizer for improvement of fertility of agricultural lands. Promotion of biogas technology seems to be one of the best options, which can not only partially offset wood consumption but can also facilitate recycling of agro-animal residues as a bio-fertilizer. Moreover, being clean and renewable, it will also contribute towards environment protection. It has been calculated by the experts at the Agricultural University that anaerobic fermentation of dung produced by livestock, through installation of about 5.0 million family size biogas plants, could meet the cooking needs of 50 million people. By doing this we can meet about 50% of the cooking requirement of the rural masses, along with the production of 96.6 million Kg of bio-fertilizer per day or 35.04 million tons of bio-fertilizer per year (Sheikh, 2010 and Asif, 2011).

1.8.4 Wind Energy

Pakistan has a considerable potential of wind energy in the coastal belt of Sindh, Balochistan and in the desert areas of Punjab and Sindh. The coastal belt of Pakistan, also referred as the wind corridor, has the potential of 50,000 MW of electricity generation. According to an estimate, 500 villages in Sindh, Baluchistan and the Northern Areas can be electrified through wind energy. Large wind turbines for power generation have not been installed in Pakistan (Sheikh, 2010).

1.8.5 Geo Thermal Energy

In different parts of the country there are number of hot springs with favourable temperature ranging from 30 to 170 ^{0}C but there has been no attempt to make use of geothermal energy. Areas within the vicinity of Karachi city and the Pakistani part of the Himalayas are potential sources of geothermal energy (Sheikh, 2010).

1.9 Objective of the Study

The main focus of the study is to evaluate biogas technology and its impacts on the local community in two villages of Sialkot and Narowal districts, by analyzing the energy expenditure of biogas users before and after the installation of the biogas plant. The health and environmental impacts of biogas technology, difference in energy expenditure between biogas users and non-users, and main barriers to the large scale adoption of biogas technology in the villages will be examined qualitatively.

The specific indicators that were undertaken to achieve the objective were the socio-economic aspect of the community, health and environment of the area.

A. To evaluate the socio-economic impacts of biogas technology the questions investigated included

1. How has the expenditure on energy changed with the usage of biogas? Has it improved with the functioning of the plant?

2. Has biogas technology released the burden of firewood collection and usage? Do women save time in cooking and cleaning?

3. Has the usage of bio slurry resulted in increased crop production and reduced expenditure on synthetic fertilizers?

B. To evaluate the health and environmental impacts the question investigated was

1. Reduction in smoke in kitchen and thus exposure to indoor air pollution.
2. Decrease in incidences of people suffering from respiratory and eye infections and fire/burning accidents among women, children and men, after biogas plant installation.

C. To evaluate the functioning of the plants and large scale adoption of the technology the following investigations were done.

1. The functional status of the biogas digester and the main problems associated with their operation.

2. The barriers to the large scale adoption and mainstreaming of the technology, policy measures that can help overcome these barriers

1.9.1 Site Description: Sialkot and Narowal district

To investigate the research questions a case study approach has been adopted. The study focuses on two villages; Habibabad village in Sialkot district and Kotli Lashwan in Narowal district. These two districts are among the areas in Punjab where biogas pilot projects were done by the government. These villages have no supply of natural gas and depend mainly on firewood and dried cow dung cakes for their cooking and heating purposes (PRSP, 2012)

1.9.2. Geographic Location and Climate

Habibabad village is situated in the Plains of Punjab between 32^0 3o$^{'}$ 0$^{''}$ North, 74^0 31 0$^{''}$ East. Tehsil Pasrur, Union Council Charwah .The terrain is flat with clay loam soils. Climatic conditions are semi-arid. The climatic conditions of Kotli Sindwan, Union Council Chardark are similar to Habibabad village. There are all brick houses and the roads are paved, irrigation is mainly carried out by tube wells. Both the villages are electrified; however there is no natural gas available. Firewood / fuel wood, dung cakes and Liquefied Petroleum gas (LPG) for cooking and heating purposes. The drinking water is pumped from underground water aquifer and is sweet (PRSP, 2012).

1.9.3 Economy

Agriculture is the main economic activity in both the villages; nearly 80% of the population is involved in agriculture. Due to increasing inflation many male members of the family have started working on daily wages and a small population is now employed in the public and private sector. The average monthly income of a household varies from PKR.7, 000 –

PKR.10, 000. In some well to do families it might go up to PKR.15, 000, but this forms only two percent of the total population (PRSP, 2012).

1.9.4 Population and Education

Kotli Sindwan has a total of 90 households with a population of 700 people. There are 60% females and 40% male population in the both the villages with males mainly heading the family (PRSP, 2012). Both the villages have primary school for boys and girls; however for secondary and higher schooling people have to send their children to the schools 2 Km away from the village. Nearly 70% of the children are attending school in Habibabad village, whereas in Kotli Sindwan almost all the children are attending school (PRSP, 2012).

1.9.5 Agriculture and Livestock

The total arable land of the village is 104 hectares. Habibababd village has a total of 200 households with a population of 1200 people; the total arable land available is 223 hectares. Wheat, rice, fodder and seasonal vegetables are mainly grown in these regions. Most of the agricultural produce is for personal consumption; the excess is either sold in the market or stored for future use. Habibabad village has a total of 480 animals (cow, buffalo and goat). Kotli Sindwan has 374 animals (98 cows, 176 buffaloes and 98 goats) on average every household has three animals (PRSP, 2012).

2. Literature Review

2.1 Biomass/ Biogas as an Alternate Energy Source

Biomass is the material from living, or recently living organisms and covers all kinds of organic matter from fuel wood to marine vegetation (Chowdhry et al, 2012). It also includes trash, animal waste/dung, cornstalk, corncobs which can be used to produce electricity and biofuels (Paras and Abbey, 2011). Biomass is considered as a resource that can yield valuable energy and fertilizer. Bio-residue is used in many countries; if this biodegradable waste is treated in an anaerobic digester it can produce environmentally sound energy and fertilizer, globally it is the fourth largest sources of energy in the world, providing about 14% of primary energy (Karli, 2006; Myles 2004).

2.2 Biogas and its Formation

When the organic matter undergoes decomposition in the absence of free oxygen, it normally generates a gas which consists of 40-70% methane, the remaining comprises of carbon dioxide mainly with traces of other gases. It is the methane composition of biogas that determines its burning efficiency. It comprises 40–70% methane, 30–60% carbon dioxide, 1% hydrogen, 0.5% nitrogen, 0.1% carbon monoxide, 0.1% oxygen, and 0.1% hydrogen sulphide. It burns cleanly; giving no soot or foul smell, similar to natural gas or the liquefied petroleum gas (LPG). Biogas has a fairly good calorific value, 5,000 Kcal/m^3 which is lower than the calorific value of natural gas 8,600Kcal/m^3 and LPG 10,800 Kcal/Kg. The anaerobic digestion is based on the fermentation of the organic waste in the absence of oxygen. Fermentation of the complex biodegradable organic waste takes place in four stages; described below and indicated in figure 8.

1. Large molecules of proteins, fats and carbohydrates are reduced to amino acids, fatty acids and sugars through hydrolysis.

2. The fermentation by acidogenesis bacteria converts these amino acids, fatty acids and sugars to volatile acids, such as lactic acids, butyric acid and valeric acid.
3. The acetogenesis bacteria consume these fatty acids and produce acetic acid, carbon dioxide and hydrogen.
4. The methogenic bacteria consume the acetic acid, hydrogen and some carbon dioxide to produce methane. The three different biochemical pathways adopted to produce methane include Acetotrophic pathways 4CH3COOH → $4CO_2$ $+4CH_4$, Hydrogenotrophic pathway
   $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ and the methyltrophic pathway 4CH3OH $+6H_2 \rightarrow 3CH_4 + 2H_2O$.
   The biogas yield and methane content varies from different substrates, biological consortia and digester condition.
   (Abbassi et al, 2012; Brown, 2006; Energypedia, 2011).

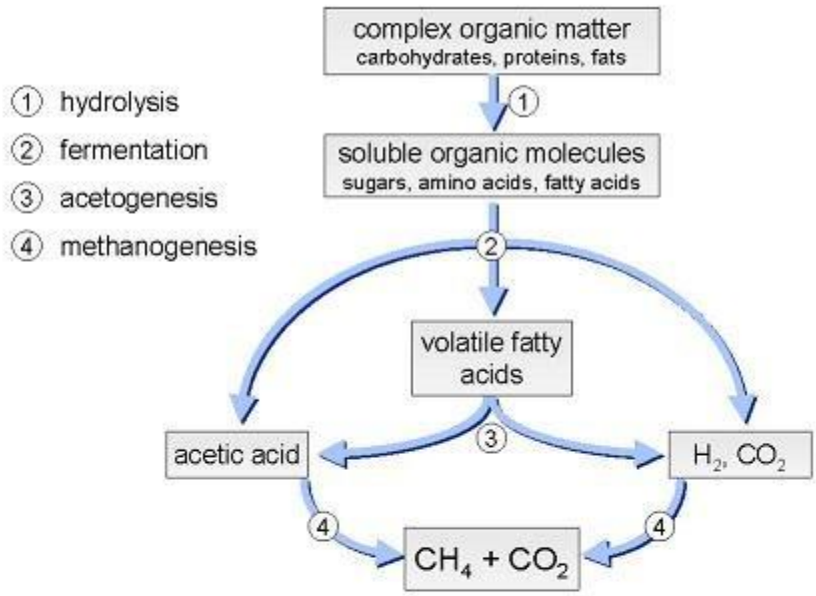

Figure: 8 four stages involved in anaerobic digestion of organic substrate (Abbassi et al, 2012)

Temperature, pH, loading rate, retention time, toxicity and mixing are some factors on which bacterial activity depends during decomposition of the organic matter. The temperature during the digestion process should be between 20^0 C and 60^0 C for the bacteria to decompose the organic waste. The pH during fermentation decreases because of the different acids produced; however it is controlled by the alkaline compounds produced simultaneously. Under controlled environment the acidity of the mixture could be reduced by adding an alkali. The amount of waste being added and the time it remains in the digester are also important, when considering the rate of the microbial activity. Frequent mixing of the substrate can disturb the microorganisms functioning. Toxic waste, if any, entering with the organic refuse can pose a threat to the bacteria as well (Abbassi et al,2012).

2.3. Benefits of Biogas

Developing countries get as much as 35% of their energy from biomass and in some countries it accounts for nearly 90% of the total energy used in the form of traditional fuels, e.g. fuel wood and dung (Chaiprasert, 2011). The use of biogas from agricultural waste is increasing because of its environmental benefits and as an additional source of income for the farmers. The closed system cycle of nitrogen due to bio-slurry usage helps maintain soil fertility as nitrogen is held within the system. Biogas is produced as a result of metabolism of methane bacteria, when the bacterium decomposes some organic material this decomposition requires water (Vindis et al, 2008).

