The Socio-economic Viability of
Renewable Energy Technologies in Rural Bangladesh

by

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ADB	:	Asian Development Bank
BBS	:	Bangladesh Bureau of Statistics
BCAS	:	Bangladesh Centre for Advance Studies
BRAC	:	Bangladesh Rural Advancement Committee
BDT	:	Bangladesh currency Taka
BPDB	:	Bangladesh Power Development Board
g	:	gram
EDI	:	Energy Development Index
EIA	:	Energy Information Administration
FIRR	:	Financial Internal Rate of Return
GDP	:	Gross Domestic Product
GTZ	:	German Technical Cooperation
HDI	:	Human Development Index
IEA	:	International Energy Agency
IRR	:	Internal rate of return
kg	:	kilogram
kgoe	:	kilogram of oil equivalent
kW	:	Kilowatt
kWh	:	Kilowatt hour
LGED	:	Local Government Engineering Department

MPEMR	:	Ministry of Power, Energy and Mineral Resources
MW	:	Megawatt
MWh	:	Megawatt hour
NEP	:	National Energy Policy
NPV	:	Net present value
PVC	:	Polyvinyl chloride
REB	:	Rural Electrification Board
RETS	:	Renewable Energy Technology
sq km	:	Square Kilometer
TCF	:	Trillion cubic feet
UNHDI	:	United nations Human Development Index
UN-IPCC	:	United Nations- Intergovernmental Panel On Climate Change
WEC	:	World Energy Council
WEO	:	World Energy Outlook

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CHAPTER 1

INTRODUCTION

1.1. Rationale for the Study

Energy is a basic need of human society and has rightly been termed by many as the 'life-blood' which keeps human civilization progressing. Without adequate access to modern energy, poor countries can be trapped in a vicious circle of poverty, social instability and underdevelopment (World Energy Council 1999). One such energy starved country is Bangladesh. In 2003, Bangladesh's energy consumption per capita was only 157 kilograms of oil equivalent (Kgoe) which is one-tenth of the world's energy consumption per capita (Hussain et al. 2007). Bangladesh's endowment of conventional energy resources is neither adequate nor varied, as a result of which it suffers from an acute energy crisis and crippling power shortages. However, Bangladesh is endowed with relatively abundant renewable energy resources such as solar and biogas energy.

The main objective of the study is to explore the extent to which renewable energy technologies (RETs), such as solar home systems (SHS) and biogas digesters, can provide reliable and affordable energy services in the rural regions of Bangladesh. The focus of my research is on rural energy because 70 per cent of the 160 million people in Bangladesh (i.e. 112 million Bangladeshis) live in remote rural areas, where the cost of extending centralized grid systems to provide electricity and other energy services is is extremely high (Assaduzzaman et al., 2009). Of these 112 million people, only 20 percent have access to electricity. Since the vast majority of rural households have no access to modern energy and the use of commercial fuels is limited, the opportunities for utilizing renewable energy technologies are potentially large.

Whether RETs are appropriate for the rural development of Bangladesh or not is studied in this thesis via a literature review and cost-benefit analyses of SHS and biogas plants which are based on data collected during various field visits and dialogues with some of the nation's energy experts. Financial rates of return and pay-back period calculations are used to argue that although RETs have high initial capital costs when compared to conventional or fossil fuel systems, they are nonetheless economically viable means of providing energy services to the rural poor. Factoring in environmental benefits makes for a very strong economic and social case for RET adoption. However, RETs development is at a very early stage in Bangladesh and there are various policy and institutional barriers that hinder this sector from being able to realize its full potential.

The thesis begins with a discussion of the history of renewable energy and its advantage over conventional fossil fuels, such as coal, oil and gas. It then moves on to explore the links between energy and poverty. Following that, it provides a brief overview of the energy situation in Bangladesh, with a special emphasis on rural energy. Then, the potential for solar and biogas technologies are assessed and evaluated based on cost-benefit analyses. It includes a discussion on the potential barriers to the dissemination of these technologies and provides possible policy recommendations. Finally, it provides some concluding remarks based on the various interviews, field trips and cost-benefit analyses.

1.2. The History of Renewable Energy

Looking back into the history of human development, it is evident that the accelerated forward march of human society actually began with the discovery of fire and its use by cave men. They were awed by the release of energy from the first fire lighted and soon learnt to put it to diversified uses to satisfy daily needs. Fire was used to exploit the energy that abounds in traditional biomass, such as firewood and bio-waste from plants and animals, as well as provide lighting, warmth, fuel for cooking and protection from wild animals (Williams 2006). Since the kindling of fire, humans discovered various sources of energies, which made an instrumental contribution to the progress and development of human civilization.

Interestingly enough, the earliest sources of energy were the traditional biomass (i.e. firewood and bio-waste) and wind, geothermal and hydropower which are known today as the ‘renewable energies’. During the pre-industrialization period, humans learned to harness these primary sources of energy, but in a less skilful and efficient manner. The energy from the sun was used in traditional drying and energy from wind and rivers were put to use to operate wind-mills and water-wheels to perform many routine hard mechanical operations, like grinding wheat to flour (Williams 2006).

Then, came the age of industrialization, when new sources of energy, such as oil, petroleum, coal and natural gas were being discovered and extracted to fuel the rapid industrialization of emerging nations. These sources of energy are known as "fossil fuels" and they are composed of hydrocarbons and are formed by nature over eons. These have been instrumental in helping mankind to climb the technological ladder for reaching the level of civilization that we know to-day (Olah et al. 2006).

However, once these fossil fuels are combusted, they cannot be replenished or renewed. The world's oil and gas reserves will be depleted by 2050 (Shafiee & Topal 2009) . Apart from this, these provide energy via combustion and, in the process release toxic emissions into the atmosphere, harming humans, animals as well as plant life and thus distort the overall ecological balance on Earth. In fact, each stage in the exploration, extraction, processing, transportation and consumption of fossil fuels is harmful for humans and ecosystems as illustrated by the recent oil spill in the Gulf of Mexico(Olah et al. 2006).

Furthermore, the large fluctuations in prices of the fossil fuels over the years, superimposed by the threat of global warming have diminished their attractiveness. Thus, at present, mankind is trying to revert back to the use of the same renewable sources of energy i.e. solar, biomass, wind, geothermal and hydro energies that they used in the pre-industrialization era, but, in a more technologically sophisticated and efficient manner. These energy resources are referred to as ‘new renewables.’

1.3. The Rationale for Renewable Energy

An increasing world population, along with growing demands to attain even higher standards of living and a cleaner environment, are putting great pressures on the rapidly depleting fossil fuel resources of the earth. In order to maintain the balance and momentum of human civilization, a more sustainable energy economy is needed, which can be achieved through an increased share of renewable energy (Dincer, 1999). This is because, unlike the non-renewable fossil fuels, renewable energy sources capture their energy from existing flows of energy, i.e. sunshine, wind, flowing water, biological processes, and geothermal heat flows which are constantly and naturally being replenished. Thus, unlike the non-renewable fossil fuels, renewable energies are not diminished by consumption (Elliot 2000). Therefore, if used appropriately and efficiently, they have the potential of providing a reliable and sustainable supply of energy almost indefinitely.

Moreover, the use of renewable energies produce minimal emissions and their increased share in the mainstream energy system, provides a much cleaner energy system compared to fossil fuels, which emit harmful gases like carbon dioxide into the atmosphere, via combustion, thus polluting the environment. The latter fuels are currently emitting an increasing amount of Greenhouse Gases like carbon dioxide, nitrogen oxides, sulfur oxides and un burnt methane into the atmosphere, via combustion, which is the root cause of the much-spoken global warming, sea-level rise and climate change (Dincer, 1999). According to the International Energy Agency, energy-related carbon dioxide accounts for 61% of global greenhouse gas emissions in the world. The various international climate conventions such as the Kyoto Protocol, Bali Convention and the recent Copenhagen Climate Summit of the world leaders demonstrate that world leaders have acknowledged the need for action (World Energy Outlook 2009).

In contrast to fossil fuel energy, renewable energies can be derived domestically from local sources. This aspect is especially beneficial to developing countries as it favors power system decentralization in these economies and enables them to pursue locally applicable energy strategies, more or less independent of the national network. It also enhances the access to energy supplies in small, isolated rural areas and helps the rural poor to attain a higher quality of life by providing better community health and educational services.

This results in potential economic, ecological, social, and security benefits for the rural poor. (Dincer 1999).

Thus, it is not surprising that serious efforts have been launched not only to initiate research and development (R & D) activities in the "new renewable energy" sector, but to make sure that industry prototypes are developed, field-tested and disseminated (up-scaled) on a fast-track basis. In fact, today the solar photovoltaic (PV) and solar thermal electricity, wind power and biomass/biogas/bio-diesel have all developed into proven and matured renewable energy technologies (RETs) and are already finding their ways into markets in both developed and developing countries (IEA, 2007).

1.4. Links between Energy and Poverty

> *"For the poor, the priority is the satisfaction of such basic human needs as jobs, food, health services, education, housing, clean water and sanitation. Energy plays an important role in ensuring delivery of these services."*
> *—World Energy Council and FAO (1999, p. 21)*

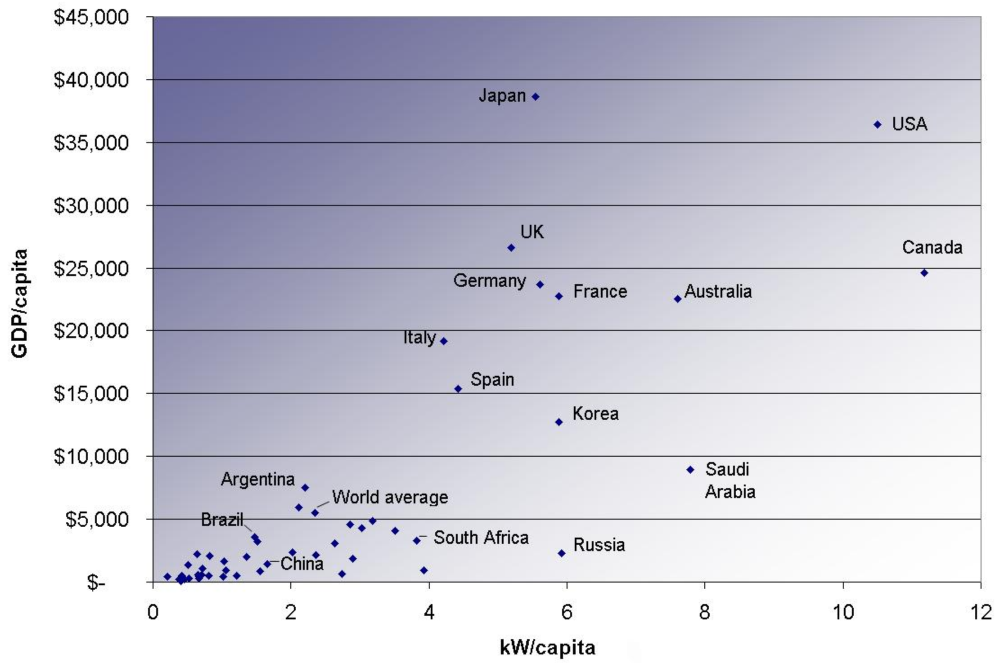
The fact that energy is so important in so many different spheres of our lives, makes it is a crucial ingredient of economic, social and environmental progress. An increasing number of individuals, economies and organizations are beginning to accept it as a fundamental component of any poverty alleviation strategy (World Bank 2000). The Millennium Development Goals, formulated at the 2002 Johannesburg Summit, stated that: *"To implement the goal accepted by the international community to halve the proportion of people living on less than US$1 per day by 2015, access to affordable energy services is a prerequisite"* *(*CSD9 2002*).*

For people living in poverty, the most fundamental priority is the satisfaction of basic human needs, which includes access to food, shelter, water supply and sanitation and other services, such as health care, education and better transport, which will improve their standard of living. Although energy itself is not identified as a basic human need, it is clearly a key ingredient for providing basic needs (WEC 1999). Without adequate access to modern energy, poor countries can be trapped in a vicious circle of poverty, social instability and underdevelopment (International Energy Agency 2004).

