Chapter 1

Introduction

1.1 Introduction:

Over the past century, the average global temperature has increased 1.2 to 1.4 degrees Fahrenheit, due to an increase in global greenhouse gas emissions. The burning of coal, petroleum, and natural gas to create electricity, provide heat and power cars, planes and trains, produces carbon dioxide emissions, which increase the planet's greenhouse gas emissions.

In Bangladesh the demand for electricity is considerably increasing. The present demand of energy is increasing day by day due to various reasons such as increasing population, the aspiration for improved living standards and general economic and industrial growth. At present electricity demand growth is about 10% which is expected to be more in coming years. The power demand in Bangladesh is about 7500MW at this moment, whereas the generation ranges only 5000- 6000MW. The installed generation capacity is 6693 MW and derated capacity is 6061 MW. Demand is estimated to exceed 10,000 MW by 2015. Power generation in Bangladesh was almost mono-fuel dependent, i.e. indigenous natural gas considering its apparent huge availability. About 89% of power previously comes from natural gas and the rest is from liquid fuel, coal and hydropower. The present share of renewable energy was only 2.5% [1]. Power generation scenario in Bangladesh is shown below in figure 1.1:
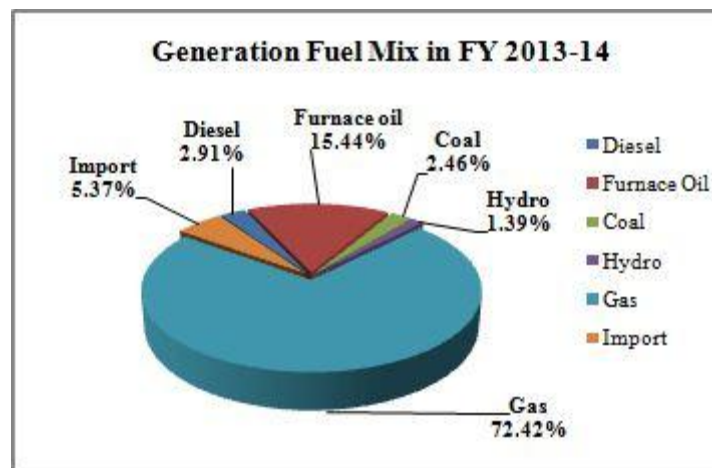

Figure 1.1: Power generation scenario [2]

Development of renewable energy is one of the important strategies adopted as part of Fuel Diversification Program. Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. By using alternative renewable energy sources, we can lower the level of greenhouse gas emissions and make our planet a healthier place. In Bangladesh, according to the plan 15% of total electricity generation will come from renewable and new energy sources. Out of various renewable sources solar, biomass, peat, and hydro-power can be effectively used in Bangladesh.

Renewable energy practices in Bangladesh are:

1. Solar Energy

2. Wind Energy

3. Biomass Energy

4. Hydro-power energy

5. Bio diesel energy [3]

1.2 Objectives of thesis:

Bangladesh is a developing country with only 38% of the population having access to electricity. Bangladesh has made very little progress in its rural electrification efforts in last 20 years. Here industrial and domestic sectors are main consumers of electricity. Only 20% of the total population has access to grid electricity with the vast majority being deprived of conventional supplies. Moreover, rapid urbanization, increasing population and dearth of fossil fuel lead to increasing demand of electricity. Day by day the gap between demand and production is increasing.

In this thesis, an environmental friendly renewable energy source which can be great source of power generation in our country is proposed. The objectives of this thesis are given below:

1. To analyze the potential implementation of hybrid energy system for an off-grid community located in Tongi, Bangladesh.

2. To propose the best hybrid energy combination for satisfying the electricity demand in a reliable way for that off-grid community.

3. To find out the cheapest and most environmental friendly hybrid energy system, a techno-economic feasibility study of the off-grid power system has been carried out using Hybrid Optimization Model for Electric Renewables (HOMER) simulation software.

4. Renewable energy sources considered in this study are: algae fuel, biogas and solar energy. Reasons behind choosing these three renewable energy sources are mainly, their availability throughout the year and easy of production and conversion to energy.

5. For different types of combinations of these renewable sources, the cost of electricity (COE) varies. Since lower COE makes the system more attractive to the user, the desired optimal combination comes with minimum COE.

6. Making the power sector financially viable and able to facilitate economic growth and ensuring reasonable and affordable price for electricity by pursuing least cost options.

7. Improving the reliability and quality of electricity supply for Hybrid renewable power system.

1.3 Outline of thesis:

In this thesis, there are ten chapters. Their outlines are described below:

The first chapter consists of power generation scenario in Bangladesh, objectives of this thesis, methodology of this thesis.

Outline of second chapter consists of solar energy conversion to electrical energy, photovoltaic cells or panels, solar module, string, solar array, photovoltaic panel construction, wiring of solar panel, solar power system connection, solar power system in Bangladesh, definition of clearness index, daily radiation, the declination angle etc.

The third chapter shows fossil fuel scenario in Bangladesh, microalgae, cultivating place of algae, photo bioreactors, algae harvesting, oil extraction from algae, wet extraction process, dry extraction process, synthesis of biodiesel, advantage of algae-fuel over other bio fuel, economic analysis of algae bio fuel production, conversion of electrical energy, properties of algae fuel etc.

The outline of fourth chapter shows the history of biogas plantation in Bangladesh, definition of biogas, composition of biogas, biogas process (hydrolysis, acidogenesis and methanogenesis), parameters for a biogas plant (anaerobic environment, temperature, acidity (pH), carbon/nitrogen (C/N) ratio), biogas plants, raw materials used in Bangladesh to generate biogas, impact of H_2S, impact of CO_2, conversion of electricity, properties of biogas etc.

The outline of fifth chapter consists of HOMER software, simulation, optimization, sensitivity analysis, building the schematic for Hybrid system, load details, component details, resource details etc.

The sixth chapter shows meaning of load, collected data of load, variation of load in every hour of a day, peak demand, off peak time, on peak time etc.

The seventh chapter shows simulation of HOMER software, load simulation, PV system simulation, biogas simulation, algae bio fuel simulation, converter simulation, design of Hybrid energy system etc.

The eighth chapter consists of cost and simulation result analysis of HRES, optimization result, cost summary, electrical energy produced in the HRES, solar power system simulation result, algae bio fuel based power system simulation result, biogas based power system simulation result, simulation result of converter etc.

The outline of ninth chapter consist of sensitivity analysis, definition of sensitivity, two dimensional graph system sensitivity analysis, optimal system type, surface plot, line graph, spider graph etc.

The outline of tenth chapter consists of conclusion of the thesis, limitations and recommendations for future works.

Chapter 2

Solar Energy

2.1 Introduction:

The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year [4]. So solar energy is a more practical type of energy due to its plentiful availability; it is derived directly from the sun. Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available in the world. Incoming solar energy from the sun is shown in figure 2.1 which is given below:
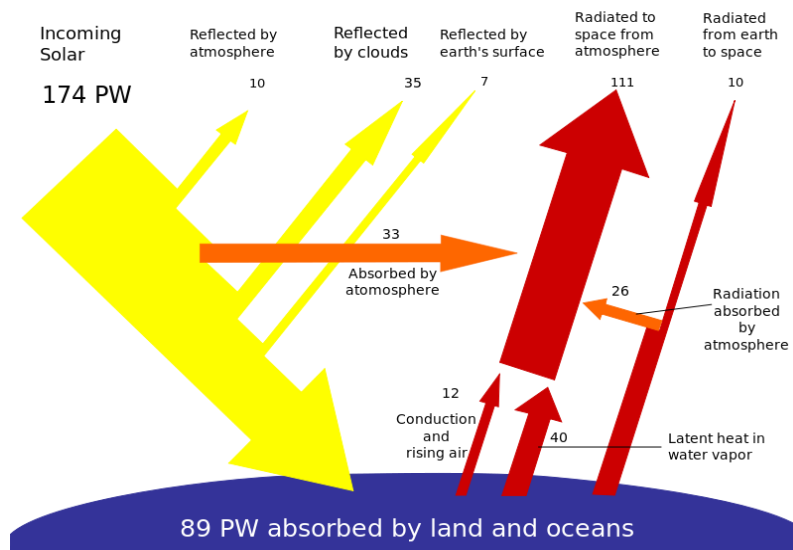

Figure 2.1: Incoming solar energy on earth surface [4]

2.2 Converting Sunlight into Electricity:

A solar cell or photovoltaic cell (PV) is a device that converts light into electric current using the photovoltaic effect. Solar cells produce direct current (DC) power which fluctuates with the sunlight's intensity. For practical use this usually requires conversion to certain desired voltages or alternating current (AC), through the use of inverters [5].

2.3 Photovoltaic cells or panels:

PV cells are made of silicon. In a crystal of pure silicon, the atoms form a lattice. The pure silicon crystal can be "doped" with a different element, i.e. small amounts of an "impurity" are added. If the doping is done with an element that has more electrons in its outer shell than silicon, there will be negatively charged electrons that are free to move around and this is called "n-type" silicon. If instead, the silicon is doped with an element having fewer electrons in its outer shell, there will be an overall shortage of electrons and the material will be p-type silicon.

In a solar cell, there will be both n-type and p-type silicon in contact with each other. Electrons will move across from the n-type to the p-type at their junction as they will be attracted to the nearby holes. Once this has happened at the junction, this area acts a barrier, stopping further electrons moving across and an electric field exists across the junction [6]. Figure 2.2 shows a solar cell.
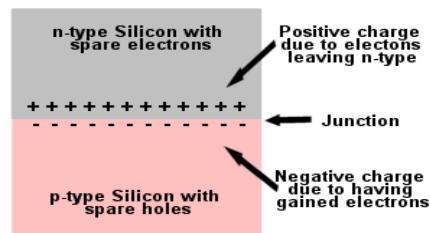

Figure 2.2: p-n junction

If light energy is absorbed by the cell, the energy will push electrons across the junction and if an electrical circuit is made between the two silicon types, the electrons will flow through it, back to where they came from and continue to do so. But we know the flow of electrons (in other words, the electric current) can be made do work on the way round, i.e. charging batteries [6]. Photoelectric effect on PV cell is shown in figure 2.3:
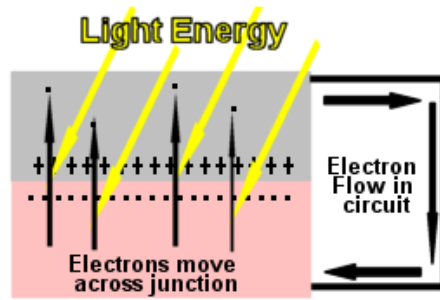
Figure 2.3: Photoelectric effect on PV cell