Biogas usage gained momentum due to the solid and liquid waste treatment. In developing countries this technology appears attractive as it addresses the problem of scarcity of firewood, and indoor air health related problems due to burning of biomass. It can save a lot of time and labor for women in cleaning, washing and cooking activities (Khoiyanban, 2010). Biogas technology has become common in countries like Bangladesh, China, India and

Nepal. The use of biogas has helped relieve women from the drudgery of cooking with firewood, which produces hazardous smoke (Paras and Abbey, 2011). Kossmann et al. (2010) have discussed the contribution of biogas technology towards the conservation of resources and development of rural communities. Langeni et al. (2009) suggest that each household utilizing biogas can save up to USD 724 a year by replacing wood with biogas, apart from other positive impacts on the environment.

Abdulkareem (2005) found that refined biogas from animal dung could be used as an alternative to petroleum-based products and that dry slurry can be used for plant nutrition. Seadi et al. (2010) outlined the economic and social benefits of biogas production. Economic benefits included solid waste treatment without long-term follow-up costs incurred due to soil and water pollution. Other benefits included reduced expenditure on pesticides; generation of income through compost and energy sales (biogas/electricity/heat) to the public grid, and improved soil agriculture productivity. The social and health effects associated with biogas included oil-improving fertilizer, decreased odor, and reduced numbers of scavengers.

(Cuellar and Webber, 2008) analyzed the potential for converting livestock manure into biogas, which could meet renewable energy portfolio of different states in U.S.A and reduce the greenhouse gas (GHG) emissions. Biogas potential was calculated using the amount of biogas produced per animal unit (1000 pounds of animals) per day and the number of animal units in the U.S. They concluded that 95 million animal unit can produce renewable energy approximately equal to 1% of the country’s total energy consumption. They further calculated that using this biogas can produce 88 $\pm$ 20 billion kWh of electricity annually replacing coal and manure and also a reduction in GHG emission by 99 $\pm$ 59 million metric tons annually , the following table 2 briefly elaborates the benefits of anaerobic digestion in developing countries (Rowse,2011).

Benefits of anaerobic digestion for developing country applications	**Explanation**	**Reference**
Improved indoor air quality	Combustion of solid biomass cooking fuels results in high levels of particulate matter in the indoor microenvironment. Particulate matter causes respiratory infections in children, adverse pregnancy outcomes, chronic lung diseases and heart diseases, and cancer	(WHO, 1979; Mihelcic et al., 2009; Smith, 1993)
Energy production in the form of biogas, which can be used as a cooking fuel	Anaerobic digestion is a net-energy producing process. Biogas, similar to natural gas, produces very little air pollution when combusted	(Mihelcic et al., 2009; Smith-Sivertsen et al., 2004)
Provides an alternative to unsustainable deforestation	One cause of deforestation is the use of wood fuel for cooking and lighting. Introduction of household anaerobic digesters and the use of biogas for cooking reduce wood fuel use and therefore reduce deforestation.	(Douglas and Simula, 2010; Katuwal and Bohara, 2009; Niles et al., 2002)
Provides treatment of human and/or animal waste	Prevents nutrient runoff into water basins which drain to ocean environments, creating environmental problems. Prevents possible diarrheal disease downstream.	(Antweiler et al., 1995; Tchobanoglous et al., 2003)

Empowers women	Women and girls typically spend more time indoors cooking, and therefore, have a disproportionate exposure to indoor air pollution from combustion of solid biomass fuels. They are more likely to develop chronic health problems related to exposure to particulate matter.	(Mihelcic et al., 2009; WHO, 2011)
The amount of bio solids to be disposed is smaller than the amount resulting from aerobic treatment processes	Most of the energy input into the anaerobic digester in the form of raw wastewater is converted to CH4 and CO2. Relatively little energy goes to cell growth.	(McCarty, 1964; Tchobanoglous et al., 2003
Nutrient- rich effluent may be used as a fertilizer for crops	Commercial fertilizers are expensive and the processes for making them are unsustainable. Nitrogen and phosphorus are nutrients excreted from the human body in the form of feces and urine. Effluent from anaerobic digestion contains nitrogen and phosphorus which may be used as a fertilizer for agricultural crops.	Jonsson et al., 2004; Mara and Cairncross, 1989; Smil, 1999;
Mitigation of methane and carbon black emissions into the atmosphere	Methane has a Global Warming Potential twenty-one times greater than carbon dioxide. Black carbon particles absorb radiation and cause warming of glaciers by	(WHO, 2011; Cakir and Stenstrom, 2005; Kandlikar, et al., n.d.; Edwards, et al., 2004)

	reducing light reflection.	

Table 2 Advantages of anaerobic digestion in developing countries (Rowse , 2011)

2.4 Disadvantages of Biogas (Anaerobic digestion)

Small scale anaerobic digesters require addition of water, so in areas where water is scarce the optimal functioning of the plant is not possible. Gas production is greatly dependent upon the temperature; if the temperature drops below 15^0 C anaerobic digestions cannot take place. The use of alkali to maintain optimal pH may be another limitation of the process. High infrastructural costs are associated with biogas digesters. Biogas is inflammable because of high methane content so there is a danger of explosion due to gas leakages (Rowse, 2011).

2.5 Anaerobic Digesters in Developing Countries

There are mainly two types of digesters commonly used in the developing countries, floating drum digesters and fixed dome digesters. The basic operating mechanism of the two is the same, fixed amount of manure and water is fed in the digester through the inlet once a day the slurry is displaced through the outlet. Thus, the inlet, the digestion chamber and the outlet are three main components common to all the digesters (Rowse, 2011).

2.5.1 Fixed Dome Digester

The fixed dome digester is also commonly referred to as the Chinese or hydraulic digester. The feedstock enters through the inlet and after digestion process the gas accumulates in the upper part of the chamber and the slurry settles at the bottom due to gravity. As more gas is produced it builds up pressure which pushes the slurry into the collection chamber through the outlet as indicated in figure 9.These digesters are built underground thus are protected and insulated. This underground construction saves space and makes it available for household usage. The size of the plant depends on the location, the number of households using the gas and the amount of substrate available. Commonly $6m^3$ volume plants are sufficient to meet the cooking requirements of a household with seven to eight members, $15m^3$ and $20m^3$ plants cater for the requirements of a larger population and thus are referred as the community biogas plants. Fixed dome digesters have a life span of minimum 20 years and are preferred as they have no moving parts and are low in cost. However, construction of the plant requires technical skills and the fluctuation in the gas pressure can cause difficulties to the users (Energypedia, 2011; Rowse, 2011).

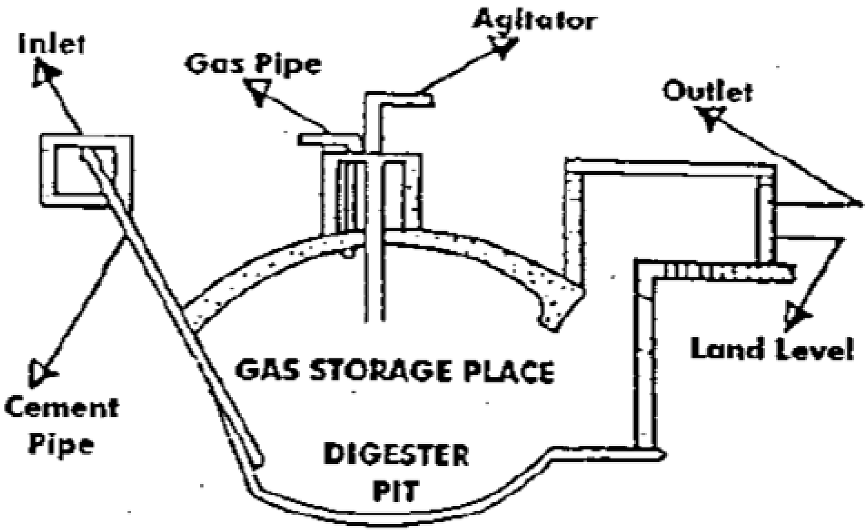

Figure: 9 Fixed Dome Digester (Singh and Maharjan, 2003)

2.5.2 Floating Drum Digesters

In the floating drum digester the feed stock enters through the inlet as in case of fixed dome; however the digestion chamber consists of a moveable inverted steel drum on the top. This steel drum moves up and down depending upon the amount of gas produced and accumulated, as shown in the figure 10. These digesters produce gas at a constant pressure; however the volume does vary, as the drum moves up when the gas is accumulated, the amount of gas can be easily detected .The main disadvantages associated with floating drum is the high cost of construction and maintenance. Rusting of the moving parts is also a common problem associated with fixed dome digesters. The drum has to be coated frequently in order to keep it rust proof (Energypedia, 2011; Rowse, 2011).

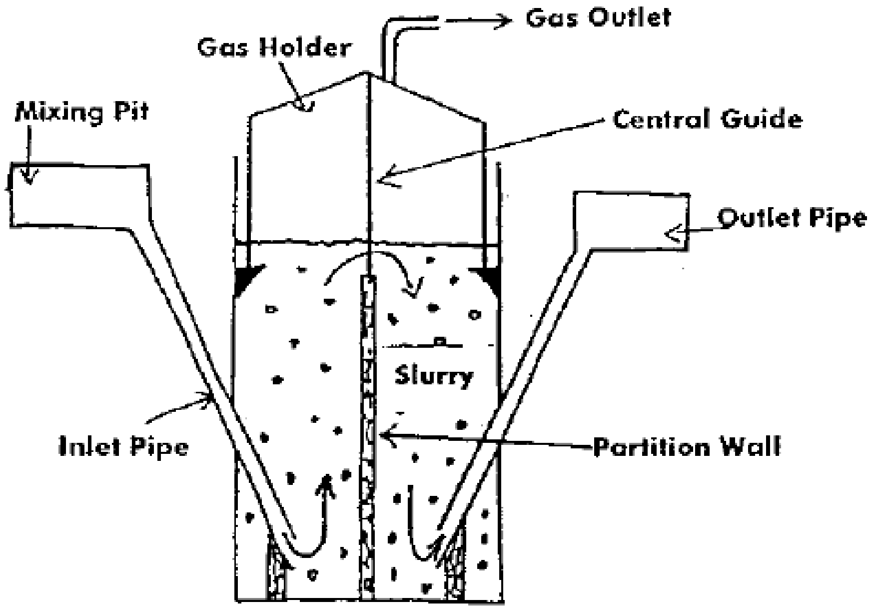

Figure: 10 Floating Drum digester (Singh and Maharjan , 2003)

2.6 The Potential of Biogas in Pakistan

Livestock is a great contributor to agricultural waste in Pakistan. Pakistan's livestock[1] population totaled approximately 163.2 million animals in the fiscal year (FY) 2011 (GoP, 2011). Of this figure, cattle and buffalos accounted for 21.8% and 19.4%, respectively (calculated from GoP, 2011). Dung production stood at 1.03 million tons in FY 2011 (GoP, 2011).There are nearly 10 million households in the country possessing livestock. It has been estimated that population of 63 million buffaloes and cows all over Pakistan can yield 990 million kg of dung per day and has the potential of producing 150 million m^3 of biogas per day and annually can generate 54,000 million m^3 of biogas (Khurshid , 2009). The potential use of dung (and its subsequent conversion to biogas) includes household cooking, lighting, and electricity generation to decrease the country's dependence on fossil fuel imports.