The links between energy and poverty can be understood from the graphs in figures 1 and 2. Figure 1 below shows that high income countries have the highest level of energy use per-capita while the low-income countries have the least energy use per-capita.

Figure 1.

Scatter plot Showing Relationship Between Income Per Capita and Energy Consumption

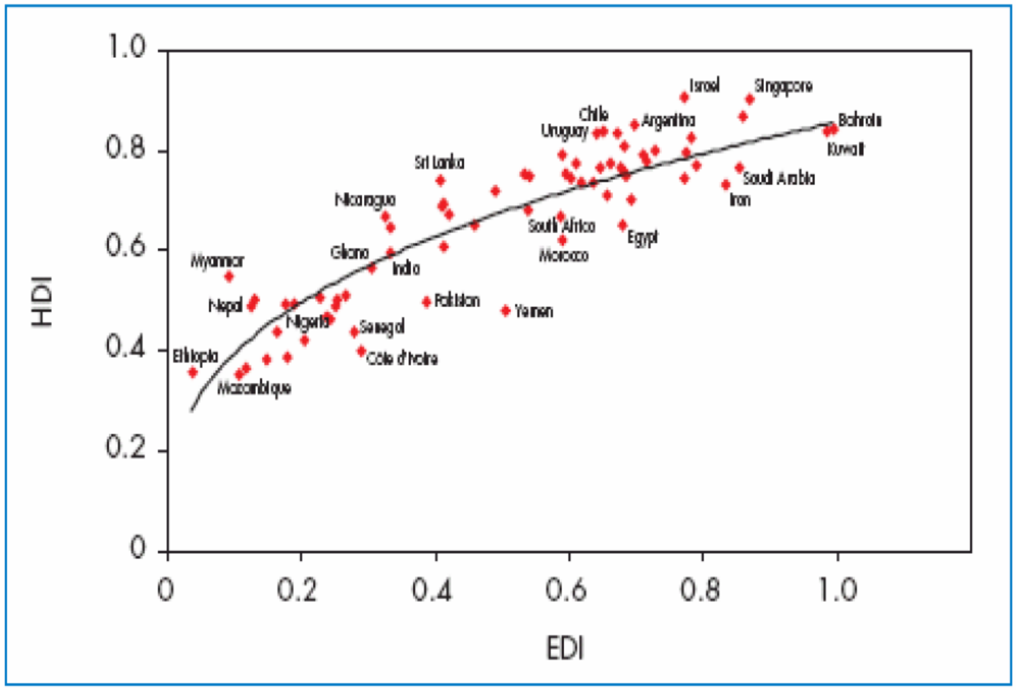


Source: IEA Analysis, 2004

The graph in figure 2 below is a plot of the Energy Development Index (EDI) against the Human Development Index (HDI). The EDI was introduced by the International Energy Association (IEA) in the World Energy Outlook 2004 with the objective of understanding the contribution of energy to human development. It is a composite measure of a country or region's progress in terms of its transition into modern fuels and the degree of maturity of its energy end use. It gives an indication of both the quality and quantity of energy services in the country (IEA 2004).

Figure 2.

Human Development Index (HDI) and
Energy development Index (EDI), 2002



Sources: IEA analysis; UNDP (2004).

Sources: IEA Analysis; UNDP (2004)

The Human Development Index, on the other hand, was introduced by the United Nations in 1990 to measure the level of social and economic development by combining indicators of life expectancy, educational attainment and income into a composite index (Figure 2). Countries with higher measures of EDI have higher HDI. These are the high income or middle income countries, like the USA and Chile that have modern and efficient energy services and high levels of economic and social development.

On the lower end of the graph are the low-income countries, like Bangladesh and Nepal, which have underdeveloped, poor quality and inefficient energy services and low levels of economic and social development. This demonstrates that higher energy use and access to more improved energy sources is associated with higher social and economic development and income per capita. However, the association can be interpreted in the other direction too, i.e. it can be argued that higher economic growth and development usually makes possible higher energy consumption.

The graph also shows that the association between energy use and income per capita is the strongest at early stages of economic development as shown by the non-linear gradient of the scatter plot. This indicates that, for poor countries, even modest increases in energy consumption are associated with much larger increases in human development and income per capita relative to the richer countries which are at the flatter portion of the curve (Cecelski 2005).

1.5. Renewable Energy's Role in Poverty Alleviation

A substantial portion of the world's poor live in remote and isolated areas, where the cost of extending centralized grid systems to provide electricity and other energy services is often prohibitive. This high cost, accompanied by low capacity utilization of such grids due to very small loads in the rural areas, make them an economically unviable and inconvenient means of extending access to energy services in rural areas (Qurashi & Hussain 2005).

In such circumstances, renewable energy technologies (RETs), such as solar photovoltaics (PV), biogas digesters, biofuels, small wind-electric turbines and micro-hydro systems are usually more affordable ways of extending energy services. This is because renewable energies can be produced domestically from local sources and they favor decentralized, small-scale energy technologies, which enable developing economies to pursue locally applicable energy strategies, more or less independent of the national network. Thus RETs can overcome geographical barriers and provide energy supplies dispersedly to poverty-inflicted remote areas of the economy which are not connected to the grid (Dialogue with Islam 2010, Appendix I).

Solar home systems are successfully being used in several poor regions of the world to power radios and televisions and charge batteries for several hours (ADB 2004). This empowers the rural poor by increasing their knowledge base and giving them access to information on local and national events, which further increase their employment prospects. Such opportunities enable the poor to lift themselves out of poverty. Apart from this, access to energy services also contribute to improved health by providing energy to refrigerate medicine and sterilize medical equipment. Moreover, by allowing electric pumps to be powered, RETs provide a local, reliable, and safe drinking-water supply that increases sanitation levels and reduces ill-health and disease among children (Flavin & Aeck 2005).

According to the World Energy Outlook 2004, 2.4 billion people in the world rely on traditional biomass fuels for their energy needs, especially cooking and lighting. The widespread use of these fuels can result in local scarcity, which forces people, especially women and children, to travel long distances and spend hours gathering straw, dung and fuel wood. This reduces the time that they could have spent on education and other more productive activities. These traditional fuels also have low calorific values and large amounts are required for cooking. This can reduce agricultural productivity, because as the agricultural residues and dung burned in stoves might otherwise be used as organic fertilizers. Apart from this, these biomass energy sources are usually inefficiently burnt in stoves, causing severe indoor air pollution (International Energy Agency 2004). According to the World Health Organization, each year, 1.6 million women and children in developing countries, are killed by the fumes from indoor biomass stoves.

Renewable energy technologies, in the form of improved biomass stoves and liquid and gaseous fuels derived from locally produced biomass, substitute the need for traditional biomass, thus alleviating the drudgery of fuel wood collection, predominantly carried out by women and children. This frees up time for girls' education, thus promoting gender equality and women empowerment in the rural areas.

Apart from the above, RETs can help alleviate poverty by directly creating employment opportunities in the rural areas. Because RETs can be produced locally, it fosters the creation of a local web of mutually reinforcing economic activities, thus providing potential sources of employment to the local community (Goldemberg 2004). Rural dwellers can become engaged in the installation, production and distribution of the RETs. This diversifies the livelihood strategies available to the rural poor and creates autonomy by reducing income dependence on agriculture, thus providing the rural poor with opportunities to lift themselves out of poverty (Flavin & Aeck 2005).

The International Labour Organization (ILO) has already announced a dedicated area job creation by renewable energy industry and services and has classified it as "Green Jobs". According to ILO estimates, over 1.2 million "Green Jobs" have been created through the use of RETs, production and services. In Bangladesh, the Ministry of Labour, Employment and Social Welfare, in close cooperation with ILO and national consultants (e.g. M/S Waste Concern) has estimated that training local youth and women as certified solar technicians and repair and maintenance specialists will create about 150,000 “Green Jobs” (United Nations Environment Program 2008).

Even though most RETS have high installation costs compared to conventional fuel systems, they are still a more economically viable and environmentally sustainable means of providing energy services to the rural poor as they are more efficient and have much lower operational and maintenance costs (Goldemberg, 2004). Furthermore, instead of being accompanied by negative externalities in the form of higher environmental costs and health hazards, created by conventional fuels, they have multiplier effects on income, education and health in the rural areas (Flavin & Aeck 2005).

CHAPTER 2

ENERGY SITUATION IN BANGLADESH

2.1. Country Brief

2.1.1 History

Bangladesh was once a prosperous region in the Indian sub-continent. In the 16th century, it became a part of British India and served as part of the British colony for almost 200 years. During this time, it witnessed an enormous drain of its wealth to Britain. In 1947, when the Indian subcontinent received its independence from colonial rule in, West Pakistan and East Bengal separated from India and jointly became the new country of Pakistan. Then, after a violent war, lasting about nine months, in 1971 the eastern wing of Pakistan attained independence as a sovereign nation - the People's Republic of Bangladesh, with its capital in the city of Dhaka. When Bangladesh finally emerged as an independent country, its economy was in dire straits. (Dutt, Dasgupta & Chatterjee et al. 1973, pp. 3-27)

2.1.2 Geography

Located in South Asia, surrounded by India, Myanmar and the Bay of Bengal, Bangladesh is a country with a large population, great poverty, a low resource base and a high incidence of natural disasters, some resulting from global climate change (CIA World Fact book 2008). The country's geographical location makes it extremely vulnerable to natural disasters such as cyclones, floods and soil erosion which not only destroy human lives but also has detrimental effects on the nation's level of productivity. During the monsoon season, about two-thirds of the country floods annually, taking many lives, destroying homes and crops and leaving the people exposed to the threats of global climate change (CIA World Factbook 2008)

2.1.3. Key Indicators

Since independence, particularly after the 1990s, Bangladesh has experienced major improvements on a number of development indicators, including rates of economic growth, poverty reduction, population regulation, infant mortality, and literacy. However, it has been less successful in tackling poverty, income inequalities, infrastructure and governance problems. An overview of the trends in the key development indicators are briefly discussed, emphasizing both the shortcomings and the achievements (World Bank Report 2007).

With a population of more than 160 million in an area of 144,000 sq km, it is the ninth largest nation in the world and the most populous of the 49 UN least developed countries. It is also one of the world's poorest economies. According to the UN Human poverty Index, Bangladesh ranked 93rd out of a total of 102 countries and in year 2000 (UN Human Development Report 2007/2008).

Although the incidence of poverty has declined significantly since independence, 49.0% of its population living below the poverty line of US $1.25 a day.

An encouraging note however, is that Bangladesh experienced strong economic growth since the 1990s with its annual growth in GDP per capita increasing from -4 percent in 1975 to 7 percent in 2005 and its GDP per capita (at constant 2000 US$) more than doubled over the same time period . Much of this growth has been attributed to increasing garment exports and remittances from Bangladeshis working overseas. Interestingly, although about half of the GDP is generated through the services sector, nearly two-thirds of the labor force is employed in the agricultural sector (CIA World Factbook 2007).

According to the United Nation's *Human Development Report 2007/2008*, Bangladesh's Human development index (HDI), increased from 0.347 in the late 1970s to 0.547 in 2007 giving the country a rank of 140th out of 177 countries. Life expectancy at birth from 45 years in the 1970s to 64 years in 2005. Although literacy rate has more than doubled, illiteracy is still persistent at about 50 percent and declining gradually, particularly among women. Mortality rate has been cut by 70 percent and gender disparity has also improved significantly since the 1970s.

Although Bangladesh has made great progress in certain key economic and human development areas as discussed in the previous paragraphs, about 80 million people are still living in extreme poverty (Bangladesh Economic Review 2007). Apart from this, there exists an increasing wealth disparity between the rural and urban areas that may jeopardize economic development and prosperity for the country as a whole (Human development Report 2007/2008).