2.4 Solar panel:

A photovoltaic cell (also called a "solar cell") is the basic building block. A PV module, sometimes called a panel, is a grouping of cells. Historically, modules with 36 cells have been most common, producing 18 to 22 volts for a 12-volt nominal output. More recently, we've seen 24-volt nominal modules for higher voltage systems [7]. Figure 2.4 shows the solar module:
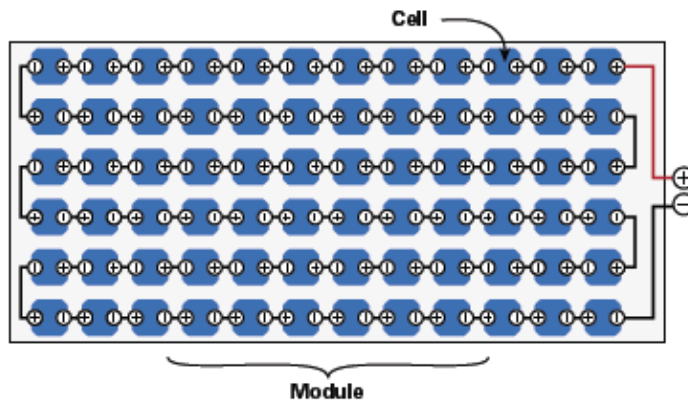

Figure 2.4: Solar cell and module

A string is a grouping of modules wired in series. Basic electrical physics tells us that connecting electrical sources in series increases voltage, which is exactly the goal of a string. Most modern solar-electric systems operate at 48-volts nominal and high-voltage grid-tied systems use up to 600 volts. With 12- and 24-volt modules, this means joining together modules to attain the higher voltage. A series string can then be used on its own or paralleled with other series strings, either to charge batteries or feed the utility grid [7]. Figure 2.5 represents the series string:
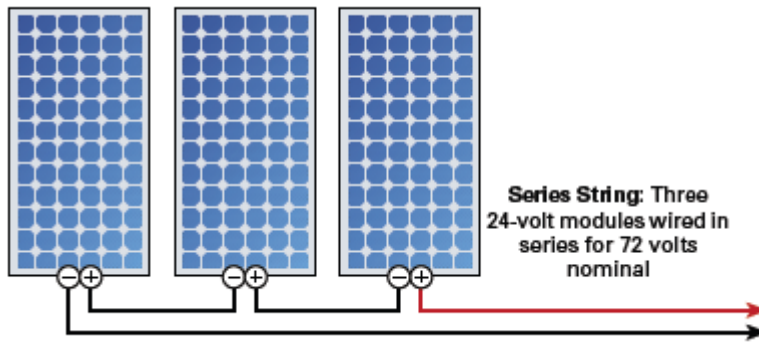
Figure 2.5: Series string

A photovoltaic array (or solar array) is a linked collection of solar panels. The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. The term array describes the whole group of modules in a system. These can be modules in series or parallel, at low or high voltage, on a single rack or multiple racks. Figure 2.6 shows solar array below:
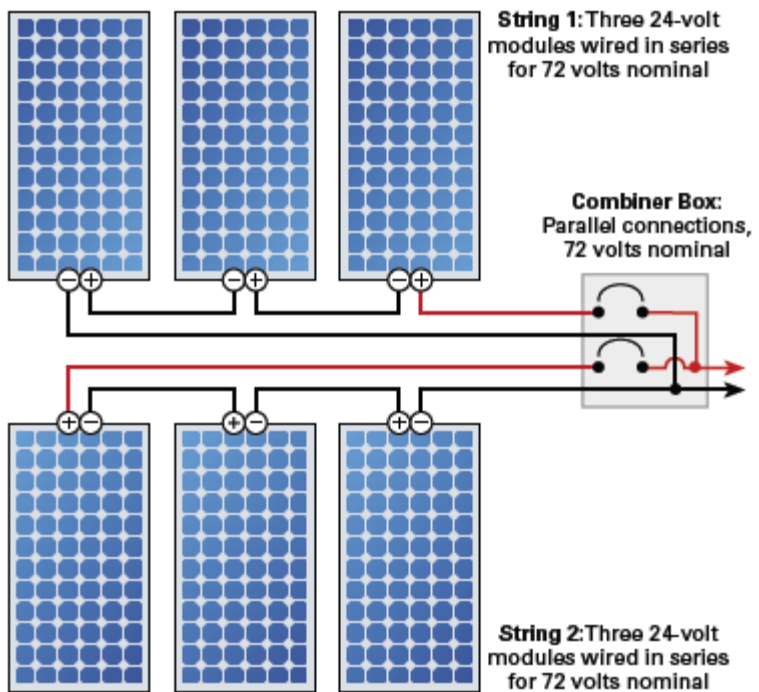

Figure 2.6: Solar array

2.5 Photovoltaic panel construction:

PV cells will sit on a tough backing plate, while the grid of electrical connections lies above and below the cells of the cells. Electrical connecting strips will go from the bottom of one cell to the top of the next, connecting cells in series.

Over this will be a non-reflective layer (Silicon is naturally reflective), to increase light absorption. Finally on top will be a layer of tough glass, and the whole structure is usually within an aluminum frame, sealed against the weather. In figure 2.7, it clearly shows that thin silver conducting strips printed to the upper surface of the cell. Also the main conducting strips which connect to the printed strips, going from the top of one cell to the bottom of the next [8].
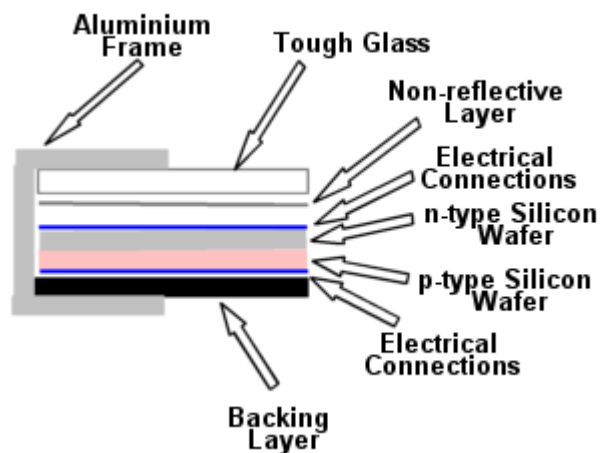
Figure 2.7: Construction of photovoltaic cell

2.6 Wiring of solar panels:

If solar panels are 24 volt, controller and batteries is 24 volt, and then it needs to wire solar panels in parallel. It would be connection all the positive connections together and separately connect all the negatives together [9]. Figure 2.8 represents parallel connection of solar panels:
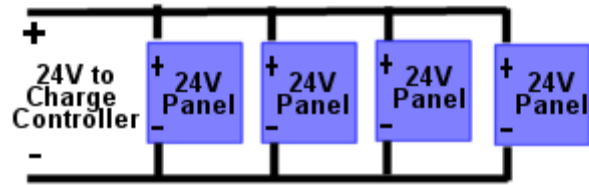
Figure 2.8: Parallel connection of solar panels

We can connect pairs of panels in series, connecting the positive terminal of one panel to the negative of the next, to increase the voltage. The effects of Partial Shading on overall efficiency should be taken into account when considering series wiring [9]. Figure 2.9 represents series connection of solar panels:
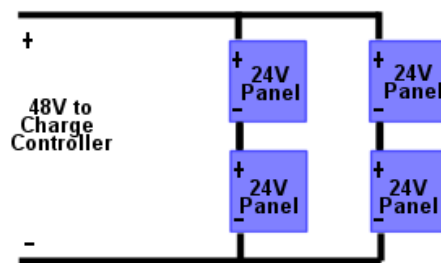

Figure 2.9: Series connection of solar panels

Basic requirements of solar power system are given below:

1. In simplest form, all that is required for a solar power system is a panel to collect the sun's energy and a battery to store that energy.

2. Most panels will include a blocking diode ensuring that the battery does not discharge through the panel when the sun is not shining.

3. A charge controller simply connects between the panel and the battery where it monitors and controls the current flow. Charge controller will stop the current flow from the panel if the battery voltage exceeds a preset level.

4. In many cases however, the power requirement is for a supply that is similar to "mains" electricity i.e., 120 or 230 volts AC (alternating current). So an inverter is needed [10].
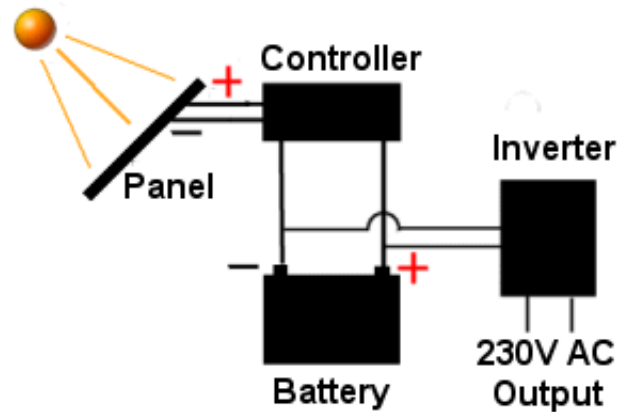

Figure 2.10: Solar power system connection

2.7 Solar power system in Bangladesh:

Bangladesh is at the threshold of a solar revolution. The long-term average Sunshine data indicates that the period of bright Sunshine hours in Bangladesh varies from 3 to 11 hours daily. The global radiation varies from 3.8 these date indicate that there are good prospect for solar thermal and photovoltaic application in Bangladesh [11].

The solar radiation varies from 3.8 kWh/m²/day to 6.4 kWh/m²/day throughout the country. According to these data, Bangladesh has high potential of solar thermal and photovoltaic applications. This immense potential of solar energy provides an opportunity for off-grid rural electrification through utilization of photovoltaic technology. The conventional solar thermal applications are cooking, drying, hot water production and others [12]. The monthly solar radiation in different locations of Bangladesh is given in table 2.1. From the table it is seen that maximum solar radiation is available from March to May whereas minimum solar radiation is available during the month of December and January.

Month	Dhaka	Rajshahi	Sylhet	Bogra	Barisal	Jessore
January	4.03	3.96	4	4.01	4.17	4.25
February	4.78	4.47	4.63	4.69	4.81	4.85
March	5.33	5.88	5.2	5.68	5.3	4.5
April	5.71	6.24	5.24	5.87	5.94	6.23
May	5.71	6.17	5.37	6.02	5.75	6.09
June	4.8	5.25	4.53	5.26	4.39	5.12
July	4.41	4.79	4.14	4.34	4.2	4.81
August	4.82	5.16	4.56	4.84	4.42	4.93
September	4.41	4.96	4.07	4.67	4.48	4.57
October	4.61	4.88	4.61	4.65	4.71	4.68
November	4.27	4.42	4.32	4.35	4.35	4.24
December	3.92	3.82	3.85	3.87	3.95	3.97
Average	4.73	5	4.54	4.85	4.71	4.85

Table 2.1: Monthly Solar Insulation at different locations of Bangladesh (in kWh/m²/day) [12]

Over the past decade, since the Bangladesh government launched a rural electrification programme. Bangladesh has doubled the number of homes with solar-generated electricity systems to 800,000 over the last year. Government, non-government organizations and educational institutions are engaged in dissemination of PV technology in Bangladesh. Some of them who plays major role in dissemination of PV technology in Bangladesh are:

1. Grameen Shakti
2. Infrastructure Development Company Limited (IDCOL)
3. Rahim Afrooz
4. Bangladesh Advancement Committee (BRAC)
5. Rural Electrification Board (REB)
6. Local Government and Engineering Department (LGED)
7. Bangladesh Power Development Board (BPDB)

The daily working activities changed after introducing of solar home systems in the stated study areas. After the solar home system installation, the scenario changed. Nobody was using kerosene pressure lamps and car batteries for lighting and entertainment purposes. Reduction of Kerosene was the main impact of the solar home system that results less pollution, less darkness, less hassle and in addition less work for cleaning kerosene lamps as well. Solar power is harmless for environment and human being.