[1] Cattle, buffalo, sheep, goats, camels, horses, asses and mules.

2.7. The History of Biogas in Pakistan

The concept of biogas is not new to Pakistan; it dates back to 1959 when the first farmyard manure plant was established in Sindh to utilize animal and farm waste to produce biogas, which the local communities consumed for cooking. In 1974, the GoP started its biogas programme and 4,137 biogas units (each with a capacity of 3,000 – 5,000 cubic feet of biogas generation) were commissioned for construction. This programme was launched in three phases. During the first phase 100 digesters were installed, funded completely by the Government. The second phase saw costs being shared by the beneficiaries and the Government. In the last phase, the Government withdrew funding; only providing technical assistance. Progress, however, remained slow in this phase. The programme was revived in the 1990s, and the Government installed 1,700 new biogas plants across Pakistan (Paras and Abbey, 2011). International researches proved that the usage of biogas can help run engines in agricultural processing and also running the irrigation pumps. Thus in the year 2000 with the help of Biogas Support Programme (BSP) 1,200 new digesters were installed which were reported to have utilized nearly 27% of the country's biogas potential. Commonly used digester design in Pakistan is the modified version of fixed dome digesters referred as the GGC 2047 Nepalese model as shown in Figure 11 (Ilyas , 2006).

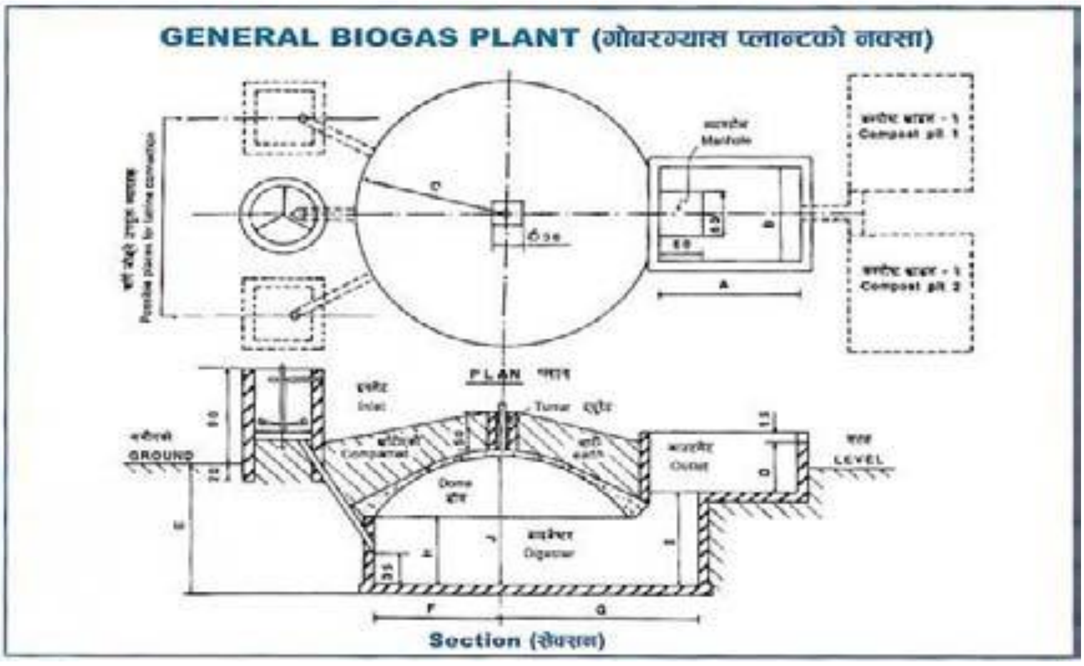

Figure 11 Modified GGC 2407 Model Fixed dome digester (Shrestha , 2010)

2.8 Asia’s Biogas Experience

2.8.1 Pakistan

Approximately 70% of the population of the country is engaged in agriculture, thus the country’s energy consumption is considered low. However the energy demand of the country is increasing annually by 24%. People in the rural areas consume the wood as fuel, thus resulting in further depletion of the low forest cover of the country. According to an estimate 90% of the wood is used as fuel in the country and CO_2 emissions of the country have gone up to 0.65 tonnes per thousand people. Like all the developing agricultural based economies Pakistan is also trying to meet its energy requirements using biogas. If cleaned up to the pipeline quality, biogas has similar characteristics as natural gas, thus can be a substitute for natural gas Ghauri et al (2011).

Amjid et al. (2011) explained that a biogas unit of 10 m^3 in size in Pakistan is anticipated to save almost PKR 92,062 per year on account of less conventional fuels spent. Women’s opportunity cost, with introduction of biogas units reportedly increased; subsequently impacting positively on household income. Pandey and Bajgain (2007) in a feasibility study of domestic biogas in Pakistan have examined the potential of household scale biogas for cooking and lighting in rural areas. The report discusses the benefits of biogas to users particularly women and children and also biogas contribution to achieve the millennium development goals. The main barriers to large-scale adoption of biogas have also been discussed. Ghimire (2007) discussed the difficulty in collecting conventional energy sources and their high cost. Economic and social benefits included saving time and money, fertilizer of higher nutrient value, fast, easy, and comfortable cooking, health benefits like reductions in smoke-borne diseases and environmental benefits such as saving forests. Clean surrounding were the main motivational factors for users to install biogas plants. Bio-slurry increased crop production (exact figures could not be calculated) and decreased the use of synthetic fertilizers.

Khurshid (2009) reported that in Pakistan per capita fuel wood requirement is $0.5m^3$. To meet this energy need an average family of ten members cuts three to four trees in a year leading to the decline of the country's forest cover and decreasing the fertility of the arable land. If biogas is used by a family of ten members it can save up to PKR 3,150/ month by reducing the expenditure on two LPG cylinders or three to four mounds of fuel wood, cow dung and fertilizers. Biogas usage besides improving the health and environmental status of the users also helps to alleviate poverty in the region. The author suggested that no further natural gas supply pipes should be laid, in his opinion this is a main step that should be taken for mainstreaming this technology especially in rural areas.

Ilyas (2006) in his paper discussed the reasons for the popularity and growing demand of biogas in the country. He concluded that the increased crop production because of bio slurry usage as an organic nutrient rich fertilizer and reduction of the workload for women and girls due to wood collection, dung cake making and cooking have been the main motivating factors.

Bhutto et al (2012) also discussed the great potential of biogas as an alternate energy in the country. They highlighted the different projects initiated by Pakistan Council for Renewable Energy Technologies (PCRET), the biogas plants installed so far have resulted in reduction in indoor air pollution and less cases of respiratory disorders. The 1000 m^3 capacity plant being set up near cattle colony in Karachi was predicted to yield many benefits for the local communities. They recommended investment by the government in large scale projects instead of financing small scale household digesters. Also the combined usage of animal manure and crop residue as feedstock will help yield more biogas which can be used for household purposes and for generating electricity. The low purchasing power of the poor farmers was another reason for lack of widespread use of this technology.

2.8.2 Nepal

Amongst developing nations Nepal has a great potential of biogas, many household and community digesters have been installed by government organizations to improve standard of living of the local people.

An average biogas plant in Nepal serving a household of 6 or 7 people generates many benefits like; saving of traditional cooking fuel such as firewood 2000–3000 kg/year, reduction of workload 1.5 to 3 hours/day, reduction in greenhouse gases up to 5.0 tons of carbon dioxide equivalent per year, reduction in indoor air pollution 3 person/household less exposed, toilet attachment nearly 65% households have toilets connected to biogas plants, improved yields due to bio slurry and less ground and soil contamination (Stichting Nederlandse Vrijwilligers (SNV) [Netherlands Development Organization], 2006).

Bajgain et al. (2005) have discussed the factors that have contributed to the success of biogas in Nepal, the financial and social benefits along with the challenges foreseen in implementing the program in the future. Wargert (2009) in a report has assessed the use of biogas in developing rural areas. He has highlighted the problems, challenges and benefits of biogas technology. In his opinion, a lack of financial capabilities and inadequate government policies are the main barriers to large-scale adoption of biogas technology.

Shrestha (2010) has highlighted the benefits of biogas in Gorkha district. He concluded that biogas users saved up to Nepalese Rupees (NRs) 2653 per household per month by not spending on fuel wood. He further calculated that the GHG emissions by biogas users was 3,656, 65 Kg CO_2 e/HH/year and for the non-users it was 6,025,54 Kg CO_2 e/HH/year, which meant that the users reduced their emission by approximately 2.4 tons/year. The effects of bio slurry on agricultural production could not be quantified. However, it was revealed that the payback period of the plants in this region was fairly high at 15.6 years; this was mainly due to the easy availability of fuel wood and its low cost and high expenditure on fertilizer despite the availability of bio slurry as the local people are not briefed properly upon the usage and advantages of the slurry.

Singh and Maharjan (2003) have assessed the socio-economic impacts of biogas technology in the hills of Nepal. They observed that people preferred biogas as it saved time in cooking and fuel wood collection and give them chance to indulge into income generating activities. Annual savings for the users were calculated to be between NRs 16,000/year to NRs 21,000/year. This also included the amount saved on health and detergent expenditure due to clean and hygienic conditions because of biogas. The limitations of this technology were that only the rich farmers and households possessing livestock could get the benefit. The poor farmers were marginalized from the usage of biogas.

2.8.3 Bangladesh

Talukder (2010) in an impact assessment of biogas plants concluded that the main motivation to use biogas is that its environment friendly, less costly and money saving. The use of chemical fertilizers is reduced and production of crops increased due to use of slurry as organic fertilizers. Saving money from not buying fuel from the market had a direct impact on the socioeconomic condition of biogas owners.

2.8.4 China

Ding et al. (2011) evaluated the efficiency of biogas digesters in saving biomass resource. According to them the biogas digesters economize on energy resources, compared with traditional coal-based or firewood dominated energy consumption. Furthermore, since crop residues of straw and other domestic animal and human excreta are effectively recycled and reused as anaerobic fermentation materials of biogas digesters, greenhouse gas emissions are significantly reduced. The application of biogas slurry to the agricultural crops has greatly reduced the expenditure of buying chemical fertilizers.

Remais et al. (2009) in a study in Sichuan province highlighted how public health can benefit from the implementation of rural energy projects. They concluded that after the construction and operation of the plant the expenditure on fuel dropped down by 68% of coal usage, 74% of wood and 6% of agricultural residue. Improved sanitation and clean kitchens were also seen as advantages by the users over the non-users. Two to three years were required to recover the cost of the plant. In cases where no subsidy was given the payback period was longer. However, it was found by the authors that the subsidy provided by the government for biogas digesters was the main motivating factor for the villagers to make use of the technology. The provinces lacking government funding for alternative energy projects had no motivation for using the technology.

Groenendaal and Gehua (2008) compared the energy situation between the biogas users and non-users in two different provinces. They concluded that impact of the digesters on the economy is very small and negligible in some cases. The saving on fertilizers was not quantified and the increase in the farm income was very small and couldn't be associated with the digester usage. The main reason for such results was the limited scope of the study and ignoring the fact that biogas technology has a great potential as organic fertilizer. However, the reduction in Carbon dioxide emissions and sulphur dioxide due to less coal consumption was a great environmental advantage.