2.2. Conventional Sources of Energy

> "*Bangladesh is now in the midst of a serious power crisis. Power generation has failed to keep pace with demand, and, in the last two years, increasing shortages of natural gas, the primary fuel used in power generation, have added to the sector's problems. This project will make a major contribution to meeting peak demand for power*."
>
> -Xian Zhu, World Bank Country Director for Bangladesh**.**

Bangladesh is an energy starved country. Its energy consumption per capita is extremely low compared to neighboring countries. As table 1 below shows, in 2003 Bangladesh's energy consumption per capita was only 157 kilograms of oil equivalent (Kgoe) which is one-tenth of the world's energy consumption per capita and half of even that of Nepal, who had a consumption per-capita of 355 Kgoe in the same year (Hussain 2007).

Table 1.

Per Capita Energy Consumption in kgoe, 2003

Country/Region	*Energy Consumption*
Bangladesh	157
Nepal	355
Srilanka	422
Pakistan	467
India	520
China	1094
World	1688
OECD	4588

Source: International Energy Agency, 2003

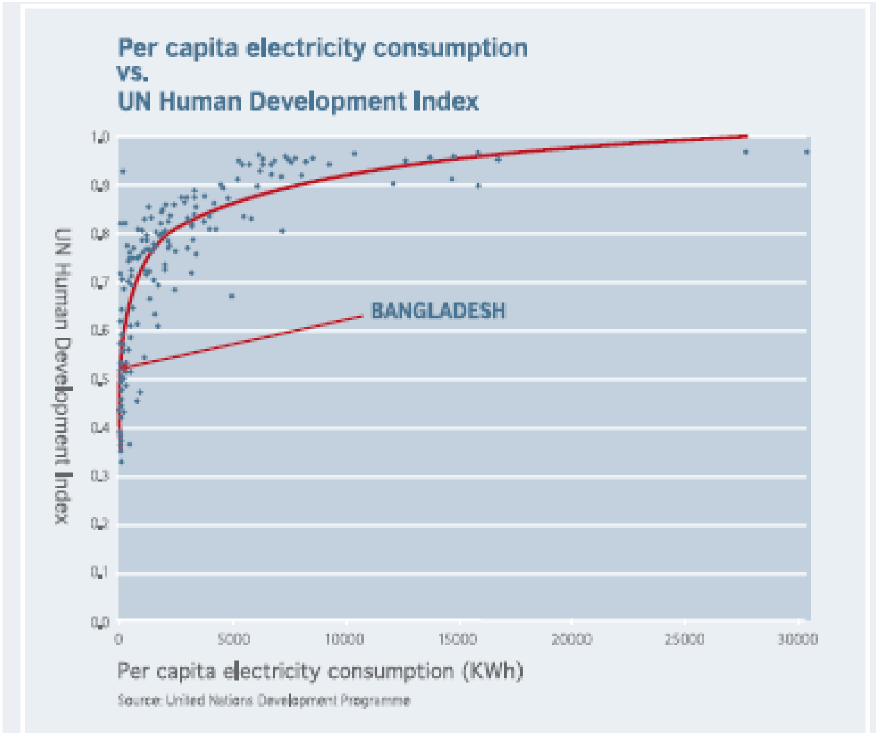
Bangladesh's endowment of conventional energy resources is neither adequate nor varied, as a result of which it is suffering from acute energy crisis and crippling power shortages. While the electricity generation capacity in the country is estimated to be 4931 MW, actual electricity generated is estimated to be between 3,500-3,800 MW. This supply of electricity is inadequate to meet its current demand of around 5,500 MW, leading to a power shortage of 1,500 MW (Bangladesh Power Development Board (BPDB), Power Cell, Energy Bangla, 2009).

Therefore, it is not surprising that access to electricity in Bangladesh is one of the lowest in the world, with about 55% of its 160 million without any access to electricity. The other 45% that do have access to electricity from the national grid suffer from load shedding in the form of frequent blackouts (*Bangladesh Economic Review 2007).* According to the World Bank, power outages and unreliable power supplies costs Bangladesh as much as 2 percent in GDP growth each year. Apart from this, manufacturers have estimated that power shortages cost them around 12 percent in lost sales annually (*Bangladesh Investment Climate Assessment 2008*).

This is critical because the output forgone due to power shortages could have driven Bangladesh beyond the threshold of 6-7 percent growth rate, which many policymakers believe would have made a significant contribution to economic development and poverty alleviation in the country (Ministry of Energy and Mineral Resources 2000). The relationship between the availability of electricity in a country and its United Nations Human Development Index (UNHDI) can be seen in figure 3. For countries such as Bangladesh, with relatively low per capita electricity consumption, small increases in electricity consumption are associated with significant increases in UNHDI.

Figure 3.

Per capita electricity Consumption and UNHDI



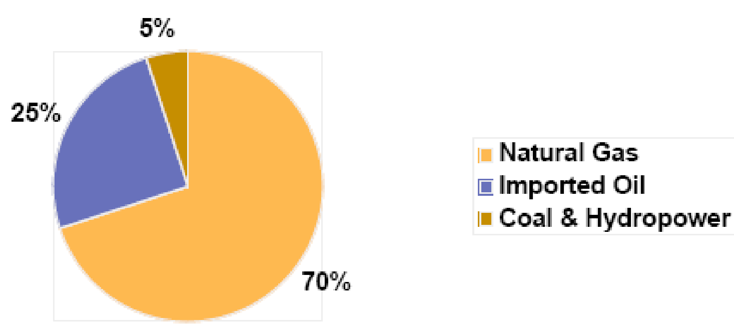
Source: United Nations Development Programme, 2007

Conventional sources of commercial energy, which include fossil fuels, such as natural gas, coal, oil and hydropower account for 32 percent of the total energy supply, while non-commercial sources of energy including traditional biomass fuels in the form of wood fuel, agricultural residues and animal dung account for the remaining 68 percent of total the energy supply (Hussain 2007). A summary of the major energy sources in Bangladesh are presented below:

Natural Gas: Bangladesh's energy sector is highly dependant on natural gas. It is the principal source of energy for the country's power, industry, commercial and domestic sectors. Compared to other energy sources, Bangladesh has a relatively large endowment of natural gas, which makes it a mono-energy economy. Till date, 23 gas fields have been discovered in the country, with a proven estimated recoverable reserve of 20.983 trillion cubic feet (TCF). As of December 2008, total 8.046 TCF gas has been produced, leaving net remaining reserves of 12.937 TCF still recoverable (Petrobangla 2008). Since, 1998, there has been very little exploration activity and only a small gas field with a capacity of 0.44 TCF was discovered in 2004. Natural gas accounts for 73% percent of the commercial energy generation in the country, while imported oil and hydropower production comprises the balance (Figure 4).

Figure 4.

Commercial Energy Consumption Pattern in Bangladesh, 2006



Source: Author, based on data from Bangladesh Economic Review, 2007

Natural gas is the major energy source in electricity generation, supplying 89% of the energy needed to generate electricity, with coal and oil supplying the remaining 11 percent (see figure 5 on the next page). 1 TCF gas can produce 22,000 MW of electricity. However, with a growing demand for energy and electricity and an increasing gas consumption, the natural gas reserves is estimated to deplete in less than 10 years (Petrobangla 2009).

This critical situation of natural gas and, consequentially, of electric power, is already physically visible all over the country in the form of very frequent 'load-shedding', lasting between six to twelve hours every day. This causes immense production and financial losses to all domestic, commercial and industrial consumers. In fact, the foreign and local investments and productions in Bangladesh have almost come to a stagnant state due to this power crisis

Figure 5

Electricity Generation by Fuel Type in 2007-2008

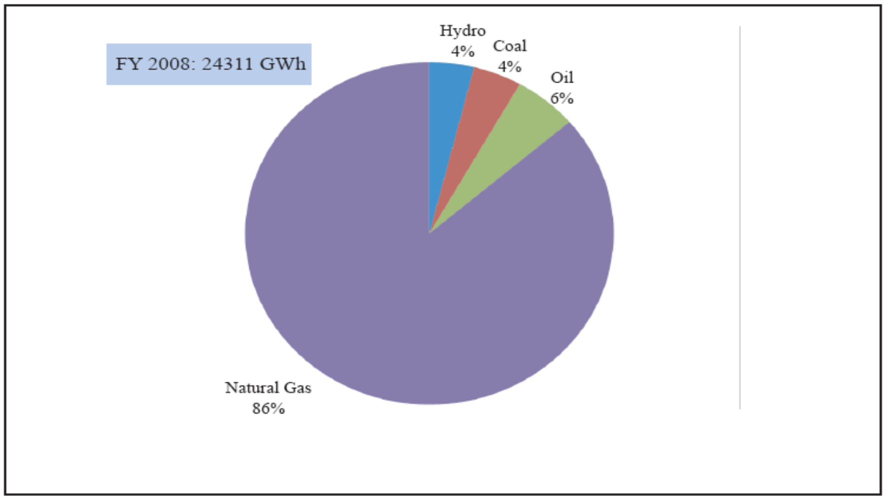


Figure 4: Electricity Generated by Fuel Type in 2007-08 (Data Source: BPDB, Ref. 2)

Source**:** Bangladesh Power Development Board, 2008

Coal : The total reserves of coal in the country are estimated to be around 2.9 billion metric tones from five major coal fields. This is capable of providing five times more energy than the current proven and probable gas reserves in Bangladesh (GCM 2009). However, due to high costs and lack of appropriate technology, the extraction of coal from these mines is not techno-economically feasible. So, extraction has been initiated only at one of the coal mines, Barapukuria in Dinajpur district. One million tons of coal per annum is to be extracted from this coal mine (Islam et al 2008). It is planned that 85 percent of its annual production will be utilized to produce electricity while the rest will be used as fuel for brick making and other purposes

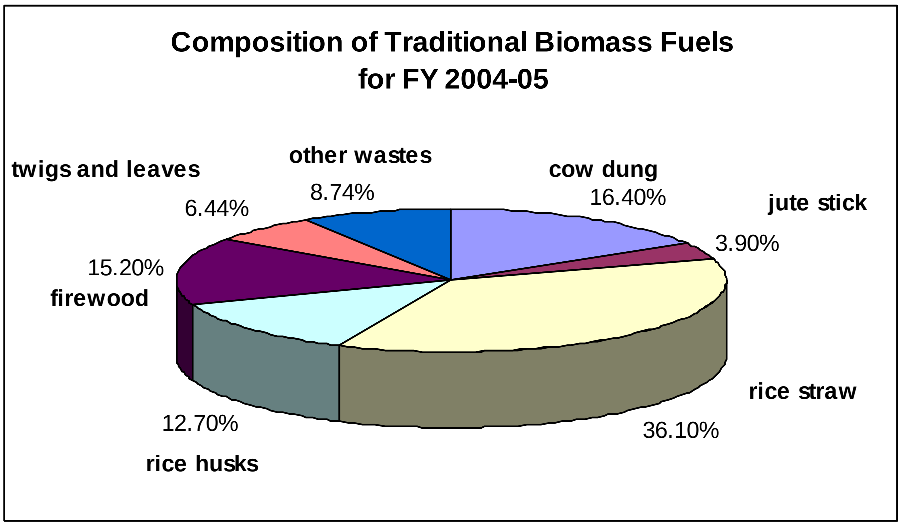
Oil: Bangladesh possesses a small proven oil reserve of 28 million barrels (CIA World Factbook 2009). It produces only 6,426 barrels per day and ranks 92nd in world oil production. Bangladesh's relatively low level of domestic reserves and production capacity make it a net oil importer. The country imported 87,660 barrels of oil per day in 2007 (CIA World Factbook 2009). Over the 2004-05 period, Bangladesh spent US $364 million and US $7214 in the import of crude oil and petroleum products respectively. The cost of import is soaring high, eating up a high proportion of the country's hard earned foreign currency reserve (Hussain 2007).