Solar energy system installation can meet almost half of the electricity demand in Bangladesh which is the urgent need for the country. So, using solar energy is getting importance and day by day, the number of installation is increasing in Bangladesh.

2.8 Solar system in HOMER:

HOMER assumes that all time-dependent data, such as solar radiation data and electric load data are specified not in solar time, but in civil time, also called local standard time. In the solar resource input window we must specify, for each time step, the global horizontal radiation. That is the total amount of solar radiation striking the horizontal surface on the earth. The power output of the PV array depends on the amount of radiation striking the surface of the PV array, which in general is not horizontal.

HOMER simulates on a time step by time step basis, to calculate the extraterrestrial flat radiation, defined as the amount of solar radiation striking a horizontal surface at the top of the atmosphere, HOMER uses the following equation over the time step [13]:

Where,

$$\overline{G}_o = \frac{12}{\pi} G_{on} \left[\cos\phi \cos\delta \left(\sin\omega_2 - \sin\omega_1 \right) + \frac{\pi(\omega_2 - \omega_1)}{180°} \sin\phi \sin\delta \right]$$

$\overline{G}_o$ is the extraterrestrial horizontal radiation averaged over the time step [kW/m^2]

G_{on} is the extraterrestrial normal radiation [kW/m^2]

w_1 is the hour angle at the beginning of the time step [°]

W_2 is the hour angle at the end of the time step [°]

2.8.1 Clearness index:

The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions [14].

The clearness index can be defined on an instantaneous, hourly, or monthly basis. The clearness index values in HOMER's Solar Resource Inputs window are monthly average values. The symbol for the monthly average clearness index is K_t.

2.8.2 Daily Radiation:

Daily solar radiation at a location in a given month is often sufficient for a basic system analysis. This data may be presented either as measured on the horizontal or measured with the measuring surface perpendicular to the solar radiation [15].

2.8.3 The declination angle:

The declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°.

The declination of the sun is the angle between the equator and a line drawn from the centre of the Earth to the centre of the sun [16].

2.9 Conclusion:

There is a vast opportunity for solar as renewable energy in future of Bangladesh. Many private companies and government should take necessary steps to hold up this opportunity. By using HOMER software we can determine PV module cost according to generation ability easily. But some inputs are needed to calculate desired cost optimization for HOMER. Clearness index and daily radiation, size of PV array, operating and maintaining cost are such like inputs for HOMER windows.

Chapter 3

Algae Bio-fuel Energy

3.1 Introduction:

Fuels are such kind of materials that store potential energy in forms that can be practicably released and used as heat energy [17]. Huge sources of energy produced from fuels, to generate steam, electricity and power transportation systems. The most common sources of fuels are oil, natural gas, coal and uranium. Together, oil, natural gas, coal and nuclear energy [18]. World is dependent on fossil fuels for energy. Energy consumption in the last two decades consists of fifty percent of the total energy consumption since the industrial revolution. But these are non-renewable energies & for solving the future energy crisis of the world it is high time to look for alternative sources. Some well-known alternative fuels include biodiesel, bio alcohol, chemically stored electricity, hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil, and other biomass sources [19].

Bangladesh has one of the lowest rates of per capital energy consumption in the world. The country's energy sources are neither adequate nor varied. Non-conventional sources of energy include biomass fuels, agricultural residues, and animal dung. Conventional sources of energy in the country include fossil fuels, such as coal, oil, natural gas and hydropower [20]. Total energy production in Bangladesh using different types of fuel is also shown in table 3.1,

Energy Source	Percentage
Natural Gas	51.7
Biofuels and Waste	29.8
Oil	15.9
Coal/Peat	2.1
Hydro	0.5

Table 3.1: Share of total primary energy supply in Bangladesh

The crisis for energy is more acute in Bangladesh, as there is no petro fuel source but only natural gas, the reserve has also dropped down to an alarming level. Again the global warming is threatening Bangladesh to be climate change victim. So there is no alternative for Bangladesh rather than renewable energy sources. Bio fuel can be a solution of this problem.

Biodiesel refers to a non-petroleum-based diesel fuel consisting of long-chain alkyl esters. Biodiesel is made by chemically reacting lipids, typically vegetable oil or animal fat and alcohol. It is a clean burning renewable fuel made through a chemical process which converts oils and fats of natural origin into fatty acid and methyl esters. Use of this diesel can reduce air pollution at remarkable level. So here our study focuses on generating electrical power from bio fuel of microalgae in Bangladesh [20].

3.2 What are microalgae:

Algae are a diverse group of eukaryotic photosynthetic organisms that constitute over 40,000 species. They can be single-celled (unicellular) or multicellular such as seaweed. Algae can be broadly categorized into two groups: microalgae and macro algae [21]. Microalgae are very small (+/- 1 to 50 im) while macro algae can reach sizes up to 60 m in length. Microalgae have been described as nature's very own power cells and could provide alternatives to petroleum-based fuels without competing with crops [22]. Figure 3.1 shows the microscopic view of microalgae.
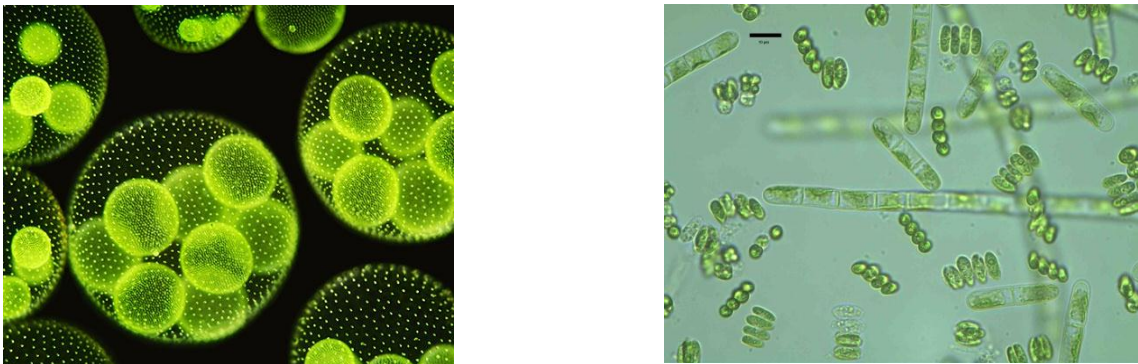

Figure 3.1: Microalgae

3.3 Cultivating place of algae:

Algae are usually found in damp places or bodies of water and thus are common in terrestrial as well as aquatic environments. Like plants, most algae require primarily three components to grow: sunlight, carbon-dioxide and water. Terrestrial algae are usually rather inconspicuous and far more common in moist, tropical regions than dry ones, because algae lack vascular tissues and other adoptions to live on land As mentioned above, algae grow in almost every habitat in every part of the world. They are easy to cultivate and can grow with little or no attention.

Cultivation place of algae are two types. They are:

1. Open Pond

2. Photo bioreactors (PBR)

Open cultivation system uses ponds or lakes with added mechanical equipment to grow microalgae. Open ponds were the first cultivation technology for mass cultivation of microalgae. In this system water levels are kept no less than 15 cm, and algae are cultured under conditions identical to their natural environment. The pond is designed in a raceway structure, as shown in Fig 3.2 in which a paddlewheel circulates and mixes the algal cells and nutrients.

The raceways are typically made from poured concrete or they are simply dug into the earth and lined with a plastic liner to prevent the ground from soaking up the liquid. Baffles in the channel guide the flow around the bends in order to minimize space. The system is often operated in a continuous mode, where the fresh feed (containing nutrients including nitrogen phosphorus and inorganic salts) is added in front of the paddlewheel, and algal broth is harvested behind the paddlewheel after it has circulated through the loop. Although open ponds cost less to build and operate than closed systems using Photo bioreactors, this culture system has its disadvantages [23]. They are:

1. The ponds can be built on any type of land but need large land areas for considerable biomass yield. Because they are in the open air, the water levels are affected from evaporation and rainfall.
2. Natural CO_2 levels in the atmosphere are not enough for continuous mass growth of microalgae.
3. Biomass productivity is also limited by contamination with unwanted algal species, organisms that feed on algae or other poisonous particles. Only few species can be grown in normal conditions.
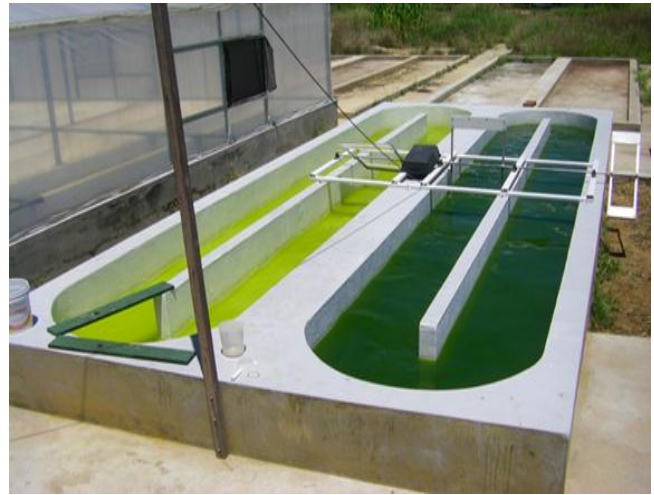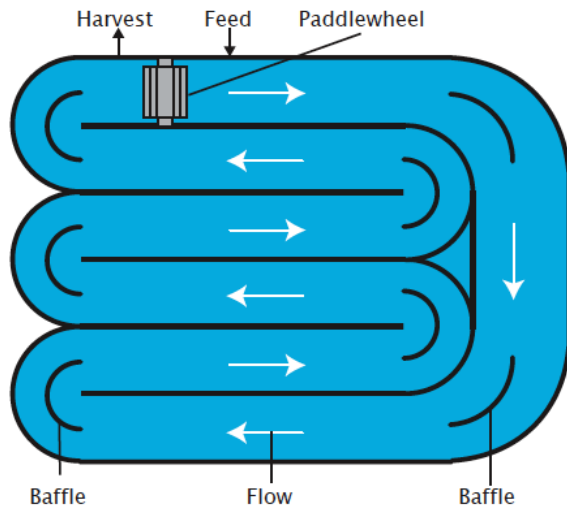
Figure 3.2: Open pond for algae cultivation

3.4 Photo bioreactor:

Photo bioreactor is a closed system which provides a controlled environment and enables high productivity of algae. A PBR system facilitates better control of culture environment such as carbon dioxide supply, makeup water supply, optimal temperature, efficient exposure to light, culture density, pH levels, gas supply rate, mixing regime etc. PBR is used to promote biological growth by controlling environmental parameters including light [24].