2.9 Africa's biogas experience

2.9.1 Ghana

Arthur et al. (2011) discussed the biogas potential in Ghana and how biogas production can reduce the over reliance on wood and fossil fuel, and help reduce greenhouse gas emissions which may be affecting climate change. Ghana has the technical potential of constructing about 278,000 biogas plants, but only a little over 100 biogas plants have so far been established. Bensah et al. (2011) have also discussed biogas development in Ghana and the issues and risks involved in developing a large-scale household biogas programme. They recommended the use of standardized digesters, increased awareness among people and more government involvement.

2.9.2 South Africa

Brown (2006) concluded that development of biogas technology in Africa has significant potential. Properly designed and used biogas digesters mitigate a wide spectrum of environmental undesirables; they improve sanitation; reduce greenhouse gas emissions; reduce demand for wood and charcoal for cooking; and therefore help preserve forested areas and natural vegetation; and provide a high quality organic fertilizer. For the developing world, biogas's greatest benefit may be that it can help alleviate poor indoor air quality. In South Africa, household biogas units have the potential to reach 400,000 residences. Approximately 16,000 more units could be constructed at school sites which currently have no power source for electricity. Economic potential of biogas development should be considered part of a national energy sector employment strategy, and of particular value for the creation of new jobs in rural areas. By 2020, 4000 new jobs could be created through the growth of biogas installation and use. Corresponding growth in the education and training sector would be needed (AGAMA Energy et al., 2003).

2.9.3 Ethiopia

Gwavuya et al. (2012) have assessed the costs of energy generation from firewood and dung in rural Ethiopia. They observed that households in rural areas largely collect their own fuel, with female household members being mainly responsible for the chore. By investing in biogas plants, households could save time and energy, and have a supply of slurry that can be used as fertilizer in agricultural production. Thus in their opinion the promotion of slurry use as fertilizer must be an integral part of a successful biogas programme. Guta (2012) has overviewed the huge potential of biogas in Ethiopia and the strategies that help to expand the energy supply by biogas and reduce dependence on fossil fuels and consequently the negative impacts on the environment. Ethiopia is the fourth largest country in the African content in terms of livestock ownership. There are large number of small scale bio digesters in the rural areas which not only provide clean fuel for cooking and lightning but also empowers the women to work in the fields and girls an opportunity to attend school. The use of bio slurry reduces the expenditure on fertilizers. The cost of the digester is the main barrier towards the exponential use of biogas technology.

2.9.4 Kenya

Hamlin (2012) evaluated the social and economic impacts of fixed dome digesters in Kenya and the challenges related to the mainstreaming of biogas technology. He concluded that the most promising advantage of biogas usage was the monthly saving in the energy expenditure of up to 3,000 KSH per month. This saving was the main motivating factor behind adopting biogas. A few households thought of buying more animals from the money saved to have more biogas and also increased milk production. The wood purchased annually has also gone down. In some cases the biogas was not sufficient enough to meet the cooking requirement and had to be augmented with fuel wood or LPG. There were reduced instances of headaches and respiratory disorders among the biogas users in comparison to the wood and charcoal users. Using biogas for lighting saved 500 KSH per month. The use of bio slurry as a fertilizer increased the crop yield on average by 6% - 10% and up to 20% in some instances.

2.9.5 Nigeria

Ndinechi et al. (2012) explored the use of animal dung as the input for biogas production. The small scale biogas plants can help resolve the energy crises in the country and completely fulfil the lighting and heating requirements. However, to fulfil electricity needs feedstock from agricultural residue is also required. Mkiramweni (2012) in a study in Tanzania also quantified the potential of biogas and concluded that feedstock from animal dung is not sufficient to meet the country’s need. It had to be augmented with the agricultural residue to completely balance the demand through alternate energy.

2.10 Europe’s biogas experience

2.10.1 Central and Eastern Europe

Lovrencec (2010) highlighted the socioeconomic benefits from biogas in 28 target regions of central and eastern Europe and concluded that biogas is positively influencing the whole society as well as the farmers by creating jobs, a cleaner environment, more productive land as the metabolized biomass is a good fertilizer and more effective than mineral fertilizers. Reduction of energy costs, and increase in farmers income are few of the benefits discussed in the study.

2.10.2 Turkey

Ulusoy et al. (2009) have evaluated two different scenarios for biogas and energy production in Turkey. The utilization of waste from tomato and pea paste production and utilization of cattle manure. They concluded that both the substrates have great energy potential and recommended the use of kitchen (organic) and agricultural waste as substrates for biogas generation. Demirel et al. (2010) studied the potential, opportunities and drawbacks of biogas energy in Turkey. They concluded that introducing biogas technology in the rural areas can open new job opportunities and generate income for the poor farmers. Electricity was also produced by using the gas to run the turbines. However, they believed more private sector involvement and raising awareness among the common people is required in making this technology form a major portion of country's energy supply.

2.11 Electricity Generation from Biogas

Munchiri et al, 2012 in a study in Kenya focused on how to produce biogas from solid waste and later generate electricity from it using a dual fuel (DF) engine to run the generator. The biogas produced is used to substitute the natural gas after up gradation and purification. The other fuel used in these dual fuel engines is diesel. Biogas is first mixed with air and then diesel is added to the mixture. This mixture of both the fuels then makes the generator function and produce electricity. The calorific value of biogas is 6 Kwh/m^3.

Pipatmanomai et al, 2008 have assessed the feasibility of electricity generation from biogas in small farms. Biogas is used to produce electricity through internal combustion engine as a replacement of diesel or gasoline. The jet engine or micro turbines then produce energy to run the generator. According to this study in Thailand 1.6 kW of electricity can be generated from 13.15 litres per minute of biogas. Sefeedpari et al, 2012 estimated the potential of cow manure to produce biogas and then electricity in a dairy farm in Iran. The total biogas potential of the farm is 15190.3 cubic meter per day, which can produce 77428.3 kWh electricity per day, which can fulfil the total electricity requirement of the farm. Raising awareness amongst the farmers and policy formulation were thought to be mandatory for utilization of the complete potential of the farm.

2.12 The Net Energy Analysis (NEA) and Energy return on the energy invested (EROI)

Net energy analysis (NEA) is an alternative to the conventional economic analysis which evaluates the energy system, it compares the amount of energy yielded to the society from a technology to the energy consumed in finding, extracting, processing and transporting it. The direct and indirect energy required in producing a unit of energy in the NEA is referred as the embodied energy. The Net energy gain (NEG) and Energy returned on Energy invested (EROI) are the concept discussed under NEA. The NEG is the difference in energy invested into the production activity and energy gained.

Net Energy Gain (NEG) = Energy Output – Energy Input

If the value of NEG is less than zero then it is considered to be a loss of energy investment.

In case of fuels the EROI is the comparison between the energy content of fuel produced to the amount of energy used in manufacturing, extraction, transportation, construction and operation of the fuel’s life cycle. Thus it is the ratio of output to input

EROI= fuel produced /Cumulative energy required to produce it

Determining the system boundaries is an important factor when doing the net energy analysis, the boundary determines to what extent direct and indirect energy is accounted for Cleveland and Connor,(2011); Arodudu,(2012); Hall et al , (2009). Cleveland and Connor,(2011) discussed that EROI is a dimensionless number as the numerator and denominator are assessed in the same units and an EROI of 10 means that 10 units are produced by each unit of energy invested in the activity and commonly expressed as 10:1. Energy breakeven which refers to the energy returned as fuels in comparison with energy invested in obtaining; is the basic criteria on which the EROI debate is focused. EROI more than one is necessary for the fuel to be produced or project to be done, as it indicates that amount of energy yielded is more than the energy invested. If the EROI is less than one it indicates that more energy is going in to the production of a specific activity than delivered by the product. Hall et al, (2009)

Hall, (2011) stated that economies not only require surplus energy but lots of it, thus the modern economies are focusing on high EROI. Murphy et al, (2010) comparing the EROI of gasoline and ethanol concluded that the EROI of oil (gasoline) is 10:1 to 20:1, whereas the EROI of corn based ethanol is 2:1. That is the main reasons why these fossil fuels are preferred over the biofuels as they yield five times more energy per unit input as the biofuels. Wakeford, (2012) states Charles Hall calculated the EROI of different energy sources in USA and concluded that the EROI for oil declined from 100:1 in 1930 to 15:1 in 2010, the global EROI is also following a same decline. The EROI of nuclear energy ranged between 5:1 and 15:1. The EROI of hydropower can be over 100:1 depending upon geographic location, wind power has an EROI of 18:1 ,Solar PV have 6.8:1, maize based ethanol has an EROI of 1:1 and for ethanol derived from sugarcane the EROI value was 8:1. It is believed that the EROI of biofuels is greatly dependent on the type of feedstock, geographic and climatic conditions, and soil fertility and farming methods. The EROI of fossil fuels is showing a decline globally because of resource depletion, however; the EROI of alternate energy sources is rising due to technological improvements. Wind and solar are considered to be more to be energetically feasible amongst the renewable energies than unconventional hydrocarbons.

3. Methodology

To investigate the research questions a survey was conducted in two villages in Narowal and Sialkot districts

3.1. Data Collection

Both primary and secondary data was used in the course of study. The secondary data mainly consists of reports and firsthand information provided by PRSP officials. The literature review was culled from academic journals and research reports.

Primary data: the main instrument of the study was data collection through structured questionnaires with the biogas users and open- ended unstructured interviews with the non-users in the villages modeled on existing biogas studies and biogas user's survey. Both qualitative and quantitative analyses were made. The survey was carried out by face to face interviews with the users. The preliminary questionnaire was developed and discussed with PRSP officials and revised from the field experience and pretesting. The questionnaire has six different sections, the first and the second section focused household characteristics, agricultural production and livestock, the third explained the biogas plant installation and functioning .The fourth part described the energy consumption and expenditure pattern, the next section considered the usage of bio slurry and its impacts and the last section highlighted the effects of biogas on users.

The indicators that were assessed to ascertain the study questions included reduction of smoke in the kitchen due to biogas, changes in income and educational status of users, time and money saved through different household activities such as cooking, feeding and fuel wood collection, bio slurry usage and its effectiveness on crop yield and soil fertility, household utilization of firewood, quantity of biogas consumption and production.

3.2 Target Group for research

There are approximately 50 biogas plants in the two districts established with the collaboration of PRSP and local residents. The cost of each plant is 26,000 PKR. These plants were installed by the government as a result of the efforts to promote alternative energy sources to sustain the environment. 20% of the cost was paid by the household that installed the biogas and the remaining 80% was subsidized provided by PRSP. Three percent of the 20 % amount contributed by the household is used for repair and maintenance of the plant. All these plants are based on the GCC Nepalese model Fixed dome technology design. These plants have a capacity of 6 m^3 and require 40-50 kg of dung per day to produce gas sufficient for a day's usage. Even if the dung is not fed every day the gas will be produced the next day but with low pressure and quality.1 Kg of dung produces approximately 40 liters of gas a day.