Till date, oil exploration in Bangladesh has been rather unsuccessful, with most companies focusing instead on the country's relatively abundant natural gas reserves. Exploration and production activities are primarily carried out by the Bangladesh Petroleum Exploration and Production Company (BAPEX) and through the country's Production Sharing Contracts (PSCs) with foreign oil companies (EIA 2006).

Traditional biomass fuels: Biomass or traditional fuels are estimated to account for 68% of the country's energy supply (Hussain 2007). Biomass fuels are comprised of agricultural residues, mainly from rice and wheat plants, paddy hush, jute sticks, twigs, leaves, fuel wood and animal dung. The amount of energy supplied by each of the fuels as a percentage of the total non-commercial energy supplied by traditional fuels is illustrated in figure 6 below.

Figure 6.

Composition of Traditional Biomass for FY 2004-2005



Source: Bangladesh Bureau of Statistics, 2008

The majority of the energy is supplied by cow dung, firewood and rice straw. The rural areas of Bangladesh are heavily dependant on this traditional biomass fuel to meet their energy needs. The total amount of biomass fuels consumed in the year 2005 was approximately 51 million metric tones and about eighty percent of Bangladeshis use biomass for cooking purposes. However, biomass is becoming exceedingly costly and scarce in recent times (Asaduzzaman et al. 2009).

2.3. Rural Energy Realities

The focus of my research is on rural energy. This is because seventy percent of the 160 million people in Bangladesh, i.e. 112 million Bangladeshis live in the rural areas. Ignoring this huge proportion of the population and just focusing on the country's urban needs, which is only representative of only thirty percent of the population, would result in inequitable social and economic development (Asaduzzaman et al. 2009). The Bangladesh economy can achieve overall economic development and accomplish middle-income status, only if the rural population is economically and socially empowered.

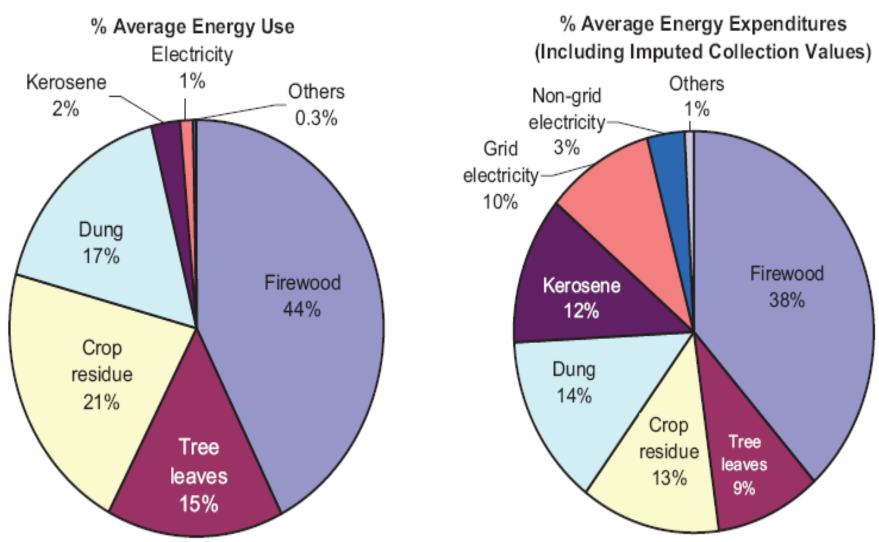
Of the 112 million people living in the rural areas, only twenty percent have access to electricity. The national grid does not extend to the remote villages where they live, and in most cases, the power lines will not reach this impoverished population for another 15 to 20 years. Apart from this out of a total of 65,000 villages only 46,720 villages have been electrified so far (REB 2007). The lack of sufficient energy sources and electricity is limiting the rural population's ability to engage in income generating activities and pushing the rural population deeper into poverty.

As mentioned earlier, majority of the rural population depend on traditional biomass fuels to meet their energy needs. However, the use of traditional fuels imposes heavy social and economic costs on the rural population.

First of all, it takes up a substantial part of the income of rural households in Bangladesh (Figure 7). The percentage of income spent on each type of biomass fuels. Out of the various types indicated, fuelwood accounts for 38 percent of total household cost. With regard to the commercial fuels purchased in rural areas, kerosene accounts for 12 percent of cost. We can also see that grid-based electricity accounts for 10 percent of cost and off-grid electricity in the form of solar PCV, storage cells and dry-cell batteries account for 3% of cost (Asaduzzaman et al., 2009).

Figure 7

Rural Energy Use and Expenditure by Energy Source



Source: Bangladesh Institute for Development Studies, BIDS Survey, 2004

Apart from this high financial cost, biomass also imposes several economic and social costs on the rural population. The inefficient burning of biomass deprives soil of essential nutrients, resulting in unsustainably low levels of organic matter in the soil. The smoke and particles from kerosene lamps and conventional stoves cause eye problems and respiratory diseases, which pose serious risks to the health of the rural population (Asaduzzaman et al., 2009).

In fact, the WHO has estimated that 46,000 women and children die each year in Bangladesh as a direct result of exposure to indoor air pollution, while millions more suffer from respiratory diseases, tuberculosis, asthma, eye problems and lung cancer. Apart from this, fuel collection also takes up a large chunk of the rural people's valuable time, which could have been spent on other income-generating activities (Asaduzzaman et al. 2009).

Although the energy needs of the rural population are modest, energy is a key ingredient in their development. Making modern energy services available to the rural population will expand and diversify the type of income generating activities that are available to them and improve their health conditions significantly. This, in turn, will make the rural population more productive and self-reliant, mitigate rural-urban disparities and migration, helping the majority of the country to come out of the vicious poverty cycle (Asaduzzaman et al. 2009).

2.4. Renewable Energy Scenario

Although the current situation of the conventional or 'mainstream energy' in Bangladesh is bleak, in terms of the large mismatch between the demand and supply of commercial energy resources and generated electricity, the renewable energy situation, by comparison, looks promising. There is scope to supplement mainstream energy with available renewable resources such as solar, biogas, hydropower and wind energies, and, at the same time, enhance energy efficiency and conservation measures to improve the overall situation of the country.

Bangladesh is endowed with a relatively significant amount of renewable energy resources such as solar radiation, biogas, biomass and wind energies (MPEMR 2008). However, due to technological, political and economic restraints, at present, the contribution of renewable energy to overall power generation in the country is less than one percent (Ministry of Power, Energy and Mineral Resources of Bangladesh 2008).

Nevertheless, the potential of renewable energy technologies (RETs) have been recognized by all and the Government of Bangladesh has announced the goal of meeting five percent of the country's total power demand with only RETs by 2015 and ten percent by 2020 (Ministry of Power, Energy and Mineral Resources of Bangladesh 2008). Although this seems to be quite an ambitious goal, it can be done if the Government provides the right incentives to efficiently harness the vast amount of available renewable resources. The main focus of the next two chapters will be on solar and biogas energy since these two are the most abundant and widely used forms of renewable energy in the country at present.

CHAPTER 4

SOLAR HOME SYSTEMS - "PLUGGING HOUSEHOLDS TO THE SUN"

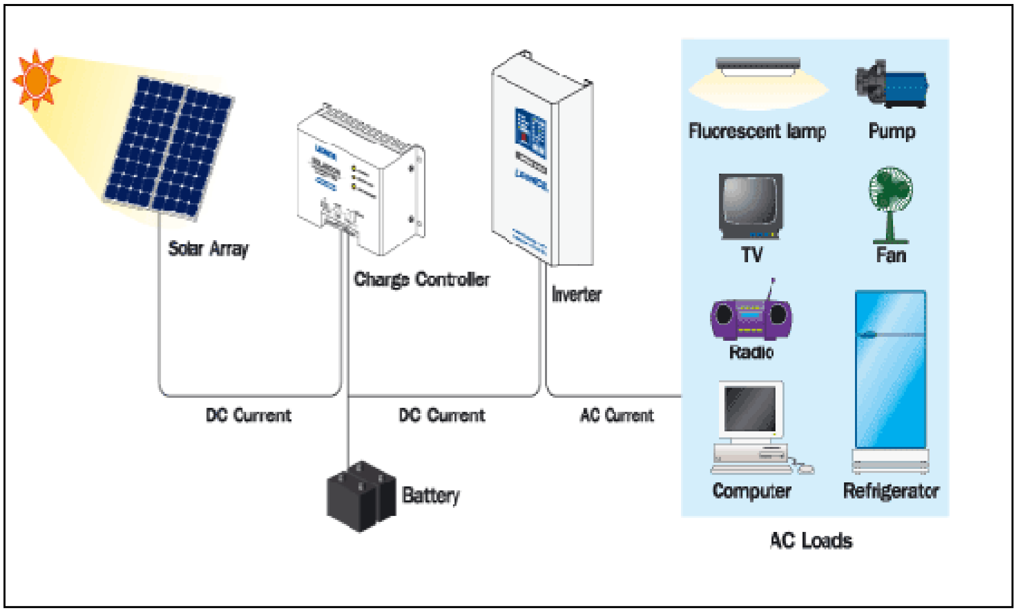
4.1. Background and technology

Solar energy is simply radiation from the sun that contains huge amounts of energy in the form of heat and light and other forms of radiation. Solar energy is the driving force behind almost all natural processes on Earth and it is the cleanest and most inexhaustible source of renewable energy (Islam & Infield 2001, pp. 49). Solar energy technologies utilize radiation form the sun in innovative ways to provide electricity.

The most common form of solar technology used worldwide is solar photovoltaic (PV). It is a method that generates electric power by converting the sun's energy directly into electricity via silicon-based cells called photovoltaic cells. The PV use semiconductor-based technology to convert solar radiation directly into an electric current that can either be used to power appliances immediately, or stored in a battery, for later use. A schematic diagram of how photovoltaic technologies convert sun's radiation into electricity is presented in figure 8 below. PV cells can be used to power appliances including calculators, watches, microwave repeater stations, lighthouses, traffic lights, street lightings, water pumping for irrigations and satellites (Islam and Infield, 2001).

Figure 8

Conversion of Solar Radiation into Electricity



Source: www. reein.org

In developing countries like Bangladesh, where the national grid extension is not economically and technically feasible, an array of PV cells are used to build solar home systems (SHSs). The SHSs use PV technology to illuminate rural households and power other essential home appliances, such as lights, radios and small black and white televisions. The main components include a solar panel, battery and a charge controller which can be operated with minimum training (Islam & Infield 2001, pp. 50). Their application in rural Bangladesh will be discussed in more details below.

4.2. Solar energy potentials in Bangladesh

Bangladesh is located in the tropical region between 20.30 and 26.38 degrees north latitude and 88.04 and 92.44 degrees east longitude. This location provides Bangladesh with a good solar energy potential. According to studies by the Renewable Energy Research Center of Dhaka University, daily solar radiation in the country varies between 4 and 6.5 kWh/m^2, which is a very favorable range for solar energy production (Islam & Infield, 2001). The main applications of solar energy in the rural areas include powering household appliances such as light bulbs, radios, televisions and mobile phone battery chargers, shops and irrigation pumps.

This study focuses on SHSs as they are the most convenient and quickest way of meeting the modest energy needs of rural households. Bangladesh has become a global model in massive and rapid dissemination of SHSs, with one of the world’s most successful energy programs working in the country. Presently, 450,000 small solar home systems (SHSs) have been installed in the country. These SHSs have a total capacity of about 22,000 Kilowatt-peak (KWp)[1] Although this represents a small proportion when compared to the national workable capacity which is about 4,500 MWp, these SHSs being highly decentralized are providing access to electricity to over one and a half million impoverished and deprived households in the remote rural areas of the country (, 2010). This displaces about 18 liters of kerosene every year, thus reducing import costs of kerosene (SWERA, 2007).