The most widely used PBR is a tubular design, which has a number of clear transparent tubes, usually aligned with the sun's rays. The tubes are generally less than 10 centimeters in diameter to maximize sunlight penetration. The medium broth is circulated through a pump to the tubes, where it is exposed to light for photosynthesis, and then back to a reservoir. A portion of the algae is usually harvested after it passes through the solar collection tubes, making continuous algal culture possible. Figure 3.3 shows photo bioreactor system:
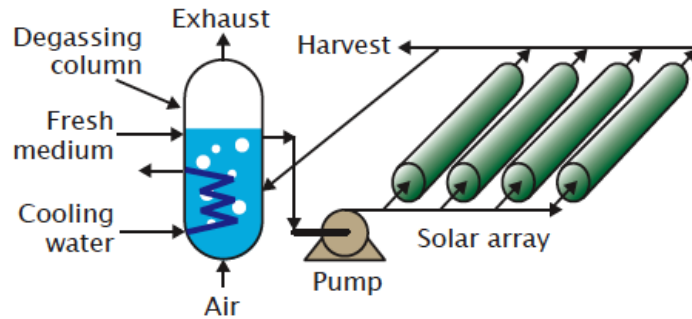
Figure 3.3: Photo bioreactor system

3.5 Harvesting and oil extraction:

Algae harvesting consists of biomass recovery from the culture medium that may contribute 20-30% of the total production cost. Now harvesting includes the removal of heavy water content and extraction of oil from algal biomass. There is no such single method that can be applied for harvesting and removing their water content. To remove large quantities of water and process large scale of algal biomass volumes, a suitable harvesting method may involve one or more steps .In microalgae aquaculture, the conventional processes used to harvest include sedimentation, centrifugation, filtration, ultrasonic separation, ultra-filtration, flocculation, sometimes with a combination of flocculation-floatation.

Oil extraction from algae means to remove the oils or lipids from walls of algae cells. Basically there are two processes named

1. Wet extract processes that focuses on disrupting the algae cells in solution.
2. Dewatering methods which remove the algae from aqueous water solution and then mechanically or chemically disrupt the cells.
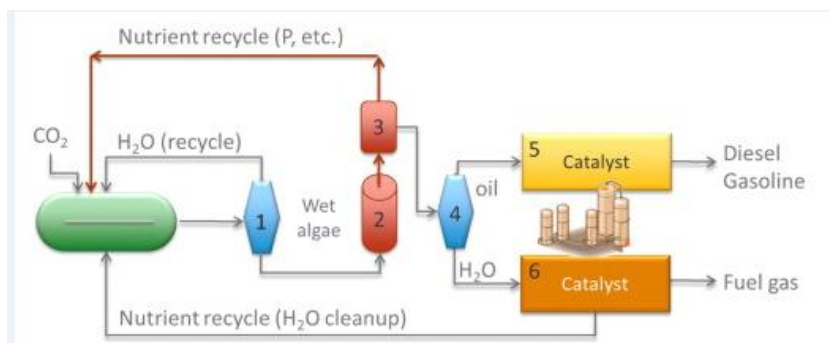

Figure 3.4: Oil extraction

3.6 Wet extraction process:

1. Freezing: The expansion of the water inside the cell as well as the water around the cell will cause the cell walls to rupture from the inside out or be disrupted by the compressive forces. The samples are investigated for three freeze cycles and algae cells began to cluster together [25].
2. Homogenization: To obtain a uniform media, in a mixture the particle size should be reduced. This reducing process is termed as homogenization. Through small valves by expelling mixture at high pressure this process is conveyed and two different tissue grinders of different homogenizing capabilities were tested to test the viability [25, 26].
3. Sonification: To induce cavitation bubbles adjacent to the algae cell wall, ultrasonic waves can be used. These ultrasonic waves can be generated by using ultrasonic reactor. Cell wall will collapse when cavitation bubbles creating a pressure as well as shock and finally contained oil is released [26].

3.7 Dry extraction process:

1. Expeller Method or Mechanical Disruption: Pressing and Bead Milling which is commonly known as mechanical disruption. By this system micro-algal biomass like seeds or nuts are subjecting to high pressure or pressing and it results the breaking of cell walls and finally it release the oil. Bead milling is generally used in conjunction with solvents to recover oil, and is most effective and economical when cell concentrations are significant and when extracted products are easily separated after disruption.
2. Hexane Extraction: Inside the single cell of algae oil is trapped by the plasma membrane (cell wall). But degeneration of plasma membrane occurs when the algae cell becomes dry and it reduces the ability to retain oil. If hexane is mixed with those dried sample, the hexane penetrated through the cell wall and oil within the cell is dissolved. Then the hexane is removed from the algae sample and oil. Dissolving with hexane also transported outside of the cell. By distillation, hexane and oil are separated.
3. This system is more effective when it is used along with "expeller method". After oil has been extracted by expeller method the remaining pulp can be extracted by hexane extraction method and more than 95% oil of algae cells can be extracted by the combination of expeller and hexane extraction method [27].

3.8 Synthesis of Biodiesel:

The method which is used for converting the oil extracted from algae cells to biodiesel is termed as Transesterification also called alcoholysis. It converts the oil into biodiesel in presence of a catalyst. Degummed oil free of all forms of impurities is reacted with a reasonable alcohol (ethanol, methanol, butanol etc.) [28]. The reaction can be represented as:
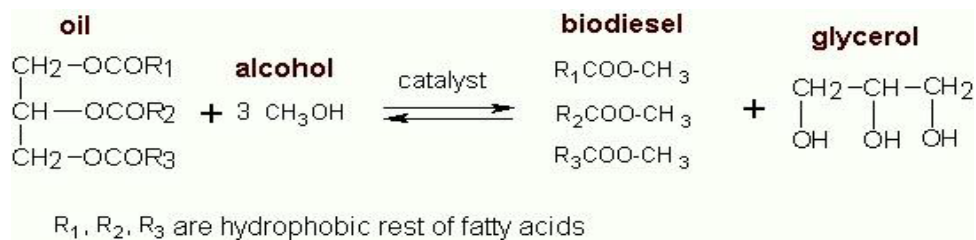
Parameters named Temperature, Reaction time and Ratio of oil to alcohol have effects on the transesterification reaction [29]. Entropy change will tend to zero as both reactants and products of the reaction are liquid. From thermodynamic parameters the feasibility of reaction can be fixed [30].

3.9 Advantage of algae-fuel over other bio-fuel:

1. From a practical point of view microalgae are easy to cultivate and can grow with little or no attention.
2. Algae has a fast growth, and all what they need to grow are water, sunlight and carbon dioxide (CO_2). They have the ability to reproduce themselves using photosynthesis by converting sun energy into chemical energy completing an entire growth cycle every few days.
3. Algal biodiesel's advantage over other bio fuels such as corn biofuel is that it does not compete with food demand, algae grow on marginal land, and it produces more oil per hector area of crop cultivation.

4. Algae can be used for several different types of renewable fuels such as biodiesel, methane, hydrogen, ethanol etc. It contains sulfur and performs as well as petroleum diesel.

5. We know that carbon dioxide is the greenhouse gas mostly responsible for climate change problem that is released in the atmosphere by fossil fuels burning. Some latest studies have shown that the production of each gallon of oil from algae consumes 13 to 14 kilograms of the carbon dioxide.

6. Also algae can be used reduce the environmental impact of algae is to draw municipal wastewater into algae plantations, as a source of nitrogen and phosphorus. This could reduce the amount of fertilizer required.

3.10 Economic analysis of Algae fuel production:

In this report a cost structure and aggregate cost elements are summarized by using accounting terminology to evaluate the production cost, and the potential economic viability of algae in producing fuel instead of producing it from conventional sources.

Cost elements
1. Total capital cost
    a. Cost of base (steel structure)
    b. Cost of bioreactors
    c. Cost of aeration system
    d. Cost for Ball Mill setup
    e. Cost for Soxhlet Extractor
2. Total maintenance cost
    a. Labor cost
    b. Cost of nutrients
    c. Cost of fresh water supply
    d. Cost of electricity
3. Cost of CO2 supply
4. Cost of Harvesting
5. Cost for lipid testing and oil extraction
6. Indirect Costs
    a. Depreciation
    b. Others

The aim is of project is to provide an affordable low cost and low maintenance photo bioreactor system for biodiesel production from microalgae that can be used in rural and sub-urban areas

of Bangladesh. Algae oil can be used as a replacement for the diesel oil needed for irrigation. Cost of production of biodiesel can be minimized. The possible costs that should be taken into consideration are given below in table 3.2:

Name of items	Cost (BDT)
10 L Glass cylinders (5 cylinders, BDT 800 each)	4,000
Frame (Wooden or plastics)	1,500
Ball Mill (2% of BDT 25,000, cost being distributed over a community of producers)	500
Other costs including cost of pH meter, thermometer, nutrient, electricity supply etc. (10% of BDT 10,000, cost being distributed over a community of producers)	1,000
TOTAL	7,000

Table 3.2: Cost analysis for algae biodiesel production [20]

Cost of land, labor, water supply, CO_2 supply has been neglected in the above analysis. Each culture will take approximately 20 days to complete growth if proper maintenance is ensured. Around one or two liters of the algae solution will be left in the cylinder to be used again as a culture for continued algae production. Hence, each cycle of 20 days will give a minimum of 40 liters of algae solution. A total of 15-18 cycles per year would be possible [20].

For assuming 10 years' service life, cost of per liter biodiesel will be around 1000 BDT. Although it is ten times expensive than current diesel price, the cost of production can be significantly reduced with a bigger size photo bioreactor. Jennifer Holmgren, director of the renewable fuels unit of UOP LLC, an energy subsidiary of Honeywell International Inc. stated it is possible to get algae oils down below $2 a gallon [20].

3.11 Conversion of electrical energy:

Diesel generators usually have a controlled fuel supply and are designed to supply regulated AC power directly. Working back from the user demand, we can find out how much power the generator must provide. The actual size of the generator will depend on the intensity of the energy source and the efficiency of the chosen energy conversion system [31].