3.2.1 Materials and Methods

All the 20 households using biogas, ten in Habibabad and ten in Kotli sindwana were surveyed.

Ten nonusers from each village were also interviewed, mainly with houses near biogas users.

Annual income saving from reduction in fuel wood was calculated at the local rate of PKR 10/Kg.

EROI of biogas plant will be calculated. It is the ratio of energy output to energy inputs. It refers to how much energy is returned from one unit of energy invested in an energy producing activity (Hall, 2011). The boundaries for this study include the biogas produced from the $6m^3$ biogas plant as the energy output. The energy inputs accounted include the human labor to construct the plant, this was done by the male members of the family, and the embodied energy (energy required to extract, manufacture and transport the product) of Poly

Vinyl Pipes (PVC) which are used to supply the biogas plant from the digester to the kitchen, bricks and cement to construct the inlet channel above ground and the underground digestion chamber. The inputs are a one-time investment, however the cumulative gas production over the periods increases, the life of each plant ranges between 20- 25 years. However, minor changes might be required that this operational life span of the plant.

EROI= **Output/ Input** EROI = **Q/H+B+C+P**

Where:-

Q is the output from one digester: the gas produced per year

H is the human energy of all the three laborers required in building the digesters

B is the embodied energy of the 1300 bricks

C is the embodied energy of the 14 bags of cement

P is the embodied energy of the 13 feet PVC pipes

The energy output (Q): the quantity of gas produced by the plant in a day

It is calculated that a 6 m^3 plant produces 1800 liters of gas per day (PRSP, 2008)

1 Liter =0.001 cubic meter (www.convertunits.com)

Thus 1800 liter = 1800 x 0.001= 1.8 cubic meter of gas per day

1 cubic meter of biogas = 22.2 MJ (Homan , 2012)

1.8 cubic meter of biogas= 1.8 x 22.2 = 39.96 MJ

Hence the total gas produced in one day is 39.96 MJ, to calculate the energy of the gas produced per year (Q), the energy of biogas per day from one plant 39.96 M J will be multiplied with 303 instead of 365 as mentioned earlier the gas produced is not sufficient during the months of December and January so the annual biogas produced from the plant can be calculate by multiplying 303 x 39.96=

39.96 x 303 = 12108 MJ/ year

So Q is = 12108 MJ/year

The human labour input (H): has been calculated as energy spent by one labour per hour per day to construct the digester. The energy expended by one Laborer per second is 671 J/Second (Ozkan et al ,2004).

So to calculate the energy spent by the laborer in one minute we will multiply 671 J/Second with 60 (as I minutes as 60 seconds) and to get energy spent by a laborer in one hour we further multiply it with 60 as one hour as 60 minutes .These calculation have been shown below

Calculation of energy used per minute: 671 x 60 (minutes) = 40,260 J/ Minute

Energy used per hour: 40,260 x 60 (hour) = 2,415,600 J/hr.

2.4156 MJ/hr. or 2.4 MJ/hr

as 1000,000 J = 1 MJ (www.convertunits.com)

For a standard 6 cubic meter biogas plant three (3) laborers, spent eight (8) hours per day, for three (3) consecutive days to complete the construction. Thus each laborer spent 24 hours (8 hours per day x 3 days) in all to complete the task. The total hours spent by all the three laborers in three days were calculated by multiplying 24 with 3, as each laborer spent twenty four hours and three laborers will spend (24 x 3 = 72).Thus a total of 72 hours were spent by the three laborers in constructing the plant. The energy expended by these laborers will be calculated by multiplying the energy spent by a laborer in one hour (2.4 MJ) with 72 to get the total amount of energy input of the laborers.

Energy spent in one hour is 2.4 MJ

In 72 hours energy spent will be 2.4 x 72 =168 MJ

Thus the value of human labor input (H) = 168 MJ

The embodied energy of brick (B): is the energy required to manufacture and transport the bricks used in the making of biogas plant. According to the Brick institute of America the energy required to manufacture and transport material for one pound of brick is 1,239(British thermal unit) BTU (Boral USA, 2009). Which is equal to 1.2 MJ/pound, as 1 BTU is equal to 0.001 MJ, thus 1,239 BTU when converted to MJ becomes (1,239 x 0.001) 1.2 MJ (www.unitconversion.org).

A standard brick is made up of 6 pounds of brick material

1 pound of brick material has 1.2 MJ of energy

6 pounds will have (1.2x 6) =7.2 MJ of energy

Thus the embodied energy of one (6 pound) brick (B) = 7.2 MJ

To construct a standard digester of 6 cubic meter capacity 1300 (6 pound) bricks are required, thus the embodied energy of 1300 bricks (B) is calculated by multiplying 7.2 MJ with 1300.

The embodied energy of 1 brick is 7.2 MJ

Energy of 1300 bricks will be = 7.2 X 1300= 9360 MJ

Thus the embodied energy of 1300 bricks (B) is 9360 MJ

The embodied energy of 1 kg of cement (C) is 4.4J/kg; a standard bag of cement weighs 50 kg (US energy Information Administration, 2005). The embodied energy of 1 bag of cement (50 kg) can be calculated by multiplying 50 with 4.4.

As embodied energy of 1 kg cement = 4.4 J

The embodied energy of 50 kg cement (1 bag) = 4.4 x 50 =220 J

The embodied energy of 1 bag of cement is 220 J, to construct a biogas digester a total of fourteen cement bags of 50 kg are required. The embodied energy of 14 bags of cement can be calculated by multiplying 220 with 14.

As energy of 1 bag of 50 kg = 220 J

Energy of 14 bags of 50 kg= 220 x 14=3080 J or 0.003 MJ

Thus the embodied energy of 14 bags of cement (C) is 0.003 MJ

The embodied energy of 13 feet PVC pipe (P): The total energy required for the production and transport of 8 feet PVC pipe is 144.96 BTU/Lineal foot (L.F) (Ohlinger, 2002), which when converted to Mega Joules per Lineal foot becomes 0.145 MJ/L.F

As 1 BTU has 0.001 MJ

144.96 BTU will have 144.96x 0.001=0.145 MJ

Thus the energy consumption for 8 feet PVC pipe is 0.145 MJ/L.F.

Hence the energy for 1 foot PVC pipe can be calculated by dividing 0.145 by 8.

As embodied energy for 8 feet pipe is 0.145 MJ/L.F

Thus the energy of 1 foot will be 0.145 / 8 = 0.018 MJ/L.F

The embodied energy of 1 foot PVC pipe is 0.018 MJ/L.F; to supply the biogas from the digester to the stove a 13 feet PVC pipe is required. The embodied energy of 13 feet PVC pipe (P) can be calculated by multiplying 0.018 with 13.

As embodied energy of 1 foot is 0.018 MJ

Energy of 13 feet is 0.018 x 13= 0.234 MJ/L.F.

Thus the embodied energy of 13 feet PVC pipe (P) = 0.0234 MJ/L.F

As we have the estimated energy values for the inputs and output used to calculate the EROI of the biogas plant, substituting these numbers can give the EROI ratio. As it is a ratio thus EROI has no units. The energy and the cost of inputs used is a one-time expenditure, however the output is continuous as long as the plant is functional. The EROI for the first year will be low, however for the concurrent years it will rise as the value of the inputs remain the same but the value of output increases with the production of biogas in the successive years.

EROI= Output/Input EROI = Q/H+B+C+P

Q= 14,585.4 MJ, H= 168 MJ, B =9360 MJ, C=0.03MJ and P= 0.0234 MJ

Putting the values in the equation we get

$$\text{EROI of biogas plant} = \frac{12,108}{168+9360+0.03+0.0234}$$

$$= \frac{12108}{9528}$$

$$= 1.3$$

Net Energy Gain (NEG) = Output – Input

= 12108-9528

= 2580 MJ

Thus the EROI of 1.37 represents that for one unit of energy going into the biogas plant 1.37 units of energy is yielded, the NEG of 2580 MJ represents a positive net energy gain. It is economically as well as energetically feasible to use biogas as an alternate energy source. The EROI of the digesters is more than one is indicative of that the production of biogas should be continued as the energy yielded is more than energy invested. a. This value will rise over the concurrent years as the value of the output increases each year if the plants are functioning properly. On the other hand, the input value will remain constant as the inputs are a one-time investment in a biogas system. If the EROI was less than one or decreasing it represented a situation in which the energy going into producing biogas would have been m wan not generating as much energy.

The reduction in carbon dioxide emission from the functional biogas plants was calculated to quantify the environmental impacts of biogas technology. (Shakti, 2009) calculated the carbon dioxide emissions from a 2 cubic meter biogas plant in Bangladesh, using this value the emission reduction from the biogas plants in the two villages under consideration was calculated. The total capacity of the plants functioning in the two villages is $114m^3$ as one plant has a total capacity of $6m^3$ so the capacity of all the plants is (6 x 19).

$2m^3$ capacity biogas plant can save up to 2.2 ton of CO_2 per year (Shakti, 2009)

Thus using this factor we can easily estimate the total saving of carbon dioxide from the surveyed biogas plants.

$2m^3$ saves up to 2.2 ton Co_2 / year

$1m^3$ saves up to (2.2 /2) = 1.1 ton Co_2 / year

$114m^3$ saves up to (1.1 X 114) = 125 ton CO_2/ year.

3.3. Limitations of the Study

The study is based on the data from two villages in Punjab. It only focuses on the benefits of biogas plants and did not consider the organizations working for women empowerment, health and poverty alleviation in the area. The biogas users visited were of similar socio-economic background and the capacity of all the biogas plants evaluated was same.

4. Results and Discussion

A survey was carried out in two villages of Narowal and Sialkot districts to evaluate the impact of biogas technology on socio economic conditions. All the biogas users were interviewed; the non-users were informally interviewed to make a comparison between them and the users. All the plants were built with the help and assistance of the PRSP. The total cost of each 6 m^3 plant installed in the villages was PKR. 26,000. 80% of this cost is subsidized by the government and the respective family just had to pay 20% of the cost, which was paid in cash by all households. The basic criteria on which the household were selected to get biogas technology was firstly the financial status of the family, if they are capable of paying the 20% of the cost and secondly have sufficient livestock to provide feed to the digesters.

The construction of the plant is simple and does not require skilled labor. Technical assistance for the fixed dome digesters was provided by the PRSP officials and the construction work was done by the family members mainly men, but in some cases females were also involved. Constructing a standard 6m^3 capacity plant approximately 14 bags of cement, 1300 bricks, 13 feet of PVC pipe and 64 labor hours (3 laborers working approximately 8 working hours per day for 3 days) are required. All the respondents had brick houses and were electrified.