The SHSs programs in the country are being supported through innovative financial models administered by non-profit organizations (NGOs) such as Grameen Shakti, Bangladesh Rural Advancement Committee (BRAC) and German Technical Cooperation (GTZ). Out of the 450,000 SHSs, about 330,000 have been disseminated only by Grameen Shakti, a sister organization of the Nobel-prize-winning Grameen Bank which was established in 1996 to promote, develop and supply renewable energy technologies to rural households in Bangladesh. Grameen Shakti has won several awards for pioneering one of the world's most successful solar programs (www.gshakhti.org). The balance has been provided by other NGOs such as BRAC, public utilities such as the Rural Electrification Board (REB), Bangladesh Power Development Board (BPDB) as well as private sector companies, such as Rahimafrooz, who are financed by Infrastructure Development Company Limited (IDCOL) (2010) .

[1] Kilowatt-peak specifies the output power of solar panels under peak / full radiation.

The map of Bangladesh in figure 9 below shows the areas throughout the country where solar home systems have been installed, suggesting uniform distribution.

Figure 9

Areas in Bangladesh with Solar Home Systems

Source: Ahammed & Taufiq, 2008.

Table 2

Number and Capacity of SHSs installed in Bangladesh , May 2006

Name of NGO or institute	Number of SHSs installed	Capacity of installed solar system (Wp*)
Rural Electrification Board	5,000	250,000
Grameen Shakti	65,000	3,250,000
Bangladesh Rural Advancement Committee	15,456	770,000
Centre for Mass Education in Science (CMES)	1,025	51,250
Thangamara Mohila Sobuj Shangha	1,003	50,150
Coast Trust	805	40,250
Srizony Bangladesh	2,384	119,200
Shubushati	796	40,000
Integrated Development Foundation	818	40,900

*Wp = Watt peak.

Source: Ahammed & Taufiq, 2008.

4.3. Cost-Benefit Analysis

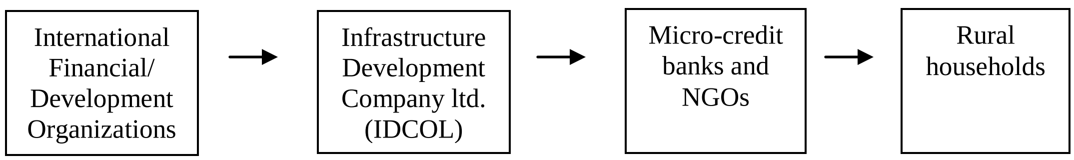
Solar photovoltaic technology comprises advanced and expensive manufactured semi-conductor equipment. The present world market price of solar panels is between US$ 2 to US $2.5 per Watt peak(Wp) (Dialogue with Islam 2010, Appendix 1). The smaller rural based SHSs used in Bangladesh comprise of average 50 Wp solar panels which can power four to six low-energy lights or three tube lights and a socket for a black and white television, radio or battery recharging as well a mobile phone charging unit for four hours daily (Dialogue with Islam 2010, Appendix I). These cost around US$ 370-400 (i.e. Tk 26,000 – Tk 28,000) with an average investment cost of about US$385. Although this initial cost may not seem as high in dollar terms, it is very high for the rural people of Bangladesh, whose average monthly income range between US $50 to US $100 (Dialogue with Islam 2010, Appendix I).

However, Grameen Shakhti, the sister organization of the Nobel-Prize-winning Grameen Bank company has helped the rural poor to partially overcome this high initial cost by designing an innovative micro-credit scheme of financing solar home systems. According to this financing scheme, the rural users are required to pay 15% of the initial cost as down payment. The remaining balance is then paid by borrowing from the nation's micro-credit NGOs and banks, such as the Grameen Bank and BRAC at a service charge of 12%. This amount is paid is repaid over a period of three years in monthly installments.

The NGOs and banks get funds to loan out to the rural households from a government owned bank in Bangladesh called Infrastructure Development Company Limited (IDCOL). IDCOL manages funds received from international financial and development organizations, such as the World Bank, German

Technical Cooperation, United Nations Development Program, Asian Development Bank and the U.S. Agency for International Development and disseminates it to the NGOs and banks that are engaged in the financing of renewable energy projects (, 2010). This structure of financing is summarized by the flow diagram in figure 10 below.

Figure 10. Financing Structure of Rural SHSs in Bangladesh



Source: Created by author based on with Dr. Khursheedul Islam, senior advisor of the Sustainable Energy Development program of GTZ, 2009.

I have based my cost-benefit analysis on data collected during my field trip to one of Grameen Shakti's typical SHS projects in Barotopa village of Gazipur district, about thirty seven kilometers north of the capital. The villagers of Barotopa had no access to electricity about five years ago since the national grid does not extend to this remote region. However, through the installation of solar panels, Grameen Shakti has lit up more than 100 out of 300 households in this small village. The solar home system installed in a typical household consists of a 50 watt peak panel, i.e. it can generate 50 watt of power during peak periods, like most other SHS in use in the country.

All calculations have been carried out at an exchange rate of 1 US dollar (USD) = 70 Bangladeshi takas (BDT) (exchange-rates.org). Households have to pay BDT 26950 (USD 385) for the installation of the 50 Wp solar panel which has a project life of 25 years. According to the micro-credit based financing system of Grameen Shakti, they are required to pay 15 % of the investment cost, i.e. about BDT 4042 (USD 57.75) as down payment. The remaining balance i.e. BDT 2695 - BDT 4042 = BDT 22957.2 (USD 327.96) is paid by borrowing funds from Grameen Shakti at a 12% service charge. The interest payment amounts to BDT 8262 (12% of BDT 22957.2) which is equivalent to USD 118.07.

The total debt payment which includes the principal and the interest debt payment amounts to about BDT 31222 (BDT 22957.2 + BDT 8262), i.e. USD446.03. This amount is typically paid by the households over a period of 3 years in 36 equal monthly installments, each amounting to US BDT 867 (BDT 31222/ 36) or USD 12. Therefore, instead of paying the initial cost of the SHS, i.e. USD 385.71 all at once, the households pay only US$57.75 as down payment, while and borrow funds from Grameen Shakti to pay the balance over a period of 3 years. This means that households have to pay only USD 12 per month as installation cost of SHSs. Given that the average monthly income of a typical rural household lies between USD 50 to USD 70, the monthly installments of

USD 12 still represent a large percentage (around twelve to twenty four percent) of average household income.

However, unlike the initial cost, the operational cost per month of 50 Wp SHSs are extremely low and stands at around BDT 360 or USD 5.14 per year only. On the other hand, households using kerosene, has to spend around BDT 3864 or USD 55.2 every year. This indicates a significant amount of savings on kerosene usage due to the installation of SHSs. After calculating a typical houehold's costs and savings, I calculated net benefits by subtracting the operational cost from the savings on kerosene, i.e. BDT 3864-BDT 360 = BDT 3504 or USD 50.06 each year. The breakdown of typical household's initial cost and details of the net benefit calculations have been summarized in table 3 on the next page. Apart from the standard monthly operational costs, users also have to pay for periodic replacement costs for the storage batteries. Such costs have been included in the discounted cash flow calculations in table 1 in appendix.

Table 3.

Breakdown of Initial Cost of a Typical SHS

Break down of Initial Cost	
Total cost of the 50 Wp Solar PV Home System	= US $385.71 (TK 27, 000)
Down payment at 15% of investment	= US $57.75 (Tk 4050)
Balance remaining to be paid (after down payment)	= US $327.96 (Tk 22950)
12% service charge on the micro-credit capital borrowed (to be repaid within 3 years)	= (12% of US $327.96) x 3 = US $118.07 (Tk 8262)
Total debt payment	= US $ 327.96 + US $118.07 = US $ 446.03(Tk 31,222)
∴**36 equal monthly installments**	= US $ 446.03/36**= US $12 (Tk 840)**
Costs and Benefits	
Operating cost of SHS	= US $5.14 (Tk 360/yr) (compare to kerosene = US $ 55.2 (Tk 3864/yr)
∴ Benefit = Savings on kerosene	= US $55.2 (Tk 3864/yr)
Net benefit	= Savings – costs **=** US $55.2**-** US $5.14 **= 50.06 (Tk 3504/yr)**

In order to find out whether the installation of solar home systems is a viable option for rural households, I used the financial internal rate of method which is based on discounted cash flows. The fundamental principle of this method of financial analysis to compare the net private costs of the investment against the net private benefits.

A stream of discounted cash flows is projected over a period of twenty five years which is the standard project life. This gives the net present value of the project. Based on the net present value, the internal rate of return (IRR) which provides a measure of the net benefits of the project is calculated. The IRR is the discount rate at which net present value is zero. Once the IRR is calculated, it is compared to the commercial interest rate which provides a measure of the net cost of capital for the investment. If the IRR exceeds the commercial rate of interest, the project is profitable and vice versa (Islam & Infield, 2001).

An iterative process of trial and error was carried out to find a reasonable range for the internal rate of return. This range was found to be between five to ten percent. Table 1 in appendix 1 shows details of the net present value calculations. We can see that when the IRR is 6%, the net present value of solar home systems is positive and when it is 7%, the net present value becomes negative. After using the IRR formula provided in the bottom of Appendix I, the exact internal rate of return was estimated to be 6.24 percent. This indicates that by installing SHSs, rural households will get a return of 6.24[1] percent on their investment. This is much lower than the accepted threshold of 12 percent which

[1] All calculated results have been reviewed by GTZ, Dhaka.

is the average commercial interest rate in the country and represents the cost of capital on investments However, in the case of solar, this threshold rate is not applicable. This is because, the government of Bangladesh, in line with its new renewable energy policy, have allocated about USD 30 million for solar projects and have extensively subsidized the cost of such initiatives. This has brought down the commercial rate of interest on solar investments to 6%. Therefore, since our calculated IRR which is 6.24% exceeds the subsidized rate of interest only marginally, we can say that solar home systems are marginally viable options for rural electrification from a private perspective.

The pay-back period for SHSs was also calculated and was found to be sixteen years (100/6.24). Given, the project life of twenty-five years, this is quite a long period of repayment. This is largely, in part, due to the high initial cost of investment. Currently, the solar panel cost per watt peak is in the range of USD 2-2.5. This is an extremely high price for a poor region like Bangladesh and represents almost sixty percent of the cost of a solar home system. As a result, there exists a wide disparity between the monthly installments paid by rural SHSs users to cover the initial cost of solar panels and their monthly energy expenditure, the former being USD 12 and the latter being USD 5.

The most ideal situation would occur when monthly installments paid by the rural users to cover the initial investment cost is more or less equal to the monthly energy expenditure of the households. Grameen Shakti, in collaboration with other NGOs in the country is already making efforts to bridge this gap by providing solar panels at the price of monthly kerosene expenditure. Such initiatives along with the falling price of solar panels will make solar a more financially viable option. Moreover, the financial analysis carried out does not include the numerous positive socio-economic impacts that SHSs have on of rural households. Quantifying and incorporating such socio-economic benefits into the calculations make SHSs even more viable. The following section explores some of these benefits.

4.4. Socio-economic benefits of Solar Home Systems

The installation of solar home systems provide a convenient and sustainable way to power households by supplying high quality, reliable, clean, and environmentally friendly energy services (Ibrahim, Anisuszamman and Kumar, 2002). It has a huge impact on the lives of the rural people in Bangladesh by providing them with numerous direct and indirect socio-economic benefits.

The installation of SHS enables children to study for longer hours and eliminate the time, hassle and cost involved with kerosene usage. About ninety percent of rural users have admitted that the use of solar home systems have drastically improved the quality and reliability of light usage, enabling their children to study for longer hours and eighty percent have agreed to the fact that SHS are much more convenient and cleaner than kerosene (Islam & Infield 2001, pp. 215). Since the SHS powers mobile phone chargers, villagers are able to use cell phones efficiently. They can use the cell phones to contact potential buyers of their local products in the city. This expands their customer base dramatically and has increases their earnings to a great extent.

Apart from these benefits, the SHS programs in the country had other positive long term impacts on the lives of the rural people. By reducing the use of kerosene wick lamps, candles and traditional fuels for lighting purposes, SHSs have reduced the smoke and smell associated with these energy sources and have improved the overall health and environmental condition in the rural areas of the country (Islam & Infield 2000).