Algae biofuel is an engine fuel that is created by chemically reacting fatty acids and alcohol. By using IC engine we can convert fuel energy into mechanical energy. A diesel generator can do this work. An electric generator is a device that converts mechanical energy obtained from an external source into electrical energy as the output. It is important to understand that a generator does not actually 'create' electrical energy. It uses the mechanical energy supplied to it to force the movement of electric charges present in the wire of its windings through an external electric circuit. This flow of electric charges constitutes the output electric current supplied by the generator. Figure 3.5 shows the conversion of electricity from algae fuel.
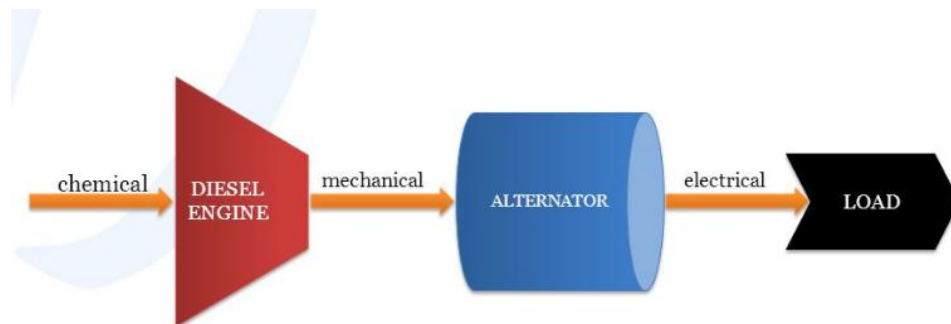
Figure 3.5: Conversion of electricity by diesel generator

3.12 Information for Homer software:

There is no information for algae fuel in HOMER by default in its library. So we have to collect data and create a new fuel profile properties for algae fuel. The following information is necessary:

Lower heating value = 41 MJ/kg

Density = 864 kg/m^3

Sulfur content = 0%

Carbon dioxide = 0.05%

Price of algae bio fuel = 0.52 $/liter

3.13 Conclusion:

The high cost of petroleum products, low coverage of the electricity grid, gasification and increasing scarcity of traditional fuel woods due to deforestation, created an energy deficit situation in rural Bangladesh. Environmental experts predicted massive deforestation if crisis is not being met from alternative source. Gas and electricity coverage cannot expand appreciably as both are in crisis now and need injection of huge capital. Renewable energy sources including biomass, hydropower, solar, wind and tidal energy need to be built up and exploited. But biodiesel and bioethanol are still in their infancy in Bangladesh, although their future is promising. Algae are considered to belong to the third generation of biofuel feedstock in Bangladesh.

Moreover, algae are eco-friendly sources of biodiesel because it reduces the amount of carbon dioxide at environment. The algae growing facilities could be situated around power plants and the carbon dioxide that is being produced routed directly to the algae so that it can grow and produce oxygen. Freshwater shortage can be mitigated by marine micro algal species utilization as they use sea water as a medium. Algal biodiesel can ensure a pollution free and safe environment as well as can meet the demand of fuel in the midst of present crisis of fuel. To keep active and increase the speed of production of industries and save the environment simultaneously, Bangladesh has to take rapid initiative for introducing those eco-friendly technologies in the sector of fuel production.

Chapter 4

Biogas Energy

4.1 Introduction:

By all measures, energy is a key determinant of socio economic development of any country. But the matter of fact is that Bangladesh faces an acute crisis in the energy sector. The population in Bangladesh is increasing along with the increasing demand of energy. The demand is increasing 10% annually. Larger energy supplies and greater efficiency are needed to meet this demand. As the conventional grid-fed electricity can only cover 15 percent of total households, biogas could be the source of alternative energy for the people in Bangladesh. The technology is rather simple and construction materials are available. This gas could be used for any purposes from cooking to household lighting, heating and even to run a television or radio or even running small machines. Moreover biogas could imprint its footstep in sustainable development in the village environment, society and economy.

In 1972, the first biogas plant was installed in Bangladesh at Bangladesh Agricultural University. From then in many other places biogas plants were set on account of research purposes. Attempts to promote biogas plants (including Grameen Shakti) for household use in Bangladesh achieved limited success especially [32].

Electricity generation by biomass gasification can solve the problems of our day-to-day life at a great extent. Even it also serves the purpose of rural electrification which is the crying need of Bangladesh. Besides producing electricity it is beneficial to the agricultural and industrial production. Some small enterprises trying to ensure energy security at countryside using biomass gasification by rice husk. The long-term potential contributions of modern biomass energy carriers in Bangladesh are significant. New policies and programs are needed to address institutional barriers to expanding the use of modernized bioenergy in Bangladesh, and to ensure that biomass is used for energy in environmentally-sensitive ways [32].

4.2 Biogas:

Biogas is actually a mixture of gases, usually carbon dioxide and methane. It is produced by a few kinds of microorganisms, usually when air or oxygen is absent. The absence of oxygen is called anaerobic conditions. Animals that eat a lot of plant material, particularly grazing animals such as cattle, produce large amounts of biogas. The biogas is produced not by the cow or elephant,

but by billions of microorganisms living in its digestive system. Biogas also develops in bogs and at the bottom of lakes, where decaying organic matter builds up under wet and anaerobic conditions. Besides being able to live without oxygen, methane producing microorganisms have another special feature: They are among the very few creatures that can digest cellulose, the main ingredient of plant fibers. Another special feature of these organisms is that they are very sensitive to conditions in their environment, such as temperature, acidity, the amount of water, etc. [33]

Biogas is comprised primarily of Methane and Carbon dioxide. Depending on where it is produced, biogas is also called swamp gas, marsh gas, landfill gas and digester gas.
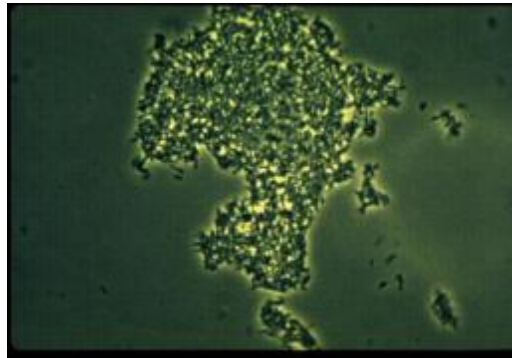
Figure 4.1: A microscope photo of the methane-producing bacteria.

Methane is a colorless and odorless gas with a boiling point of -162°C and it burns with a blue flame. Methane is also the main constituent (77-90%) of natural gas. Chemically, methane belongs to the alkanes and is the simplest possible form of these. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m3. Due to carbon dioxide being somewhat heavier, biogas has a slightly higher density of 1.15 kg/m3. Pure methane has an upper calorific value of 39.8 MJ/m3, which corresponds to 11.06 kWh/ m3. If biogas is mixed with 10-20% air [34]. Composition of biogas is given below in table 4.1:

gas	Percentage
methane	55 − 70

gas	Percentage
Carbon dioxide	30 – 45
Hydrogen sulphide	1 – 2
Hydrogen	1 – 2
Ammonia	1 – 2
Carbon monoxide	Trace
Nitrogen	Trace
Oxygen	Trace

Table 4.1: Composition of biogas.

4.3 Biogas process:

Biogas is produced by putrefactive bacteria, which break down organic material under airless conditions. This process is called "anaerobic digestion" What may be a waste product from some bacteria could be a substrate (or food) for others, and in this way the bacteria are interdependent. The biogas process is often divided into three steps:

1. Hydrolysis
2. acidogenesis and
3. methanogenesis.

4.3.1 Hydrolysis:

During hydrolysis long-chain molecules, such as protein, carbohydrate and fat polymers, are broken down to monomers (small molecules). Different specialized bacteria produce a number of specific enzymes that catalyze the decomposition, and the process is extracellular – i.e., it takes place outside the bacterial cell in the surrounding liquid. Proteins, simple sugars and starch hydrolyze easily under anaerobic conditions [34].

4.3.2 Acidogenesis / Fermentation:

In a balanced bacterial process approximately 50% of the monomers (glucose, xylose, amino acids) and long-chain fatty acids are broken down to acetic acid . Twenty percent is converted to carbon dioxide and hydrogen), while the remaining 30% is broken down into short-chain volatile fatty acids [34].

4.3.3 Methanogenesis:

The last step in the production of methane is undertaken by the so-called methanogenic bacteria or methanogens. Two different groups of bacteria are responsible for the methane production. One group degrades acetic acid to methane and the other produces methane from carbon dioxide and hydrogen. Under stable conditions, around 70% of the methane production comes from the degradation of acetic acid, while the remaining 30% comes from carbon dioxide and hydrogen. The methanogens do not release much energy in the process [34]. Methanogens from decomposition of different sources are given in table 4.2:

Source	Process	Energy yield kJ/mol methane
Hydrogen	$4H_2 + CO_2 = CH_4 + 2H_2O$	131
Formic acid	$4HCOOH = CH_4 + 3CO_2 + 2H_2O$	145
Methanol	$4CH_3OH = 3CH_4 + CO_2 + H_2O$	105
Acetic acid	$CH_3COOH = CH_4 + CO_2$	36

Table 4.2: Energy yield of methanogens from decomposition of different sources

4.4 Parameters for a biogas plant:

4.4.1 Anaerobic environment:

As mentioned earlier, the methanogens need an oxygen-free environment – they are obligately anaerobic. A biogas reactor therefore has to be airtight. The small amount of oxygen dissolved in the liquid/biomass fed to the plant is quickly used up by, for example, aerobic bacteria that must

have oxygen, or by facultative anaerobic bacteria that *can* use oxygen for their respiration, if it is present.

4.4.2 Temperature:

The rate of biochemical processes generally increases with temperature. As a rule of thumb, the rate is doubled for every 10-degree rise in temperature within certain limits. This is also the case with the biogas process. In this situation there are, however, several types or strains of bacteria involved that have adapted to the different temperatures.

psychrophiles 0 – 20°C

mesophiles 15 – 45°C

thermophiles 40 – 65°C

Common to the bacteria is that they are very sensitive to changes in temperature. In practice, biogas plants are run at either a mesophilic level of around 37°C, where fluctuations of approx. ± 2°C are tolerated [34].

4.4.3 Acidity (pH):

Despite the methanogens using organic acids for some of their food intake, they cannot cope in an acidic environment. The optimum environment is a pH of between 6.5 and 8, and the preferred level is 7.2 [34].

4.4.4 Carbon/nitrogen (C/N) ratio:

Just like any other organism, methanogens need a number of macro- and micronutrients in order to grow. The most important macronutrients are nitrogen (N), phosphorus (P) and potassium (K). Nitrogen is used by bacteria to produce proteins. The nitrogen content is often quoted in relation to carbon, as this gives an indication of whether there is sufficient nitrogen available for bacteria. Normally the C/N ratio should be less than 30/1, as nitrogen otherwise becomes the limiting factor for bacterial growth. On the other hand, the nitrogen level should not be too high as this can then also inhibit the process [34].

4.5 Biogas plants:

A distinction is made between batch and continuous plants.