Despite the rural set-up only six respondents said that they completely relied on agriculture as their main source of income, five respondents said agriculture along with the service sector was main income source, five said they were labourers and four said they were employed in the service sector. All the digesters were fed with animal dung and the biogas produced was used for cooking. The amount of dung added to all the digesters was same, 45 kg and the feedstock was put once a day. Water equal to the volume of dung also had to be added to the inlet so that decomposition can take place. To mix this slurry of dung and water the mixer in the inlet was used, according to the respondents it just took five minutes to mix. Plants were located near the shed and gas was supplied to the users' house with the help of PVC pipes. Availability of land for constructing the plant and the distance of the shed from the house were reported as major reasons why the non-users couldn't get biogas. However, the primary challenge faced by the non-users when inquired about not using the technology was the limited availability of subsidy. Even if the household could easily spare money for the plant yet they were waiting for the next round of subsidy the government will be giving for biogas plants.

The non-users were mainly involved in the service sector rather than agriculture. The environment of the users as observed was much cleaner, with no smoke from the burning of dry dung cakes, or the flames of firewood, no flies on the animal and the dung consequently no smell of dung. The kitchen was clean with no soot on the pots and walls. On the contrary, the non-users claimed that they had a separate room where they used the firewood for cooking, as the soot from the flames not only painted the walls black but also the pots and pans. One of the non-users brought forth an interesting fact that how media had affected their consumption pattern, earlier women leaned the pot and pans with sand or mud but the advertisements of the detergents have provoked them to buy these soaps and detergents which has increased the monthly expenditure by Rs.500. On being asked about the usage of dung cakes for cooking and hygiene and health conditions, the non-users said they are born and raised in this environment so for them it is normal for them to use the dung. The non-users strongly felt the importance of biogas stove as a lot of time is saved when cooking, especially lighting up the firewood and dung cakes required a lot of time. However, when the fire was ignited intensity of both flames was the same. Another benefit was the convenience of moving the stove wherever required if it is raining or there is a storm but unfortunately the non-users had to light the fire under the same conditions or wait for the weather to settle. The users did feel that due to biogas stoves they had less exposure to smoke but there was no record regarding the diseases and illness prevalent before the installation of the biogas digesters. There was no proper dispensary to give evidence about the diseases.

4.1 Functional status of biogas plant and biogas usage

All the biogas digesters were in good condition. Out of all the twenty biogas plants in both the villages only one plant in Sialkot district was non-functional. The non-functioning of the plant according to the respondent was due to poor operation; the inadequate amount of gas, dung was fed once in four days. Although the family owned one cow and one calf, they felt that either the dung was insufficient or due to some technical fault in the plant the gas wasn't being produced. However, the users were satisfied with the functioning of the plant, the gas produced was sufficient enough to meet their cooking requirement. The biogas stove was used for cooking for five to six hours the whole day, preparing the three meals and tea for the family. However, during winters when the ambient temperature drops the decomposition slows down; hence very little gas is produced and is not sufficient to cook food, but can be used to make tea or warm up the food. During these months the households either use LPG cylinders for cooking or dung cakes made of the dried bio slurry; which was in excess after being used in the fields.

4.2 Livestock and land ownership

All the plant users possessed livestock with a minimum of two animals each household and a minimum of 45 kg dung produced every day. Four out of twenty households' possessed more than five animals including poultry and produced nearly 75 kg– 95 kg of dung daily. Four other household's possessed three animals and their daily dung production was 60 kg. The rest had two, three and four animals respectively with a dung production of 45 kg, 60 kg and

70 kg per day. Many non-users had no animals and thus no chance of getting a biogas plant. Usually the households own animals produced enough dung but in case if the users with two animals needed some dung, they easily borrowed it from their neighbors without paying any cost. Availability of land is also a necessary requirement in order to have a biogas setup. All the families possessed land starting from one acre to six acres. Four possessed five acres of land and all was arable, three households possessed six acres of arable land, three households possessed three acres, two houses held two acres and majority of the houses had one acre of land which was arable, two households didn't own it but had leased in the land. Cereals like wheat and barley was the main agricultural produce of these household along with fodder for the livestock and some seasonal vegetables for their own use. The families having larger land holding consumed 25% of their produce and saved the remaining portion which was either sold to buy seeds or other necessities or sold in the market after keeping a little reserved for the family's future need. However, the houses with one acre of land just grew the crop for their own use and not for commercial use.

4.3 User's motivation to choose biogas

The users were asked about the main motivating factors behind installing the technology: the non-availability of other fuel sources, motivation from existing plant owners, or saving of time and energy. 12 out of twenty respondents agreed that it saves time and energy, whereas seven households believed that besides saving of time and energy, non-availability of alternatives also made them opt for biogas technology. For all the non-users main motivation behind opting for this technology in future was the benefits the users were enjoying in terms of time and energy saving, clean indoor and ambient environment, significant decrease in fuel expenditure and reduction in workload of women of the family. Two respondents stated that women have more time as they don't have to walk for 2 km to the official site by the government to make dung cakes and dry them so now in the spare time they have started making footballs, the famous export of Pakistan; thus adding a few more rupees to the family's income. These factors were also the main reason why the biogas users were satisfied with their biogas plant and recommended its widespread usage. The use of slurry was a great monetary support for users and convincing for the non-users.

4.4 Maintenance work and cost of repairing

When inquired about the repair and maintenance problems of the plant and the repairing cost, the owners as well as the PRSP staff replied that if not twice at least once a month the biogas plant is monitored by trained government officials and if necessary any problem with the plant it is taken care of. The users were briefed earlier about the common joints and jets that need to be cleaned frequently for proper functioning, so till now not much repair work has been done on any plant, even on the non-functional plant. Five responded that so far no maintenance work has been required thus no expenditure was made by them on the maintenance of the plant. However, the other fifteen respondents said they had spent around PKR 500 – PKR 700 for small repair works, like changing of the mixer's handle, changing the nozzles or removing the water in the jets. The PRSP staff had trained these people on plant usage and maintenance.

4.5 Use of bio slurry

An important output of the biogas plant besides gas is the bio slurry that is produced as a result of the decomposition of organic waste. This slurry is a mixture of water and dung that is rich in nitrogen (N), potassium (K) and phosphorus (P), and after compositing if applied in the fields it serves the purpose of natural soil nutrient. According to the literature the efficient use of slurry helps to expedite the payback period of the biogas plant as it reduces the use of expensive urea and DDP, the synthetic fertilizers used to increase crop yields. According to the users and non-users the annual expenditure on synthetic fertilizers comes to PKR 4000 –

PKR 6000. For majority of the users this expenditure has gone down, but not for all, as all of them are not using the slurry in their fields. The users of the slurry reported an annual saving of PKR 8000, as they were not purchasing the chemical fertilizers anymore. Fertilizers are used twice a year before the sowing of rice and wheat crop.

Seventeen respondents agreed that they were using the bio slurry after compositing in their fields and the remaining was dried and dung cakes were made to be used during the winter months when the gas is not sufficient. The slurry had to be spread in the fields in a liquid form thus two respondents didn't use it and drained it in the watercourse. A few respondents used the slurry through irrigation canal directly. The non-functional plant had no slurry. Two users of the slurry revealed that using the slurry increased their crop production and this yield provided them with a benefit of nearly PKR 100,000 in a year. The households using slurry had to spend no money or very little on the purchase of the fertilizers. 11 families said that slurry completely meets their fertilizers requirement that is 50 kg per year however two said that the slurry meets half of their needs and they had to purchase the remaining amount of 25 kg. The smaller land holdings of one acre and 2.5 acres required less fertilizers so two respondents said that the slurry was more than their requirement the remaining was either used by the neighbors in their field or it was dried and dung cakes were made out of them.

4.6 Environmental and Health impacts

The main environmental benefit of the biogas technology is reduction in methane and carbon dioxide emissions to the atmosphere. These are the potent GHG which cause the temperature of the earth to rise. In this study we calculated the emissions reduction of carbon dioxide from the nineteen functional biogas plants. The total capacity of the plants functioning in the two villages is $114m^3$, if $1m^3$ saves up to (2.2 /2) = 1.1 ton Co_2 / year

$$114m^3 \text{ saves up to } (1.1 \text{ X } 114) = 125 \text{ ton } CO_2/\text{ year.}$$

The outcome is significant as only 19 digesters can bring such a reduction if this technology is used more appropriately and at a wider scale it can further reduce the emissions to a great extent. Indirect environmental benefits include smoke free kitchens as using biogas releases no soot, which is released in the case of burning dung cakes or fuel wood. The reduction in income spent on fuel wood and firewood is although very minor as much still is consumed for heating purposes during winter. Much of the wood used is cut from the common property thus increasing the rate of deforestation in the country. Using biogas releases the burden from the natural forest cover. The slurry being organic does not contain any chemicals which when enter the water body can end up in algal growth and water contamination, threatening the aquatic life (Khan and Ghauri, 2011). However, the households dumping their slurry into the drain were causing negative impacts on the environment.

The respondents agreed that women and children of their families were healthier after the use of biogas as the smoke caused respiratory irritations and cough, eye irritations headaches and dizziness. A female respondent who was a patient of asthma reported serious breathing problems when in contact with smoke from burning of dung, so the biogas stove was a relief for her. All the respondents agreed that gastrointestinal diseases weren’t prevalent even before the technology was installed and also no accident of burning from the fuel wood reported. No proper dispensary or medical data was available which could have helped us quantify the number of patients falling sick due to poor hygienic conditions. The dung cakes in the houses of the non-users were right next to the eating place, of the family, thus all the flies and other insects were sitting there as vector of diseases. The houses of the non-users did smell of the dung and animals, whereas the houses of all the users were all clean no animal or dung or flies around the place.

4.7 Impact on Women and girls

The use of biogas has improved the social as well as the economic status of the females, as the fuel wood collection, cooking, making of dung cakes is all done by the females. The use of gas stove saves the women from a lot of drudgery. The government has reserved a site almost 2 km away from the village where all the women go to make dung cakes. Setting a flame with fuel wood or dry dung takes a lot of time, thus the females have to spend two hours for cooking one meal in a day. All the respondents agreed that mixing dung and water in the digesters was a simple task and was mainly done by lady of the house. The cleaning of the cooking utensils was very easy now. All the female respondents replied that now it took them half an hour to clean the pots and less than ten minutes to clean the kitchen against one hour they spent earlier in washing and half an hour in cleaning the kitchen. As very little dung was left being fed in the digesters so for making a couple of dried caked they didn't have to go far away. They made cakes in their own backyards. All the kids were attending school but four households responded that now the girls also have started attending school because of availability of time with them and reduction in work load of their mothers and grandmothers. All the children (boys and girls) were attending primary school, however, secondary schooling was only preferred for a small proportion. Girls from these respondents got a chance to attend secondary school. Two households reported that as now there is more time available with women and they have involved themselves in the manufacture of footballs; a famous export of Pakistan.

4.8 Saving on conventional fuels and energy expenditure

The survey tried to assess the quantity of fuel used before and after the installation of biogas. All the respondents agreed that for ten months the biogas produced is sufficient to meet their cooking requirements. However during the months of December and January as the temperature drops energy production is low and it had to be augmented with other fuel so that the basic cooking needs of the family are met.

There was a great reduction in fuel wood consumption but it had a small impact on the income saving, as 80% of the biogas households were getting the fuel wood from the community trees and hence were not paying for them. The remaining 20% paid for their wood, these households collectively consumed 3,960Kg of fuel wood annually. The yearly expenditure for these households was PKR 39,600 on fuel wood.