By powering radios, televisions and cell phone batteries and by electrifying schools, it has increased the knowledge base of the poor people and expedited the mass education scheme of the government. This, in turn, has empowered and increased the employment prospects of the rural people. Solar technology has also enabled shops, mills and micro businesses in the villages to be open for longer hours and have encouraged the new and innovative micro business ventures to emerge, thus increasing income generating activities in the rural powers (Islam & Infield 2001, pp 215).

Moreover, SHS programs have directly impacted the generation of employment opportunities in the local community by training the local community, including women, on the installation, maintenance and operation of solar technologies and creating thousands of 'green jobs' in the vicinity of their operation (Bangladesh Ministry of Labor, Employment and Social Welfare). These green jobs empower the rural poor and provide them with a means to lift themselves out of poverty. Apart from this, by training and employing women, they uplift the socio-economic status and productivity of rural women in the country (Islam & Infield 2001, pp 216). According to an ILO estimate of 2008, 660 local women have been trained as certified technicians in the repair and maintenance of solar PV systems (United Nation's Environment Programme 2008).

Factoring in the above mentioned positive externalities or social benefits of SHSs into the financial analysis will increase the rate of return on the investment, thus increasing their viability as an alternative option for rural electrification and development (Islam & Infield 2001, pp 160 and pp 215).

4.5. Challenges and Policy Recommendations

Despite the positive aspects of SHSs, up-scaling and large-scale dissemination of Solar technology faces great challenges and barriers. However, where there are challenges, there are opportunities too, provided that such challenges are overcome with appropriate strategies and actions. This section discusses some of the major barriers to the dissemination solar technology in Bangladesh and possible policy recommendation.

The major challenge is the high initial cost of the solar panels. As a partial solution to this problem, the government of Bangladesh, after continuous advocacy by renewable energy activists, has eliminated import duty on solar technology to zero. While this hurts local production, initiatives are being taken by local disseminating organizations to engage in assembly production of solar panels. By producing components of the solar panel locally, these organizations will help to reduce the price of the panels by a significant amount. Seven companies have already applied for loans to the government to carry out local components production and assembly (Dialogue with Islam 2010, appendix I). Making parts of components or accessories of solar systems available locally can also increase acceptability of the technology by users (Ahammed & Taufiq, 2008).

Lead-acid storage batteries in solar home systems require frequent maintenance and provide a weak technical link in the system. While the PV Panels come with a guarantee of twenty years from their manufacturers, the expensive, deep cycle batteries are given only a five-year warranty (Islam & Infield, 2001). Only Grameen Shakti provides free maintenance and replacement of batteries, but none of the other disseminating organizations provide such services free of cost (Dialogue with Islam 2010, Appendix I). Part of this problem can be overcome by providing technical training to the users during installation to enable them to solve minor problems such as replacing fuses and replacing bulbs on their own. This will avoid technician calls and increase the reliability of the system (Ahammed & Taufiq, 2008).

Moreover, the overall efficiency of solar PV cells/panels is still low. The commercial Polycrystalline Silicon Cells/panels have average efficiency ranges of about 13 percent (Islam & infield 2001, pp. 217). During monsoon seasons, efficiency becomes lower and charging is often incomplete. Apart from this, installation of the larger solar panels typically requires large areas of land (about 100 sq. feet per kWp solar panel). This restricts the dissemination of solar technology in certain regions.

There is still a large lack of public awareness and acceptance on the function ability and the various beneficial aspects of Solar PV. Furthermore, the rural people usually lack financial foresight and base their decisions on short term gains rather than long term financial savings. So, it is very difficult to convince them about the far-reaching positive long term benefits of solar. This lack of awareness and acceptance necessitates a concerted effort on the part of the government and the disseminating organizations to make the benefits of the solar technology known to people through the media and via practical demonstrations.

Another important shortcoming of solar technologies is that they have not yet been able to penetrate into the urban sector of Bangladesh because of their high initial costs which make them much more expensive than the national grid. This has important negative implications for the poor. This is because the urban sector consumes more than eighty percent of the country's energy supply and if initiatives are not taken to increase the efficiency of electricity generation in the urban sector, it will put increasing pressure on the country's energy resources and deprive both the urban and rural poor from their share of electricity supply.

This problem can be overcome by the introduction of grid-connected solar technology and the use of feed-in tariffs (FITs) which is a metering system through which excess photovoltaic electricity produced during off peak period is stored in solar chargers and then sold to the government for use in the national grid. This will help to increase the reliability and capacity of the national grid, thus reducing power shortages and load shedding. Sixty three countries in the world, including India, have successfully introduced FITs (Dialogue with Islam 2009).

CHAPTER 5

BIOGAS TECHNOLGY -
"TURNING RUBBISH INTO RESOURCES"

5.1. Background and Technology

As previously mentioned, about eighty percent of the population in Bangladesh uses biomass for cooking purposes. Moreover, fifty percent of Bangladesh's total energy supply comes from biomass sources. Biomass fuels are comprised of agricultural residues, mainly from rice and wheat plants, paddy husk, jute sticks, twigs, leaves, fuel wood and animal dung. However, the conventional way of using biomass imposes several economic and social costs on the rural population. Apart from this, biomass is becoming increasingly scarce and expensive, imposing additional financial cost on the already poor rural households (Asaduzzaman et al., 2009).

Biogas technology provides a highly effective and environmentally friendly way to use biomass more efficiently and thus conserve on biomass resources. It involves the construction of biogas digesters which are fed with organic material such as cow dung, poultry litter, night soil, agricultural residues as well as human and industrial waste. These organic materials are decomposed under anaerobic conditions, i.e. under closed conditions "without air" to produce a very useful fuel called biogas in the biogas digesters (Nes, Boers & Islam, 2005).

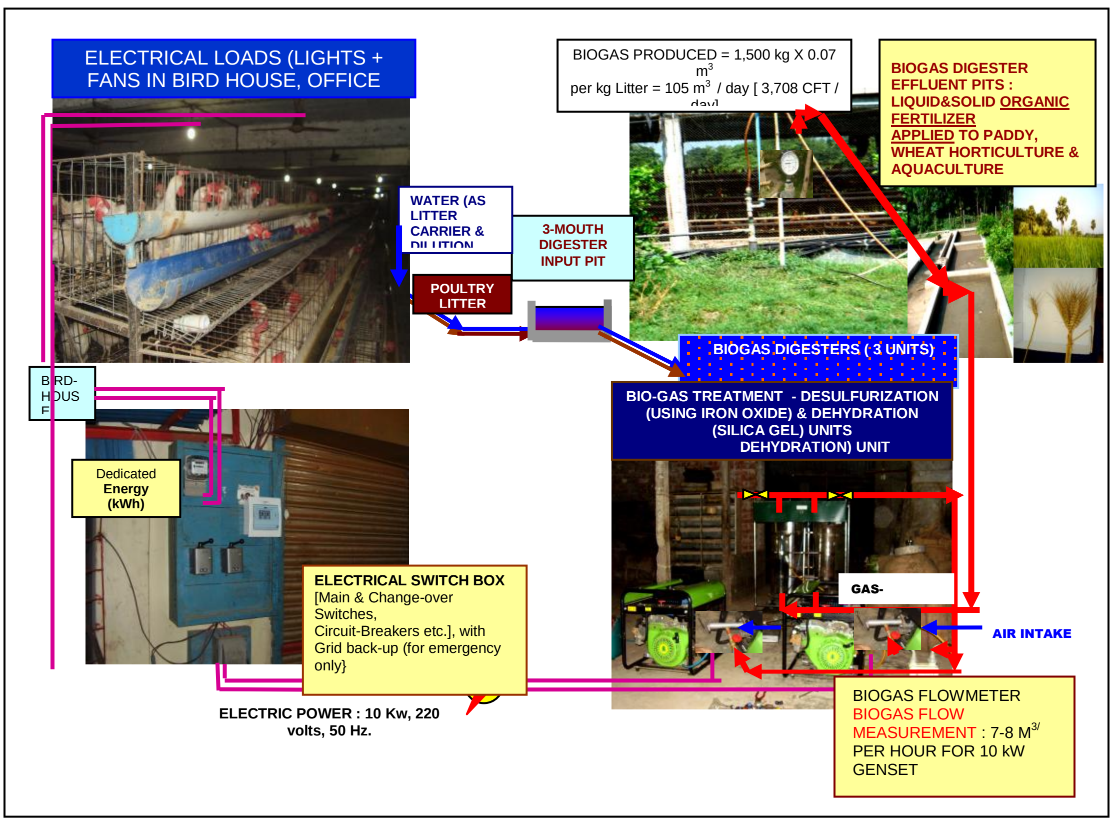
Biogas is a combustible gas, typically comprising of about sixty percent methane and forty percent carbon dioxide. Its production is caused by anaerobic bacteria which breaks down the complex carbon and hydrocarbon molecules of organic wastes or substances into the simplest member of the hydrocarbon family, methane, which is also the major constituent of natural gas (Chynoweth et al, 2001). The major difference between biogas and natural gas is that biogas consists of a large proportion of carbon dioxide along with methane, while natural gas consists of about ninety to ninety four percent methane. Apart from this, biogas, being a waste-to-energy intervention, is a renewable energy source or a "green technology" with multiple advantages.

Biogas is often termed as a win-win renewable technology because by using only one inexpensive input, i.e waste, it produces three very useful outputs. The first output is combustible fuel for cooking and heating, the second is electric power produced using internal combustion engines and small turbine generators and the third and the most useful output is organic fertilizer for use in agriculture. The latter is produced from bio-slurry, which is the nitrogen-phosphorous-potassium rich effluent that flows out of biogas digesters during the production of biogas. Bio-slurry, both in its liquid and solid/dried state has been proven to be an excellent organic fertilizer and soil conditioner which prevents the loss of important soil nutrients caused by the excessive use of chemical fertilizers (Sasse, 1988).

A biogas plant consists of biogas digesters, gasholders, a hydrogen sulfide removal unit and a moisture removal unit.. Figure 11 below shows a schematic diagram for the production of biogas from poultry litter. Water is added to poultry litter and the resulting slurry is directly fed into the inlet chamber of the biogas plant. The slurry is converted into biogas inside the digester.

Figure 11

Production of Biogas and Electricity from Poultry Litter



Source: Pictures taken and arranged by author based on field visit to Raj poultry, a commercial biogas project of the GTZ, Dhaka.

The newly produced biogas then travels through a PVC flexible pipe into a hydrogen sulfide removal unit where the hydrogen sulfur content in the biogas is reduced to an acceptable limit. Then, the biogas passes through a water trap and a small moisture filter unit which removes the water content of the biogas. Finally, the gas enters into the generator which converts it into electricity. Bio-slurry produced during the conversion process passes out of the digester into a tube and is collected in an effluent pit for later use in agriculture (Zaman, 2007).

Electricity is usually generated with a mixture of thirty percent of diesel and seventy per cent of biogas. However, this is not cost-effective due to the high price of diesel (Zaman, 2007). In order to overcome this problem, Sustainable Energy Development (SED) team of GTZ, led by Dr. Engr. Khursheedul Islam, developed an innovative system of electricity generation from biogas without the use of diesel. The system uses locally-produced biogas, an air-mixed carburetor and a retrofit to reduce hydrogen sulfide and water (Dialogue with Dr. Khursheedul Islam 2010, Appendix II)

5.2 Biogas potential in Bangladesh

Bangladesh, being an agricultural based economy, has a huge potential for biogas technologies. Livestock and poultry rearing is an integral part of the agricultural system and more than eighty percent of the rural households are engaged in livestock rearing (Islam et al., 2006). There are about 150,000 poultry farms and 25,000 dairy farms in the country and they produce adequate animal waste such as litters and cow-dung to commercially generate biogas (BBS, 2008).