Batch plants are filled completely and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling. Large gasholders or a number of digesters are required for uniform gas supply from batch plants [35].

Continuous plants are filled and emptied regularly -normally daily. Each design is suitable for continuous operation, but the feed material must be flow able and uniform. Continuous plants empty automatically through the overflow. Continuous plants are more suitable for rural households. The necessary work fits better into the daily round. Gas production is constant, and somewhat higher than in batch plants.

Three main types of simple biogas plants can be distinguished:

   a. Balloon plants,
   b. Fixed-dome plants,
   c. Floating-drum plants.

4.6 Raw materials used in Bangladesh to generate Biogas:

Bangladesh is an agro based country where most of the agricultural works are still depends on animal power, mainly cows and buffaloes. In rural Bangladesh, the majority of households raise live stocks. Almost every family in rural Bangladesh has at least a cow or a goat. In 2002 cattle and buffaloes occupied 65% of the total livestock, whereas, sheep and goats were 20% and poultry was 5% [32].

Fuel wood, agricultural residues and animal excreta are used as the raw materials to produce biogas. But these materials are not available everywhere in the country. Cow organs are relatively easy to use and collect. Besides, this material is available throughout the country.

4.7 Impact of H_2S:

In Bangladesh, H_2S presence in biogas from poultry waste was found from 0.30% to 0.8%. However, the tolerable level of H_2S in pipe line quality natural gas is 4 ppm. On combustion, H_2S forms SO_2 which is also toxic and corrosive. Therefore to make the system sustainable and user friendly a H_2S removal system is required in producing electricity from biogas [36].

The biogas containing H_2S, CO_2 and other constituents comes to the H_2S removal unit from biogas plant through a PVC flexible pipe. The Iron Sponge process is used to remove H_2S. The unit consists of two gas tight transparent cylindrical plastic tanks. The gas containing H_2S or the sour gas is passed through a bed of red oxide in the form of steel wool. The red oxide has a high affinity to react with H_2S. The chemical reaction of red oxide with H_2S is given in the following equation.

$$Fe_2O_3 + H_2S = Fe_2S_3 + 3H_2O$$
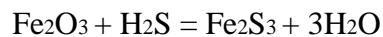
After reaction with H_2S the steel wool becomes black iron sulfide. For continuous regeneration or revivification of steel wool or ferric oxide a small amount of air or oxygen is added to the inlet sour gas stream to oxidize the Fe_2S_3 back to Fe_2O_3 immediately the H_2S is absorbed. The continuous regeneration reaction is given below [36].

$$Fe_2S_3 + 3\ O = Fe_2O_3 + 3S$$
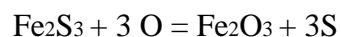
4.8 Impact of CO_2:

In biogas from poultry waste CO_2 presence is about 40%. CO_2 has no heating value and its removal is required to increase the energy intensity of the gas per unit volume. Sometimes CO_2 removal is also required because it forms a complex called CO_2. CO_2which is quite corrosive in presence of water [36].

Hence, for small scale power generation plant CO_2 removal is not mandatory.

4.9 Conversion of electricity:

There are different kinds of technology to convert the chemical energy in the biogas into electricity. In biogas conversion the chemical energy in the molecules is converted to mechanical energy in a controlled combustion system, then, this mechanical energy activates a generator producing electrical power.

Technologically far more challenging is the first stage of the generator set: the combustion engine using the biogas as fuel. In theory, biogas can be used as fuel in nearly all types of combustion engines, such as gas engines (Otto motor), diesel engines, gas turbines and Stirling motors etc.

External combustion engines such as Stirling motors have the advantage of being tolerant of fuel composition and quality. They are, however, relatively expensive and characterized by low efficiency. Their use is therefore limited to a number of very specific applications.

In most commercially run biogas power plants today, internal combustion motors have become the standard technology either as gas or diesel motors [37].
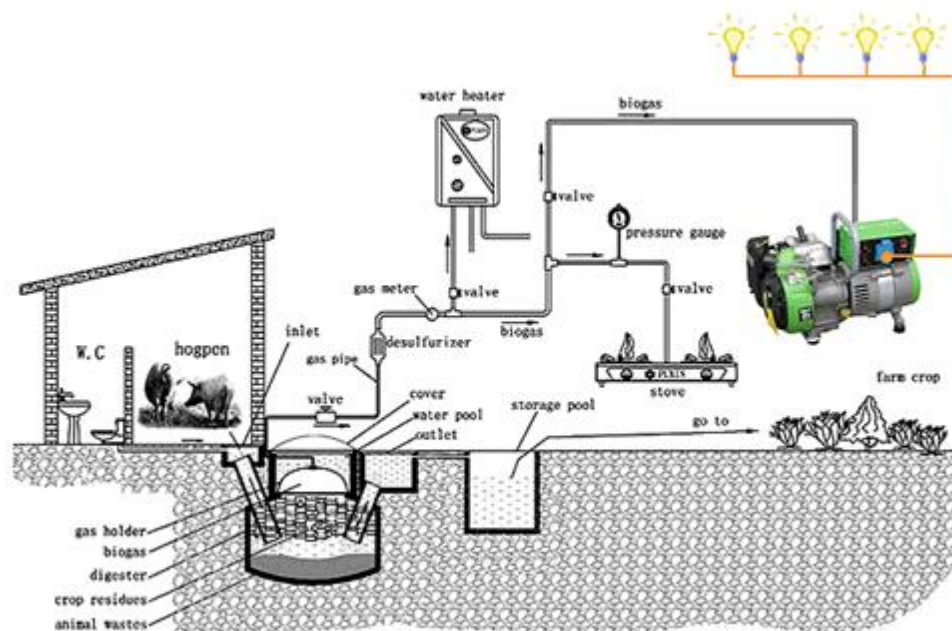
Figure 4.2: Biogas plant used for power generation [37]

For use in gas or diesel engines, the gas must fulfil certain requirements:

1. The methane content should be as high as possible as this is the main combustible part of the gas;
2. The water vapor and CO_2 content should be as low as possible, mainly because they lead to a low calorific value of the gas;

3. The sulphur content in particular, mainly in form of H_2S, must be low, as it is converted to corrosion-causing acids by condensation and combustion.

4.10 Information in Homer:

1. The price of biomass is 1taka per kg. So it is 12.5 $/tone

2. The lower heating value is 20 MJ/kg

3. Density is 0.72 kg/m3

4. The annual average of available biomass is 0.246tonnes/day.

4.11 Conclusion:

Biogas technology is not that simple. A number of issues must be considered when generating gas such as temperature, mount of liquid etc. So technical knowledge is must at the users end. In this regard, Government's support is important. Government should work as a promoter of this technology and information dissemination about biogas. Government can provide small credits and finance villagers to set up plants.

The Government of Bangladesh should carry on further researches in this technology. More research is needed on community based biogas digester so that biogas could become a regular source of energy in Bangladesh. Government must encourage foreign entities to invest in biogas technology to make it an industry. Government should also increase the budget after research purposes in this sector.

Chapter 5

HOMER Software

5.1 Introduction:

For designing and analyzing hybrid power systems ,there are some softwares that we can use by providing a mix of conventional generators, cogeneration, wind turbines, solar photovoltaic, hydropower, batteries, fuel cells, hydropower, biomass and other inputs. HOMER is a computer model that simplifies the task of designing hybrid renewable micro grids, whether remote or attached to a larger grid. HOMER's optimization and sensitivity analysis algorithms allow to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs and energy resource availability.

5.2 Overview:

The HOMER Energy principles have been working with economic and engineering optimization of micro grids for over 2 decades. HOMER Energy's team includes the economist and engineer who originally created the HOMER software while at National Renewable Energy Laboratory (NREL), along with professional managers, analysts and other business professional.

HOMER provides the detailed rigor of chronological simulation and optimization in a model that is relatively simple and easy to use. It's adaptable to a wide variety of projects. For a village or community-scale power system, HOMER can model both the technical and economic factors involved in the project.

5.3 Simulation:

HOMER simulates the operation of a system by making energy balance calculations in each time step of the year. For each time step, HOMER compares the electric and thermal demand in that time step to the energy that the system can supply in that time step and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides in each time step how to operate the generators and whether to charge or discharge the batteries.

HOMER performs these energy balance calculations for each system configuration that we want to consider. It then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the conditions that we specify, and estimates the cost of installing and

operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest.

5.4 Optimization:

After simulating all of the possible system configurations, HOMER displays a list of configurations, sorted by net present cost (sometimes called lifecycle cost), that we can use to compare system design options.

5.5 Sensitivity analysis:

When we define sensitivity variables as inputs, HOMER repeats the optimization process for each sensitivity variable that we specify. For example, if we define wind speed as a sensitivity variable, HOMER will simulate system configurations for the range of wind speeds that we specify.

5.6 How to get started:

5.6.1. Creating a new HOMER file:

When we start HOMER, it looks for the most recently saved file and opens it. If HOMER cannot find the file, it displays a blank window. For this exercise, create a new HOMER file:

a. Click New File, or choose File, from the menu to create a new HOMER file. HOMER displays a blank schematic on the Main Window. Figure 5.1 shows new window for equipment given below:
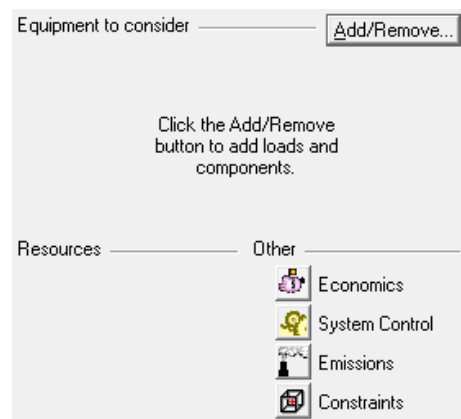
Figure 5.1: New window for equipment

5.6.2. Building the schematic:

The schematic represents all of the technology options that we want HOMER to consider: it is not a schematic of a particular system's configuration. The schematic may include components that are not in the optimal design.

a) Click Add/Remove [Add/Remove...] to choose the components that someone wants HOMER to consider. HOMER displays all of the possible components in the Add/Remove window like figure 5.2.
b) Select the Primary Load 1 check box.
c) Select the PV, Generator 1 and Converter check boxes.
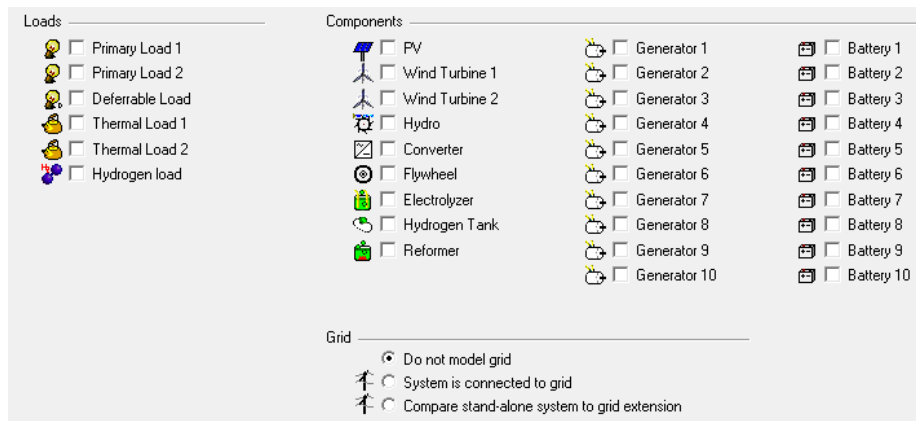
Figure 5.2: Electrical component in HOMER

Now HOMER displays buttons on the schematic that represent the load and components (the PV, Primary load, Generator 1 and Converter).