As 1Kg of fuel wood = PKR 10

Thus 3,960 Kg of fuel wood = 10X 3,960 = 39,600 PKR

75 % of all the users were consuming fuel wood for cooking before the installation of biogas digesters, out of which 53% of the households were consuming 1800 kg of fuel wood annually, 27% of the households were consuming 960 kg of wood annually, 7 % consuming 3,360 Kg of wood and 7% consuming 4,800 kg of wood annually before biogas technology. Collectively all these households were consuming 28,080 Kg of wood annually. This number went down to 2,520 Kg of wood annually after biogas usage. The consumption of dung cakes for cooking also declined from 5,760 Kg dung (as the households were consuming 480 Kg of dung in one month, in one year they consumed 480 x12 =5,760 Kg) before biogas to 1200 Kg (100 Kg in one month and in one year 100 x 12 = 1200 Kg) of dung per year. The reduction in fuel wood collection from community land thus released the burden of the forests and grass cover of the area, also there was a in reduction GHG emissions due to non-burning of wood. The use of wood stained pots and cooking utensils black due to soot, removing these stains was difficult as well as time consuming and increased the consumption of detergents by PKR 400 per month. The non-users were still facing this problem and complained about the increased expenditure due to excessive detergent usage.

The households saved a major chunk of their income by consuming less quantities of LPG. 75 % of the households surveyed were using LPG in addition to fuel wood to meet their cooking requirements before using biogas. It was calculated that annually 2,004 Kg of LPG was consumed by these households costing PKR 160,320 before the biogas plants were installed. The average annual household expenditure before on LPG cylinder was PKR 14,400.

Total LPG used for cooking in one month was 167 Kg

so in a year gas consumed was 167 x 12 =2,004 Kg in year

The cost of one 15 kg Cylinder is PKR 1200

Price of 1 Kg will be 1200/15= PKR 80 per Kg

Price of 2,004 Kg is 2,004 X 80 = PKR 160,320

The households' expenditure on LPG cylinders was completely eliminated with biogas plant installation thus their consumption and spending on LPG after biogas was nil. Fuel wood and dung cakes were used during the months of December and January to fulfil cooking requirement. However; the fuel wood was used during winters for heating purposes as well even after the installation of biogas digesters as biogas was used only for cooking and not space heating. By reducing their expenditure on LPG cylinders and using slurry the payback period of these plants is calculated to a year and in case of those households purchasing fuel wood for cooking before biogas installation is 17 months nearly a year and a half.

4.9 EROI of Biogas Plant

EROI= Output /Input EROI = Q/ H+B+C+P

Where

Q is the output from the digester: the gas produced per year

H is the human energy of all the three laborers required in building the digesters

B is the embodied energy of the 1300 bricks

C is the embodied energy of the 14 bags of cement

P is the embodied energy of the 13 feet PVC pipes

The energy output (Q): the quantity of gas produced by the plant in a day

As we have the estimated energy values for the inputs and output used to calculate the EROI of the biogas plant, substituting these numbers can give the EROI ratio. As it is a ratio thus EROI has no units. The energy and the cost of inputs used is a one-time expenditure, however the output is continuous as long as the plant is functional. The EROI for the first year will be low, however for the concurrent years it will rise as the value of the inputs remain the same but the value of output increases with the production of biogas in the successive years.

Where Q= 14,585.4 MJ, H= 168 MJ, B =9360 MJ, C=0.03MJ and P= 0.0234 MJ

Putting the values in the equation we get

$$\text{EROI of biogas plant} = \frac{12{,}108}{168+9360+0.03+0.0234}$$

$$= \frac{12108}{9528}$$

$$= 1.3$$

Net Energy Gain (NEG) = Output – Input

= 12108-9528

= 2580 MJ

Thus the EROI of 1.37 represents that for one unit of energy going into the biogas plant 1.37 units of energy is yielded, the NEG of 2580 MJ represents a positive net energy gain. It is economically as well as energetically feasible to use biogas as an alternate energy source. The EROI of the digesters more than one, is indicative of that the production of biogas should be continued as the energy yielded is more than energy invested. This value will rise over the concurrent years as the value of the output increases each year if the plants are functioning properly. On the other hand, the inputs are a one-time investment in a biogas system. If the EROI was less than one or decreasing it represented a situation in which the energy going into producing biogas would have been more than the amount of energy being generated.

5. Conclusion and Recommendations

5.1 Conclusion

The literature concluded that fossil fuels: coal .oil and gas ,still form a major chunk of global energy supply, however, the growing environmental crises have forced the economies to divert their energy focus to renewable sources like, wind, solar, and biomass. The use of agricultural and farm waste as an energy source in form of biogas is a common practice specially in developing countries where majority of the population is dependent on agriculture. Many different government and non-government organizations are working in all the these countries to develop appropriate programs to harness the valuable energy from this waste, Even in developed countries like Germany and USA many agricultural, industrial and domestic activities are fuelled with biogas. There is a great potential of biogas globally, but is not utilized to its maximum because of lack of technical and financial barriers.

Pakistan is no exception to the developing countries, it has a great potential of biogas and many small scale biogas programmes funded by government and private organizations can be seen helping people to meet their energy requirements. However, as in the case of other countries, due to low government involvement in promoting large scale dissemination of biogas plants and a lack of technical and financial assistance this energy source cannot be exploited to its maximum

The survey for the study was conducted during October, and the impacts of biogas technology were explored. All the biogas plants in both the villages were functioning well except for one plant in Sialkot. The main reason for the non- functioning of the plant was lack of technical know- how about the operation and shortage of feedstock. There was a great reduction in fuel wood consumption but it had a small impact on the income saving, as 80% of the biogas households were getting the fuel wood from the community tress, hence are not paying for them. 75 % of all the users were consuming fuel wood for cooking before the installation of biogas digesters, out of these 53% were consuming 1800 kg of fuel wood annually, 27 % of the households were consuming 960 kg of wood annually 0.07 % consuming 3,360 Kg of wood and 0.07% consuming 4,800 kg of wood annually before biogas technology. Collectively all these households were consuming 28,080 Kg of wood annually. This number went down to 2,520 Kg of wood annually after biogas usage. The consumption of dung cakes for cooking also declined from 5,760 Kg dung before biogas to 1200 Kg of dung per year. However, the households saved a major chunk of their income by consuming less quantities of LPG. 75 % of the households surveyed were using LPG in addition to fuel wood to meet their cooking requirements .It was calculated that annually 134,268 Kg of LPG was consumed costing PKR 8,861,688 before the biogas plants were installed. The average annual household expenditure before, on LPG cylinder, was PKR 12000 .The households' expenditure on LPG cylinders was completely covered with biogas plant installation thus their consumption and spending on LPG after biogas was nil. Fuel wood and dung cakes were used during the months of December and January to fulfil cooking requirement .However; the fuel wood was used during winters for heating purposes as well.

Eighty five percent of the respondents were using bio slurry as a substitute to the chemical fertilizers, thus not only reducing the household expenditure on chemical fertilizers, but also improving the yield. O.15% respondents drained the bio slurry in the nearby water course and were not using the slurry, as they had no proper knowledge on how to use it. It was estimated that annually PKR 8000 was spent on the fertilizers by the household before the bio slurry usage in the fields.

Women experienced time saving of 2.5 hours to three hours per day by cooking on the biogas and going for collecting fuel wood. They had more time to perform the household chores and were able to give more quality time to their family. Two of the respondents disclosed that due to the biogas digesters, women got an opportunity to indulge into football making and generating income for the family. The reduction in indoor air pollution had a positive impact on the health and the ambient environment.

The reduction in carbon dioxide emissions from biogas plants was also calculated. It was estimated that all the nineteen functional biogas plants can save up to 125 ton of carbon dioxide per year. Although it is a small number, however if this capacity is used on wide scale throughout the country the overall emission reduction from biogas plants collectively will make a greater impact on the environment firstly by reducing the emissions of GHG as well releasing the burden of the natural forest cover of the country.

The payback period for these plants 6 m^3 capacity digesters has been calculated to be 17 months, approximately a year and a half, in case of price associated with fuel wood consumption, but in our study as the fuel wood is not purchased but collected from nearby resources, the respondents in these villages have reduced a lot of expenditure on LPG cylinders, thus if payback is calculated in terms of LPG cylinder, it will take only a year for the households to recover the cost of the plant (PRSP, 2012).

The main hypothesis regarding the impacts of biogas on the socioeconomic, health and environmental on the users has been verified. The cooking needs were fulfilled thus releasing the pressure on the forests and reducing Co_2 emissions. The use of the slurry reduced the expenditure on the chemical fertilizers and the reduction in LPG purchase delivered the economic benefit, and women spending more quality time with the family are the social benefit.

The EROI (the amount of energy invested in getting the final energy output) of the biogas was also calculated, by dividing the output of the plant (the gas produced in one year) by the energy of the inputs (energy of the human labourer, the embodied energy of the bricks, embodied energy of cement and PVC pipes required to construct the plant). The EROI of the 6 cubic meter capacity plant turned out to be 1.53 for the first year, which when compared with that of fossil fuels or biofuels is little low, however in the concurrent years its value will increase as the value of the output i.e. the gas produced increases, whereas the value of the inputs remain the same as the inputs are a one-time investment for this system. As the EROI is more than one it represents a positive net energy gain and the production of biogas can be considered as an alternate energy source.

Overall the direct and indirect benefits of biogas technology strongly recommend its feasibility in the rural areas.

5.2 Recommendations

Based on the findings of the survey and existing literature the following recommendations have been proposed for the wide scale dissemination of biogas across the country.

There are many direct and indirect benefits of biogas some of which cannot be quantified, the livestock farmers should be briefed upon these advantages and motivated through subsidies and other financial assistance programme for the use of this technology. Greater public involvement is required for enhancing the use of biogas technology. A business model based on the public- private partnership should be developed for promoting the biogas program at household level.

Proper workshops and training sessions should be conducted to brief the users about the operation and maintenance of the digesters. The use of bio slurry as an alternative to chemical fertilizer should be stressed.

Community biogas digesters with a capacity of 100 m^3 and more should be installed so that electricity generation can be feasible economically and environmentally. Feedstock for the digesters besides livestock waste should also be encouraged this will not only help generate more gas but also help mitigate the sanitation problem. Installation of biogas digesters at institutional level should also be encouraged. Hotels, restaurants, schools and orphanages should be encouraged to have biogas plants for their organic waste treatment.

The application of Clean Development Mechanism (CDM) of United Nations for Climate Change Control (UNFCCC) can help finance more biogas projects in the developing countries. As the CDM is a flexible system and gives a chance to the developed countries the global north to displace their emissions reductions by selling them to the developing countries. The avoided GHG emissions from the CDM projects will generate Certified Emission reductions (CER) which the rich countries can buy.