According to the Agriculture Sample Survey 2005 carried out by the Bangladesh Bureau of Statistics, the country has a cattle population of 25 million and a poultry population of 188 million (BBS, 2008). The Institute of Fuel Research and Development (IFRD) has estimated that the total livestock population of the country can produce about 30 billion m^3 biogas which is equivalent to 1.5 million tons kerosene or 3 million tons of coal (Islam et al., 2006). This biogas has the potential of reducing energy deficit by more than 15 percent. Apart from this, it is also possible to get biogas from human excreta. If all the households in the country can be brought under biogas technology, human wastes alone has the potential of producing about 10 billion cubic meter of biogas (Islam et al., 2006).

Bangladesh started its journey in the biogas sector with a small demonstration plant constructed by the Bangladesh Agricultural University in the 1970s. Later, under a government subsidized program to make biogas technology popular, a total number of 18,000 plants were installed up to the 1990s (Dialogue with Islam, 2010 in appendix I). Today, under various programs supported by the Netherlands Development Organization (SNV), German Technical Cooperation

(GTZ), Local Government & Engineering Department (LGED) among others a total of 45,000 biogas plants have been installed in the rural areas of the country. According to IFRD, there is potential of 4 million biogas plants in the country (Islam, 2006). Each of these plants has a capacity of 3-4.9 cubic meter biogas production per day. Majority of them produce biogas from poultry droppings (Dialogue with Islam 2010, appendix I).

About 20 thousand tons of chicken droppings can be obtained from the existing poultry farms in the country every day and these have the potential to produce 75 thousand cubic meter of biogas and about 1000 MWh of electricity per day (Zaman, 2007). This makes about three hours of average daily power production available, besides providing fuel for cooking three meals a day for an average household (based on field observations, 2010)

Until about 2006, biogas was used only for cooking purposes. In 2008, GTZ initiated a pilot project for electricity generation from biogas using hundred percent biogas run internal combustion engine generators under the leadership of Dr. Engr. Khursheedul Islam. Starting from only a 10KW pilot project, the capacity of biogas based power is now greater than 500 kw. Currently, a disseminating program is being promoted by GTZ to reach a capacity of 50 MW in the next five years. This targeted 50 MW power capacity will be generated from only 10 percent of total poultry farms in the country which means that the potential of power generation from poultry in the country is immense (Dialogue with Islam 2009, Appendix I).

5.3. Cost-Benefit Analysis

I have based my cost-benefit analysis of biogas technology on data collected during a field trip to a typical domestic biogas plant installed by GTZ in partnership with GTZ in Gazipur district. Most small domestic biogas plants in the rural areas are constructed on backyard poultry farms consisting of 400 to 1000 hens on average which produce around 45 kg litter/day. They consist of a biogas digester, gas holder, moisture unit and a retrofit and have a capacity 3 cubic meters per day

The cost of constructing a typical domestic biogas plant is BDT 30,000, i.e. is USD 428.6. However, in order to promote the dissemination of biogas technology, the Government of Bangladesh provides a subsidy of Tk 7000 (USD 100) as an incentive to all biogas users. So, in essence, rural households have to pay BDT 23,000 or USD 328.6 instead of Tk 30,000 for the biogas plant. The payment scheme of biogas is the same as Grameen Shakti's micro-credit based scheme. The households are required to pay a down payment of 15 percent, i.e. BDT 3450 or USD 49.3. The remaining balance of BDT 19,550 or USD 279.3 is loaned out to the users by Grameen Shakti at a service charge of 12 percent. Interest payments amounted to BDT 7038 ([12% of BDT 19,550] X 3) or USD 100.5 over a repayment period of three years and total debt payment amounts to about BDT 26,588 (BDT 19,550 + BDT 70389), i.e. USD 379.8. The rural households are required to pay this amount over a period of 3 years in 36 equal monthly installments, each amounting to US BDT 739 (BDT 26,588/ 36) or USD 10.6.

Biogas plants, once constructed have a long life of 25 to thirty years and require no repairing. It only has an annual operation cost. However, unlike the high initial cost of installation, the operational cost of biogas plants stands at around BDT 1,200 (USD 70) per year or BDT 100 (USD 1.4) per month only. This cost is extremely low compared to the cost of fuel wood. An average household spends BDT 780 (USD 11.1) per month on fuel wood for cooking. By using biogas for cooking they are able to save BDT 9360 (USD 133.7) every year, enjoying a net benefit of BDT 680 (USD 9.7) or BDT 8160 (USD 116.6) per year per month (BDT 780-BDT 100). Their net benefit represents as much 27 percent of the initial investment cost of BDT 30,000. The monetary costs and savings associated with a typical domestic biogas plant are summarized in table 4 below.

Table 4.

Capacity and Financing Scheme of a Typical Biogas Plant in Bangladesh

CAPACITY	3 cubic meter of biogas
INPUT	42.8 kg litter/day (from 430 Hens of Backyard Poultry)
FINANCING SCHEME	
o Total Cost of a Domestic Biogas Plant	Tk 30,000 (US $428.6)
o Less Government Subsidy	Tk 7,000 (US $100)
o Balance Remaining	**Tk 23,000 (US $328.6**)
o Down Payment @ 15% of Investment	Tk 3,450 (US $49.3)
o Balance remaining to be paid (after down payment)	Tk 19,550 (US $279.3)
o Add 12% service charge on micro-credit capital borrowed for 3 years (i.e. [12% of 19,550] X 3)	Tk 7,038 (US $100.5)
o Total debt payment (service payment + principal amount)	**Tk 26,588 (US $379.8)**
o 36 monthly installments	**Tk 739 (US $ 10.6)**
NET BENEFIT	
o Operational cost of biogas plant	BDT 1200/yr (USD 17.1)
o Cost of fuelwood	BDT 9360/yr (USD 133.7)
o Savings on fuelwood	BDT 9360/yr (USD 133.7)
o Net benefit (savings-cost)	BDT 9360- BDT 1200 **= BDT 8160**

In order to find out whether the installation of domestic biogas plants is a viable option for rural households, I used the financial internal rate of return (FIRR) and payback period methods. The first FIRR analysis does not include the benefits received from the sale of the organic fertilizer produced or the sale of electricity generated from biogas production. It also does not take into account any subsidy and considers the actual investment cost to check whether biogas plants are financially viable without the sale of fertilizers, electricity and without government subsidy.

Since, biogas involves no periodic replacement or repairing costs, the discount rate was found simply by using the straight pay back period. First of all I divided the initial investment of BDT 30,000 by the net benefit of BDT 8160 to get the straight pay-back period which is 3.67 years. Then, I used the reciprocal of the payback period which is 0.27 or 27% (1/3.67) to find a reasonable range for the discount rate. Based on the result, I decided the range to be between 25 to 30 percent.

I used an iterative process of trial and error to find the discount rate at which the net present value becomes 0. Table 2 in Appendix II shows that at the end of 25 years, the net present value is positive when discount rate of is 25 percent, but becomes negative when discount rate is 28 percent. Therefore, the lower discount rate is 25 per cent, while the higher discount rate is 28 percent. I plugged these values into the FIRR formula indicated at the bottom of table 2 in Appendix II.

The exact internal rate of return was estimated to be 27.41 percent which is much higher than the commercial rate of 6 percent. The payback period was determined by dividing 100 percent by this IRR, i.e. 100/27.41 to get a payback period of 3.64 years. This means that it takes only 3.64 years for the return on the biogas plants to repay the original investment of BDT 30,000. Thus, even without government subsidies and the sale of organic fertilizer, biogas plants are an economically feasible option for providing energy for cooking and lighting in the rural areas.

I carried out a second FIRR analysis incorporating the surplus value added by the sale of the organic fertilizer produced from the biogas digesters. A typical small domestic biogas plant yields 20 kg of fertilizer per day or 7300 kgs every year. The fertilizer is sold in local markets at a cost of BDT 4/kg . Therefore, every year, rural households earn about BDT 29, 000 which is equivalent to USD $414 from the sale of fertilizers. Once, the value of this highly potent organic fertilizer is incorporated into the FIRR analysis, the internal rate of return jumps to 126 percent and the pay back period plummets to 0.79 year. This means with the sale of organic fertilizer, the biogas plants pay for themselves in less than a year. Once the environmental and social benefits accompanying biogas use is incorporated into the analysis, the IRR will be even higher and the pay-back period will be less.

5.4 Environmental and Social Benefits

The use of biogas technology has far-reaching positive health and environmental implications for surrounding areas. This is clearly demonstrated by the commercial biogas plant at Raj poultry farm in Faridpur district, a flagship project of GTZ installed in 2007. The farm is a private-owned farm with about 15,000 layer birds. The biogas plant built in this farm consist of three biogas digesters which produce 90 cubic meter of biogas every day, part of which is used for cooking purposes, while rest is used to generate electricity with two 5 kwh generators (Field visit to Raj poultry, 2010).

First of all, the use of biogas plant technology at Raj poultry generates enough electricity to be able to power the poultry as well as the surrounding region, thus providing the rural poor with access to electricity. Secondly, it provides a clean, environmentally friendly way of cooking without the emission of harmful gases into the atmosphere. This has led to the improvement of the overall health and environment condition of the surrounding area (Field Visit to Raj Poultry 2010).

Thirdly, the organic fertilizer produced as a byproduct of biogas production is used to fertilize the surrounding farm fields and fish ponds, thus increasing the agricultural productivity of the region without the harmful environmental consequences of toxic chemical fertilizers. Finally, the biogas technology has eliminated the hygienic hazards posed by the vast amount of chicken droppings from the poultry. Villagers who were interviewed all agreed that the installation of the biogas plant has significantly reduced the smell of poultry litter in the region. Thus, biogas technology, truly is a win-win option for the impoverished, rural population of Bangladesh.

However, there are certain challenges and barriers associated with the dissemination of biogas technology which need to be overcome in order enjoy the full potential of this renewable energy technology. These are discussed in the following section.

5.5 Challenges and Policy Recommendations

Biogas technology is still relatively new in Bangladesh. As a result, there is a lack of trained masons who can build biogas plants properly, the technical know-how, appropriate equipments as well as the skills and services to maintain them. Apart from this, the construction period of a biogas plant is about twenty to thirty days, which is too long for implementing nation wide large scale disseminations of the technology. This is a major barrier to the fast dissemination of biogas technology.

In order to overcome this constraint, capacity building should be immediately initiated on wider scales, involving the unemployed rural youth to develop. This will not only remove the capacity gap in biogas technology, but will also generate employment and also entrepreneurship in the renewable energy sector in rural areas. Grameen Shakti and several other NGOS have approached the SED program of GTZ for training support (Dialogue with Islam 2010, appendix II).

Another major barrier to the generation of power from poultry is the size of poultry farms. Electricity can be generated from biogas only in farms with a bird population of more than 5000 layer birds. This limits the ability to generate electricity in regions without big enough poultry farms. As a result, biogas is usually used as a fuel for cooking in the rural areas in spite of the fact that power generation from biogas is a great necessity in view of the acute power crisis in the country (Nes et al., 2005).

This problem can be overcome by diversifying the inputs to biogas production. Presently, biogas technology in Bangladesh is limited to only inputs from poultry and dairy farms, i.e poultry litter and cattle dung, whereas in developed nations all kinds of agricultural residues are being used for biogas production. The diversification of inputs will widen the opportunity to use biogas more widely.

Another potential drawback related to biogas technology is that people are not aware of the value of the slurry as organic fertilizer. Development NGOs should collaborate with the government to develop national awareness programs or media campaigns, using television, radio and the print media to educate people about the benefits of using slurry as fertilizer. This will promote “Green Fertilizer” and reduce the use of chemical fertilizers which involve the use of fossil energies and are otherwise environmentally destructive.