5.6.3. Entering load details:

The load details are inputs to the HOMER simulations. The load inputs describe the electric demand that the system must serve.

a) Click Primary Load 1 on the schematic to open Load Inputs.
b) Type Remote Load as a label for the load.

c) Choose AC as the load type.
d) Now fill up the daily load data file or import a sample file.

5.6.4. Entering component details:

The component inputs describe technology options, component costs, and the sizes and numbers of each component that HOMER will use for the simulations.

a) Click Generator 1 on the schematic to open the Generator Inputs window.
b) In the Costs table, enter the following values: Size, Capital, Replacement, O&M. Note that O&M stands for operation and maintenance. Generator O&M costs should not include fuel costs, since HOMER calculates fuel costs separately. Window will display like figure 5.3.

Costs			
Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)

Figure 5.3: Cost input window

c) The values in the Sizes to consider table are called optimization variables. The table should look like the one shown below.

Sizes to consider
Size (kW)
0.000

5.6.5. Entering resource details:

The resource inputs describe the availability of solar radiation, wind, hydro, and fuel in each time step of the year. For solar, wind, and hydro resources, we can either import data from a properly formatted file, or use HOMER to synthesize hourly data from average monthly values.

5.6.6. Examining optimization results:

a) Click 'Calculate' to start the simulation. While HOMER is running, the progress indicator shows approximately how much time remains before HOMER finishes the simulation (for this example, approximately one second).

b) When HOMER is finished running the simulations, click the Optimization Results tab and click 'Overall' to view a table of all feasible system configurations.

c) To view a table of sorted system designs, click the Optimization Results tab and click Categorized.

5.7 Conclusion:

HOMER is primarily an economic model. We can use HOMER to compare different combinations of component sizes and quantities and to explore how variations in resource availability and system costs affect the cost of installing and operating different system designs.

Chapter 6

Load Calculation

6.1 What is load:

Residential load is a term which is used to describe the amount of electricity entering a residence at any given time. The amount of electricity a residence can access is typically limited by the amount of its service drop. When homes are constructed or electrical systems are renovated, we must perform a number of calculations to estimate maximum residential load to determine how the system should be laid out, with the goal of preventing electrical problems caused by overloading the system [38].

Residential load calculations determine the amount of service drop appropriate to a residence, the type of wiring which should be used and how circuits should be arranged. The most efficient power generators are used during the highest peak demand times for power, which is based on the information gleaned from the load curve. Engineers use complicated formulas to calculate the loads curves, which in turn determine which method of supplying power is best at a given point in time.

6.2 Collected data of electrical load:

In this thesis, 4 houses in Tongi of Gazipur were randomly selected for residential load calculation. Now the collection of load data is given below in table 6.1 to 6.4:

For house 1:

Appliances	Power (W)	Number of appliances	Operating time (h/d)
Light	10	6	6
fan	150	4	6
TV	40	1	5
computer	120	1	3

Appliances	Power (W)	Number of appliances	Operating time (h/d)
Fridge (300 litre)	350	1	9
others	50	2	2

Table 6.1: load data for house 1

For house 2:

Appliances	Power (W)	Number of appliances	Operating time (h/d)
Light	10(4) , 40(1)	5	6
fan	50	3	7
TV	70	1	4
Fridge (210 litre)	250	1	8
DVD	15	1	3
others	50	2	2

Table 6.2: load data for house 2

For house 3:

Appliances	Power (W)	Number of appliances	Operating time (h/d)
Light	40(2) ,10 (3)	5	6
fan	50	3	6
TV	70	1	4
others	3	40	3

Table 6.3: load data for house 3

For house 4:

Appliances	Power (W)	Number of appliances	Operating time (h/d)
Light	60(3) ,13(3)	6	5
fan	60 , 50	2	4
TV	100	1	3
computer	100	1	3
Fridge (165 litre)	180	1	8
DVD	15	1	0.5
others	30	2	4

Table 6.4: load data for house 4

After collecting all load data, total loads of four houses were calculated according to hour by hour. For example: In 00.00 – 01.00 am,

All fridge are operating in all houses. So load for fridge is (350W+250W+180W) =780 W.

For average number of running fan, calculated load for celling fan is =510 W.

Other appliances are off at 00.00-01.00 am .So the total load is (780W+510W) =1290 W or 1.290 kW.

Similarly we estimated total operating load for 24 hours individually. All our estimation is given below in table 6.5:

Time (h)	Load (kW)
0.00-1.00	1.290
1.00-2.00	1.285
2.00-3.00	0.920

Time (h)	Load (kW)
3.00-4.00	0.510
4.00-5.00	1.473
5.00-6.00	1.460
6.00-7.00	1.290
7.00-8.00	0.309
8.00-9.00	0.310
9.00-10.00	0.313
10.00-11.00	0.535
11.00-12.00	0.428
12.00-13.00	0.350
13.00-14.00	0.550
14.00-15.00	0.657
15.00-16.00	0.642
16.00-17.00	0.79
17.00-18.00	0.93
18.00-19.00	1.746
19.00-20.00	2.135
20.00-21.00	2.410
21.00-22.00	2.120
22.00-23.00	1.160
23.00-24.00	0.670

Table 6.5: Daily load estimation for four houses

6.3 Peak demand:

Peak demand is used to refer to a historically high point in the sales record of a particular product. In terms of energy use, peak demand describes a period of simultaneous, strong consumer demand or a period of highest demand in a billing period [39].

Peak demand, peak load or on-peak are terms used in energy demand management describing a period in which electrical power is expected to be provided for a sustained period at a significantly higher than average supply level. Peak demand fluctuations may occur on daily, monthly, seasonal and yearly cycles. For a utility company, the actual point of peak demand is a single half hour or hourly period which represents the highest point of customer consumption of electricity.

If we draw load (kW) vs. time duration graph from estimated data then it shows us the variation of load with time. Load duration curve is shown in figure 6.1:

Figure 6.1: Load duration curve

In this curve, it shows us that the peak demand hour is 6.00 pm to 10.00 pm. In that time most of the appliances are running. So electricity demand is high of that time. On the other hand,in 7.00 am to 4.00 pm is the off peak time of this load duration curve .

Chapter 7

Simulation by HOMER

7.1 Load simulation:

The HOMER load consists of three components: the primary load, thermal load, and deferrable load. The primary load is the electrical demand that the power system must meet at any specific time. The thermal load is the heat demand that must be served and the deferrable load is the electrical demand that can be served at any time within a certain time span.

In addition to the average energy demand, the HOMER model also requires an hourly load profile to enable an hourly simulation of the operation of the system by making energy balance calculations for each of the 8760 h in a year. We collected a monthly (January) averaged daily load profile for four houses in Tongi of Gazipur. The primary load varies over 24 hour and different months of the year. These monthly averaged 12 sets of load data were input into the HOMER model. Homer creates hourly load values from the scaled-load data based on the monthly averaged daily load profiles. The daily and hourly noise inputs allow randomness to be added to the load data, thereby making the load profile more realistic. We incorporated randomness by applying daily 15% and hourly 10% noise inputs.

All load data has already shown in article 6.2. Now we have to input all data in HOMER software. The procedure is given below:

1. First primary load for load calculation from equipment box were selected.

2. Then we have to choose a load type (AC or DC). AC type load was selected.

3. Then monthly average electrical load value for each hour of the day were entered. HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that we specify in scaled annual average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The average load is reported in kWh/day but the peak load is reported in kW. Figure 7.1 shows us the baseline load input data in HOMER.

Figure 7.1: Load data

4.   Then the "Ok" button was pressed and ran the simulation.

After simulating HOMER gave us some information which were calculated in HOMER. Such as load daily profile:
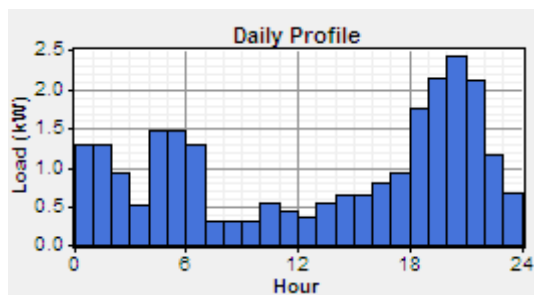
Figure 7.2: Load daily profile

Annual daily profile:
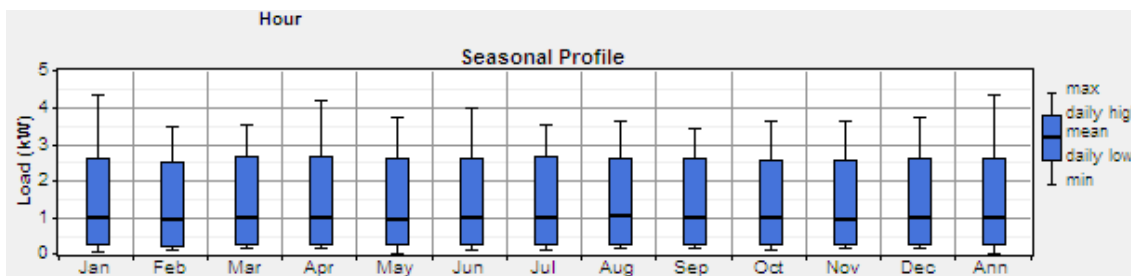
Figure 7.3: Annual daily profile

In annual daily profile (from figure 7.3), it shows us top side of each bar indicates the high daily load in KW and down side of each bar indicates the low daily load in KW.

DMap (data map):

A DMap (data map) is a type of graph showing one year of time series data. With time of day on one axis and day of the year on the other, each time steps of the year is represented by a rectangle which is colored according to the data value for that hour. The DMap format often allows to see daily and seasonal patterns more easily than we could with a simple time series plot. DMap for load data is given in figure 7.4.
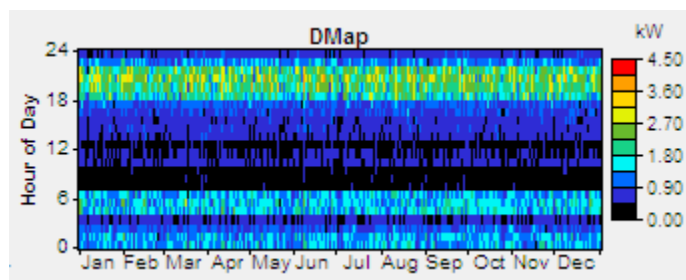
Figure 7.4: DMap for load

In DMap each pixel indicates the load data in KW for one hour. It also shows the average load is 24.3 KWh/d, peak load is 4.34 KW and load factor is 0.233.