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ANNEX 1

Questionnaire BIO GAS User Households Survey

1. Household Identification

This section is to be completed for each household visited

A. Name of the plant Owner	________________________________
B. Contact Telephone No	________________________________
C. Type and Size of Plant	__Cow/Buffalo dung _____Cum_____
D. Type of Financing	Cash/Credit /Both__________________
E. Date of Installation	Month……./Year……_________________
F. Type of House	Kucha/Semi Pucca/Pucca______________
G. Electrified	_Yes/No___________________________
H. Main income source of family	Agriculture/Business/Service/Remittances
I. Respondent's Name	____
J Date of interview	____

K. Time of Interview commenced	________________________________
L. Time interview ended	____________________________________-

2 Household Characteristics

Can you please tell the number of all the members of your household who usually live here, sleep and eat from the same kitchen, including yourself. Do not count temporary visitors

201	202	203	204	205	206
Member	Gender	Age	Highest – level education completed	Main Occupation	Approximate income
Coding for Answers	1.Male 2.Female	For children<1 years write the number of months	Write the number for the grade level passed. Put 0=never 1.Primary 2.Middle School	1.Agriculture 2.Small Business 3.Teaching 4.Govt Service 5.Other Services 6.Politics/Social	Yearly income (Estimated in PKR)

			3.Matric 4.F.A 5.B.A 6.MA 7.Phd	Work 7.Student 8.House Wife 9.Others (specify)	

207 Gross Family Income from individuals (salary, remittances/business)
208 Total expenditure for example in food ,health, education per year

Land Holding

209 Arable land Acres	210 Non Arable Land	211Total Land Area

Agricultural Production

Agricultural Production	Production in Kg	Consumption in kg	Saving in Kg	Current Market price /kG
212 Cereals				
213 cotton /Sugarcane				
214.Pulses				
215 Vegetable				
216.Fruits				
217.Oil seeds				
218.Fodder				

Livestock Ownership

Livestock	Adult	Calf	Total

219.Cow/Oxen			
220.Buffalo			
221.Goats			
223.Horse/Donkey			
224.poultry			
225.The quantity of dung production per day ,kg			

3. INSTALLATION AND FUNTIONING OF BIOGAS PLANT.

3.1. What is the motivating reason behind installing a biogas plant? (Answers can be more than one)

1.	Non-Availability of other fuel sources
2	Motivation from existing plant owners
3	Saves times and energy

3.2 How much did you spent on your biogas plant?

1. PKR________________ 2. Do not know

3.3. The amount of cement, brick, pipes and labor involved in the construction of the plant.

Cement	Bricks	Labor	Pipes
Number of bags	Number of bricks used	How many laborers were required?	The number of pipes used
Cost of one bag	Cost of one brick	Number of hours of each laborer	The cost of each pipe

3.4 Is your biogas plant functioning? If yes are you satisfied with the functioning of the plant?

1. Yes 3.No

3.5 What are the main reasons for satisfaction?

1. Enough gas for cooking 2.Enough gas for lighting 3.Easy cooking/Lighting 4.Utensils are Cleaner 5.Saving in cooking fuel 6.Workload reduction 7.Benefits from bio slurry

3.6 What are the reasons for not being satisfied?

1. Plant has failed; it does not work at all 2.very little gas for cooking /lighting 3. Often encounter technical problems. 4. More added Work 6 Food Cooked in Gas is not tasty

3.7 If the plant has failed, what are the reasons for such failure?

1. Poor workmanship during construction. 2. Poor operation 3.Poor maintenance 4.others

3.8. What is the frequency of feeding the plant?

1. Daily 2.Once in two days 3.Once in three days 4 Once in four days

3.9 How much dung is fed at one feeding? Is the amount same for all the feedstock? (Yes/No)

1.___________kg 2.Do not know

3.10. Do you use other feeding materials besides dung?

1. No 2.Kitchen and household wastes __________kg/day 3.Poultry Dropping _____________kg/day

4. Agricultural wastes ______________kg/day

3.11 How much water is required to mix dung?

1. More than the volume of dung 2.Equal to the volume of dung 3.Less than the volume of dung.

3.12 What are the common problems with your plant?

1. Gas leakages through joints 2 .Mal/Non-functioning of stoves 3.Slurry in pipeline 4. Clogging of pipes because of condensed water 5.Low gas production

3.13. How much PKR you need per year for operation and maintenance of your plant?

1. Rs_____________________ 2.Cannot say ______________________ 3.Not applicable

4. SAVING OF CONVENTIONAL FUEL SOURCES

4.1 For what purpose is biogas used?

1. Cooking only 2.Lighting only 3.Cooking and Lighting both………4.Others (Specify)

4.2How many stoves/gas lamps have you installed?

1.1/2/3/4 stoves (single burner double burner) 2.1/2/3/4 gas lamps

4.3 How long the stove is burnt in a day (calculate the timing on stove /lamp hour)?

1.Stove . _______Hrs Lamp __ Hrs. in the evening, if used

4.4 For how many months is the gas insufficient?

1. Throughout the year 2 during winter months (from ______to______) 3.Other (specify)

4.5. If the gas is not sufficient what do you supplement it with? (Amount in kg/ price in PKR/Kg)

1. Fuel wood ____kg @ PKR____ per Kg 2.Dung Cake ______ Kg @ PKR _____ per Kg 3.Kerosene _____ litre @ PKR _____per litre.

4.6. How much fuel was required for cooking Before the installation of biogas plant per month?

1. Fuel wood_____ Kg @ PKR ______per Kg 2.Kerosene _______ liter @ PKR ____ per Liter.3.LPG _______ cylinder @ PKR per cylinder of __kg 4.Electricity _______.unit @ PKR _____.per unit 5 Dung Cake ______ Kg @ PKR _____ per Kg.6.Agricultural wastes _____kg @ PKR ____ per kg

4.7 How much fuel is required for cooking After the installation of biogas plant per month?

1. Fuel wood_____ Kg @ PKR ______per Kg 2.Kerosene _______ liter @ PKR ____ per Liter.3.LPG _______ cylinder @ PKR per cylinder of __kg 4.Electricity _______.unit @ PKR _____.per unit 5 Dung Cake ______ Kg @ PKR _____ per Kg.6.Agricultural wastes _____kg @ PKR ____ per kg

4.8 How much fuel was required for lighting Before the installation of biogas plant per month?

I. Kerosene_______ liter @ PKR ____ per Liter 2.Candle _______ no @PKR _______per.no 3. Electricity _______.unit @ PKR _____.per unit

4.9 How much fuel was required for lighting After the installation of biogas plant per month?

I. Kerosene_______ liter @ PKR ____ per Liter 2.Candle _______ no @PKR _______per.no 3. Electricity _______.unit @ PKR _____.per unit

4.10. Do you buy fuel wood, dried dung or agricultural wastes or collect it from common /own sources?

1.Buy fuel wood @ PKR___ / kg, dung cake @PKR ___ / kg and agricultural wastes @ PKR______ kg from vendors. 2. Collect from forest/community land/own land/other sources. 3 both 1 and 2,

4.11What is the quantity of fuel wood you buy or collect in a year?

1. Buy _____ Kg/yr

2. Collect ____ Kg/yr

4.12 . How much fuel wood can you collect from the forest/community land/own Land source in a day?

1. Less than 25 Kg 2.25-35 Kg 3.35-45 Kg 4 50-75 Kg 5.more than 7 5Kg

4.13 What is the average time required to collect firewood (hrs/day)?

1. Less than 0.5 hr. 2. 0.5-1 hr. 3. 1-2 hrs. 4. 2-4 hrs. 5. 4-7 hrs. 6. More than 7 hrs.

4.14 Do you feel that your expenditure in fuel collection has gone down because of biogas plant?

1. No not at all 2. Yes to some extent 3.Yes significantly 4.it has gone up 5 Do not know

4.15. Have you experienced any advantages of biogas over the other conventional fuel sources?

1. No 2. Less Costly 3. Comfortable and easy to operate 4 Environment friendly 5.Energy Efficient

4.16. Have you experienced any time saving after the installation of biogas palnt?

1. No;time is not saved 2. Cooking ______ hrs. saved per day……3.Collection of water_____ hrs. Added 4 mixing of dung and water ____ hrs. added. 5 Collection of fuel wood _____ hrs. saved 6. Cleaning of cooking utensils ___ hrs. saved 7.Caring of cattle__________ hrs. saved/added

5.USE OF BIOSLURRY

5.1 Do you use biogas slurry on farm?

1. Yes 2. No

5.2 If no, what do you do with the slurry?

1. Sale to others 2.Give out to others 3.Drain to water courses or drains .4. Others (Specify)

5.3 Why you do not use slurry?

1. It has lesser nutrient value; 2.It is difficult to use 3.No land to use 4.Others (Specify)

5.4 If Yes, What do you do with the slurry?

1. Use as organic fertilizer without composting 2.Use as organic fertilizer after composting 3.Use slurry through irrigation canal directly 4.use as fish food.

5.5 How much fertilizer (all N, P, K) you need to use before installation of the plant?

1. Never use chemical fertilizers 2 Less than 10 kg per year 3. 10-25 kg year 4.25 to 50 kg per year 5.More than 50 kgs per year

5.6Have you experienced any saving in chemical fertilizer after the use of bio slurry?

1. No 2. Less than 10 kg per year (PKR__ per kg) 3. 10-25 kg year 4. 25 to 50 kg per year 5. More than 50 kgs per year

6. EFFECT OF BIOGAS ON USERS

6.1 What are the main benefits of biogas plants related to health and hygiene?(Multiple answers)

	1. Liberation from smoke borne diseases
	2. Reduction in burning cases
	3. Absence of black soot in kitchen/house
	4. Reduced expenses related to health

6.2 Number of children of school going age, attending school

	Before biogas	After biogas
Male		
Female		

6.3 How much time is spent for the following activities before and after the installation of biogas plant?

Activity	Before		After	
	Time in	Who used to do?	Time in	Who does
Collection of				
Caring of cattle/				
Cooking				
Cleaning of cooking				
Cleaning of kitchen				
Collection of water				
Collection of dung				
Preparation of dung				
Plant feeding NA NA				

6.4 Did any of the family members had the following diseases/problems before the installation of biogas plant? If yes, is there any change after the installation of biogas plant?

Disease/Problem	Before Biogas plant	After Biogas plant
Respiratory diseases	No/Yes	NA /
Headache/dizziness	No/Yes	NA /
Eye burning/irritation	No/Yes	NA /

Diarrhea and dysentery	No/Yes	NA /
Burning cases	No/Yes	NA /
Any other	No/Yes	NA /

6.5 Has any of your female household members started the following activity?

1. Started attending school 2.Started income generating activity 3.Joined other group /institution please specify

6.6 What are the main demerits of biogas plants related to health and hygiene?

1. None 2.______________________ 3______________________

ANNEX 2

Discussion Questions with the Non-users

1. General Household information

2. Educational Qualification

3. Occupation

4. Health and Sanitation conditions and commonly prevalent diseases, the average expenditure on health.

5. Main agricultural crop yield and fertilizer usage.

6. Livestock information , dung utilization

7. Current source of energy for cooking and heating , amount and energy expenditure

8. Time spent by females in doing household work and how do they use their leisure time if any?

9. Reasons behind not installing the biogas