CHAPTER 6

CONCLUSION

The main purpose of this thesis was to evaluate the extent to which renewable energy technologies, such as solar and biogas, can extend affordable and reliable energy services to the rural poor in Bangladesh. Interviews and field visits to several of the country's biogas and solar projects have revealed a very promising picture of the potential of renewable energy in the country. Presently, about 450,000 units of solar home systems with a total power generating capacity of 22,000 kw-peak and 45, 000 biogas plants have been installed in the rural areas of Bangladesh. Being highly decentralized, these technologies are providing access to electricity to about two million impoverished and deprived people in the remote rural areas of the country.

Solar home systems have the potential of growing into a million units generating 50 mw-peak of electricity in the near future. In order to evaluate the economic feasibility of solar technology, a private cost-benefit analysis of solar home systems was carried out using the internal rate of return method. Based on data collected during a field visit to one of the typical Grameen Shakti solar programs, it was found that the internal rate of return on solar home systems is around 6.24 percent, which is slightly above the commercial interest rate on solar of 6.00 percent. This means that currently solar home systems are a marginally viable project. However, with the price of solar panel prices falling by five percent every year coupled with escalating kerosene price, the viability of solar home systems as an emerging option of rural electrification is expected to increase.

Biogas plants are gaining rapid popularity in the country and have the potential of growing into 4 million units. By only using one inexpensive input, i.e waste, biogas technology can produce three extremely valuable outputs i.e. clean fuel for cooking and heating, electricity and highly potent organic fertilizers. In order to evaluate the economic feasibility of biogas plants, two private cost-benefit analyses were carried out using the internal rate of return and pay-back period method. The first analysis was carried out without incorporating income received from the sale of the organic fertilizers produced during biogas conversion. It was found that biogas plants have an internal rate of return of about 27.41 percent with a pay-back period of about three and a half years. The second analysis, which incorporated the income generated by the sale of organic fertilizers, yielded an internal rate of return of 125 percent and a payback period of less than one year. This shows that biogas technology is extremely viable for the rural population.

All the cost-benefit analyses were carried out without including the numerous positive social and environmental impacts that solar and biogas technologies have on the lives of the rural people. Instead of being accompanied by the negative externalities, in the form of higher environmental costs and health hazards created by conventional fuels, these technologies have multiplier effects on income, education and health in the rural areas and avert negative environmental effects. Thus, in spite of the high installation costs of solar home systems and biogas plants, when compared to conventional fuel systems, these technologies are more economically viable and environmentally sustainable means of providing energy services to the rural poor.

The Government of Bangladesh has declared a noble vision of providing electricity to all by the year 2020. Although this seems to be quite an ambitious goal, it can be achieved, if the Government provides the right incentives and policies to efficiently harness the vast amount of available renewable resources. Such policies and incentives could play a key role in putting Bangladesh on a clean energy track and providing the long term energy solution for the country.

APPENDIX I

Dialogue With Dr. Engr. Khursheedul Islam

January 15, 2010

Dr. Engr. Khursheedul Islam is the Senior Adviser for the Sustainable Energy for Development (SED) Program of the German Technical Cooperation (GTZ) in Bangladesh. He has led several projects involving the dissemination and promotion of key renewable energy technologies in Bangladesh. Islam has pioneered the application of Solar PV as stand-alone Solar Home Systems (SHS) in Bangladesh. Recently, he has pioneered the method of electric power generation using 100 percent biomass. On January 15, 2010, I had the opportunity of having a personal dialogue regarding with this energy expert regarding the status of renewable energy technologies in Bangladesh. The following is a brief transcription of the dialogue.

Maisha: Why do you think renewable energy has a bright future in Bangladesh?

Islam: About 70 percent of the population in Bangladesh lives in remote, rural areas, where the cost of transmitting fossil fuels or extending the national electricity grid is extremely high. On the other hand, renewable energy sources, such as solar energy from the sun, biomass and wind energy, being locally available, favor decentralized, small-scale energy technologies and enables the country to pursue locally applicable energy strategies, independent of the national network and provide access to energy services to poverty-inflicted off-grid areas. Being situated in a tropical region, Bangladesh receives ample sunshine which makes the application of solar technology appropriate for the country. Apart from this, being an agriculture-based economy, more than eighty percent of the rural households are engaged in livestock rearing, which means that there is enough poultry and dairy waste to produce biogas energy. If these energy sources can be harnessed effectively, the country can achieve its goal of providing electricity to all by 2020.

Maisha: How has Bangladesh's experience with solar technology been so far?

Islam: You will be pleased to know that Bangladesh has become a global model model in the massive and rapid dissemination of Solar Home Systems (SHSs). Till date a total of 450,000 SHSs have been installed in the rural areas, with 20,000 being installed every month. This rapid dissemination is being supported by the innovative micro-credit based financing scheme of the Grammen Bank. Majority of the funds for investment in renewable technologies come from the international development and financial institutions, such as the World bank, United Nations Development Program, United States Agency for International Development and the German Technical Collaboration which are channeling funds to a government owned bank in Bangladesh called Infrastructure Development Company Limited (IDCOL). IDCOL distributes these funds to NGOs such as Grameen Shakti and BRAC and other NGOs which are involved in the dissemination of renewable energy technologies.

Maisha: What about the high initial cost of solar panels? Won't that be a barrier to the dissemination of solar technology in the country?

Islam: Presently, the price of 50 Wp solar panels is around USD 2-2.5 per panel, which is extremely high for a country like Bangladesh where the monthly income of the average rural household is around USD 50 to USD 100. However, the Government of Bangladesh has allocated about USD 30 million for solar projects and has extensively subsidized the cost of such initiatives. Apart from this, some of the NGOs and private renewable energy companies are trying to bring down the cost of these panels by producing components of the solar panel locally. Seven companies have already applied for loans to the government to carry out assembly production.

Maisha: What can a 50 Wp solar panel do?

Islam: A 50 Wp solar panel can power four to six low-energy light bulbs or three tube lights, a socket for a black and white television, a fan as well a mobile phone charging unit for four hours daily.

Maisha: Has solar technology been able to penetrate into the urban areas in Bangladesh?

Islam: No, not yet because the national grid is much cheaper than solar home systems in the urban areas. However, it is very important to introduce solar technology to the urban sector because urban areas uses about eighty percent of the country's energy supply, thus putting pressure on the country's energy resources and depriving both the urban and rural poor form their share of energy supply. Renewable energy activists, including myself, have suggested that real-estate builders should install solar panels in the rooftops of every apartment they build and include the cost in the apartment rents just as they do for diesel generator. Then, the feed-in tariffs system can be used to increase the capacity of the national grid, thus benefitting both the urban and the rural poor.

Maisha: What are feed-in tariffs?

Islam: Feed-in tariff (FIT) is a metering system through which excess photovoltaic electricity produced during off peak period is stored in solar chargers and then sold to the government for use in the national electricity grid. This will help alleviate the load-shedding problem in the country by increasing the reliability and capacity of the national grid. Sixty three countries in the world, including India, have already implementing FITs.

Maisha: When was biogas technology first introduced to Bangladesh?

Islam: In the 1970s, Bangladesh Agricultural University a constructed a small demonstration plant. Later, under a government subsidized program to make biogas technology popular, a total number of 18,000 plants were installed up to the 1990s. Today, under various programs supported by the Netherlands Development Organization (SNV), German Technical Cooperation (GTZ), Local Government & Engineering Department (LGED) among others, a total of 45,000 biogas plants have been installed in the rural areas. Most of these plants are based on poultry litter and each of them has a capacity of 3-4.9 cubic meter biogas production per day.

Maisha: Which renewable energy technology do you think is the most appropriate in the case of Bangladesh?

Islam : At present, the rate of return on the commercial use of biogas is the highest. This is because by using one inexpensive and readily available input, i.e. waste, three very valuable outputs, i.e. clean cooking fuel, electric power and highly potent organic fertilizers re being produced by biogas digesters. The savings on fuel cost resulting from the use of biogas is extremely high amounting to about BDT 10,000 per year. This is a lot for the rural people since their average monthly income range between BDT 5,000 to BDT 10,000 per month.

APPENDIX II

Table 1

Discounted Cash Flow Analysis for a Typical Solar Home System in Bangladesh

PROJECT LIFE	INV. COST(Tk)	Operating Cost/Year	Savings Tk	Net Benef. Tk	NPV r1	NPV-II rII
					6%	7%
0	27,000	0	0	0	-27,000	-27,000
1	-	360	3,864	3,504	3306	3275
2	-	360	3,864	3,504	3119	3061
3	-	360	3,864	3,504	2942	2860
4	SW/Cable	360	3,864	3,504	2775	2673
5	200	360	3,864	3,304	2469	2356
6	Batt. Repl.	360	3,864	3,504	2470	2335
7	12000	360	3,864	-8,496	-5650	-5291
8	400	360	3,864	3,104	1947	1807
9	-	360	3,864	3,504	2198	1906
10	200	360	3,864	3,304	1956	1679.6
11	-	360	3,864	3,504	1957	1664.7
12	-	360	3,864	3,504	1846	1555.8
13	-	360	3,864	3,504	1741	1454.0
14	12,000	360	3,864	-8,496	-3983	-3294.9
15	200	360	3,864	3,304	1,461	1197.5
16	400	360	3,864	3,104	1295	1051.4
17	-	360	3,864	3,504	1379	1109.3
18	-	360	3,864	3,504	1301	1036.7
19	SW/Cable	360	3,864	3,504	1228	913.6
20	200	360	3,864	3,304	1092	853.8
21	12000	360	3,864	-8,496	-2649	-2051.9
22	-	360	3,864	3,504	1031	790.9
23	-	360	3,864	3,504	972	739.2
24	400	360	3,864	3,104	813	611.9
25	2700	-	2700	2700	667	571.9
	Net Present Value (NPV)				**683**	**-2,135**
					DCF 6%	**DCF 7%**
Financial Internal Rate of Return (FIRR)					**r1**	**r2**

FIRR	**6.24%**	**IRR Formula used :**	**r1+(r2-r1)[r1/(r1-r2)]**	**6% + (7-6) x [683 / (683-(-2135)]**
				6.0 + 0.2423 = 6.24% *

Notes: *All calculations have been reviewed by the German Technical Cooperation, GTZ, Dhaka, Bangladesh

Table 2

Discounted Cash Flow Analysis for a Typical Domestic Biogas Plant in Bangladesh

PROJECT LIFE	INVESTN. COST(Tk)	Operating Cost/Year	Savings Tk	Net Benef. Tk	NPV r1	NPV-II rII
					25%	28%
0	30,000	0	0	0	-30,000	-30,000
1	-	1,200	9,360	8,160	6528	6375
2	-	1,200	9,360	8,160	5222	4980
3		1,200	9,360	8,160	4178	3891
4		1,200	9,360	8,160	3342	3040
5		1,200	9,360	8,160	2674	2375
6		1,200	9,360	8,160	2139	1855
7		1,200	9,360	8,160	1711	1450
8		1,200	9,360	8,160	1369	1132
9		1,200	9,360	8,160	1369	885
10		1,200	9,360	8,160	1095	691.2
11		1,200	9,360	8,160	876	540.0
12		1,200	9,360	8,160	701	421.9
13		1,200	9,360	8,160	561	329.6
14		1,200	9,360	8,160	449	257.5
15		1,200	9,360	8,160	359	201.2
16		1,200	9,360	8,160	287	157.2
17		1,200	9,360	8,160	230	122.8
18		1,200	9,360	8,160	184	95.9
19		1,200	9,360	8,160	147	74.9
20		1,200	9,360	8,160	118	58.5
21		1,200	9,360	8,160	94	45.7
22		1,200	9,360	8,160	75	35.7
23		1,200	9,360	8,160	60	27.9
24		1,200	9,360	8,160	48	21.8
25		0	0	0	0	17.0
	Net Present Value (NPV)				**3,816**	**-918**
					DCF 25%	**28%**
Financial Internal Rate of Return (FIRR)					**r1**	**r2**

FIRR	**27.41%**	**IRR Formula used :**	**r1+(r2-r1)[r1/(r1-r2)]**	**25% + (28-25) x [3,816/(3816-(-918) = 27.14 %**

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