7.2 PV System Simulation:

1. First PV module from equipment box are selected.

2. Then the size, capital cost, replacement cost and O&M cost for different PV module were entered. Capital cost is the summation of PV panels, mounting hardware, control system, wiring, installation, battery, charge controller. Cost window for PV is given in figure 7.5.

Figure 7.5: Cost of PV system

3. Then the 'ok' button was pressed and ran the simulation.

Then we have to enter the solar resource input. The latitude and longitude of Tongi are respectively 23°9115' and 90°3889'. After entering the location of Tongi and "enter monthly averages" was selected.

Then the "get data via internet" button was selected. After pressing the button we got data about clearness index and daily radiation of Tongi. The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth.

From the simulation it shows the average clearness index is 0.491 and annual average radiation is 4.51 KW/m2/d. The monthly data is shown in figure 7.6 and 7.7.

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.607	4.174
February	0.580	4.622
March	0.576	5.368
April	0.528	5.516
May	0.489	5.390
June	0.394	4.413
July	0.349	3.861
August	0.384	4.074
September	0.399	3.862
October	0.549	4.579
November	0.596	4.232
December	0.612	3.991
Average:	0.491	4.506

Figure 7.6: Monthly clearness index and daily radiation of Tongi
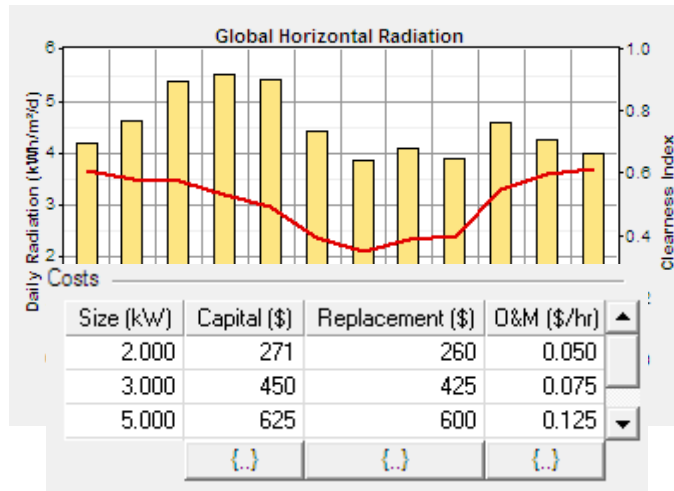
Figure 7.7: Clearness index and daily radiation curve

7.3 Biogas simulation:

- First a generator for biogas was selected from equipment box.
- Then the size, capital cost, replacement cost and O&M cost for different generators were entered. The type of the generator is AC types. Cost window for generator is given in figure 7.8.

Figure 7.8: Cost of generator

- The generator was kept in optimized mode and the time period as all week was selected. Then the fuel as 'biogas' was selected and pressed 'ok' button for simulation.
- Now we have to enter biomass resource input. From our data collection in Tongi, we assumed that there are 15 cows, 5 buffalo, 13 sheeps, 38 chickens, 22 humans in survey residential. The average discharges from those animals and humans are given in table 7.1:

Animal or human(per)	Discharges (kg/day)
cattle	10
buffalo	12
sheep	1
chicken	0.1
human	0.5

Table 7.1: Average discharges per day

From above data we estimated that total biomass is about 237.8 kg/d or 0.2378 tones/d .Hence 1kg=0.001 tone.

The price of biogas is 1taka per kg. So it is 12.5 $/ton and the lower heating value and density are respectively 20 MJ/kg and 0.72 kg/m^3. The annual average of available biomass is 0.246tonnes/day. Monthly average value of available biomass are given below in figure 7.9 and 7.10:

Month	Available Biomass (tonnes/day)
January	0.238
February	0.254
March	0.245
April	0.253
May	0.248
June	0.233
July	0.256
August	0.239
September	0.246
October	0.251
November	0.253
December	0.238
Annual average:	0.246

Figure 7.9: Available biomass for different months
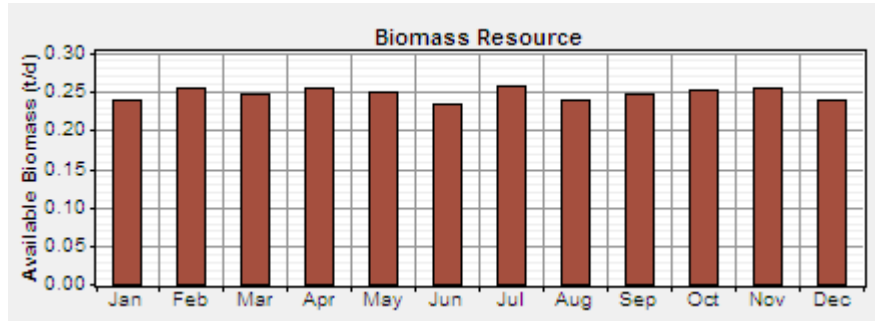
Figure 7.10: Biomass resource

7.4 Algae biofuel simulation:

- First a generator for algae bio fuel was selected from equipment box.
- Then the size, capital cost, replacement cost and O&M cost for different generators were entered. The type of the generator is AC type. Cost window for generator is given in figure 7.11.

Figure 7.11: Cost of generator

- There is no information of algae biofuel in HOMER, but the window allows to specify the properties of a new fuel. The properties are initially copied from the fuel which was selected when the 'New' button is clicked. Change the properties as required and give the new fuel a unique name to distinguish it from others. HOMER will add this new fuel to component library. Figure 7.12 shows the new window for algae fuel.

Figure 7.12: Properties of algae biofuel

It shows us that the lower heating value and density are respectively 41 MJ/kg and 864 kg/m³. We entered slope 0.25 L/h/KW as output. This window shows us efficiency curve. Curve is given below in figure 7.13:
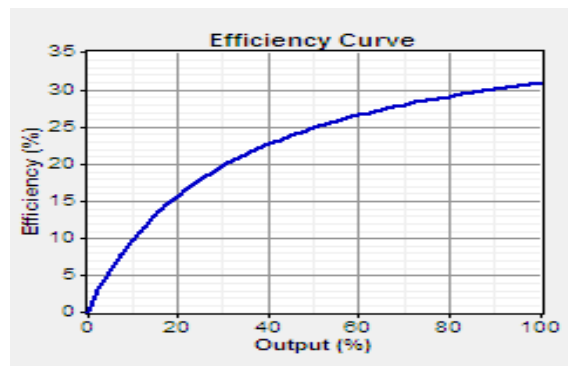
Figure 7.13: Efficiency curve algae biofuel

- The generator was kept in optimized mode and selected the time period as all week. Then we selected the fuel as 'Algae' and press 'ok' button for simulation.
- Now algae fuel per gallon price is $2. So fuel price in per liter is $0.52. In algae windows these values were entered.

7.5 Converter simulation:

A converter is required for systems in which DC components serve an AC load or vice-versa. A converter can be inverter (DC to AC), a rectifier (AC to DC) or both. So when we entered the cost of converter we integrated the cost of both inverter and rectifier.

- First a converter from equipment box was selected. If we do not use a converter between AC and DC bus bar, HOMER gives us error and warns to use converter for conversion of AC to DC or vice-versa.
- Then the size, capital cost, replacement cost and O&M cost for converter were entered. The type of the generator is AC type. Cost window for converter is given in figure 7.14.

Figure 7.14: Cost of converter

- Then 'ok' button was pressed for simulation. Window gave us a cost curve of converter. Curve is given below in figure 7.15:
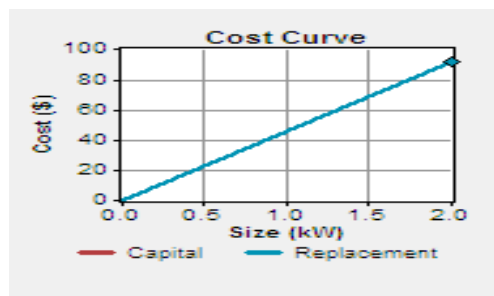
Figure 7.15: Cost curve

7.6 Design of Hybrid Energy System:

After determining properties of each component and calculating the power that they can produce, the system performance should be evaluated to find out how those components work together as a system hour-by-hour. When simulating the operation of the system, HOMER checks to ensure that the system's operating capacity is always sufficient to provide primary load and operating reserve.

After determining and providing all inputs data for load, energy sources and other maintaining equipment HOMER gives us a single line model hybrid energy structure which is shown in figure 7.16:
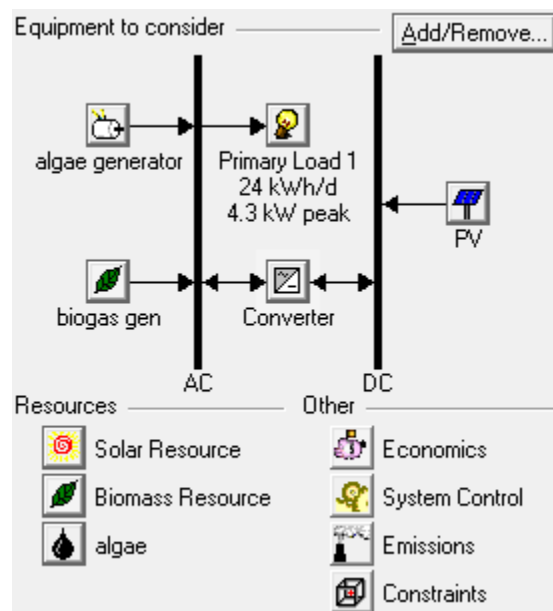
Figure 7.16: Hybrid model for 1.01 kW.

Figure 7.16 depicts the schematic diagram of the designed HRES model for 1.01 kW. The hybrid model for 1.01 kW average load consists of two 2 kW generators, 2 kW photovoltaic arrays. The model is capable to provide 1.01 kW average load and up to 4.3 kW peak load. Here it shows us PV array is connected to DC bus and other two generators are connected to AC bus and primary loads are to AC bus bar. So electrical energy from only AC bus bar is supplied. That's why only inverter operates.

Chapter 8

Cost and Simulation Result Analysis

8.1 Introduction:

In order to design hybrid system, HOMER simulates thousands of possible integrated components, discards infeasible configurations and puts all feasible systems in order based on total net present cost. The next step after simulation is the result analysis which includes optimizations results, economic analysis, emission analysis and grid extension comparison result. HOMER determines technical feasibility of a configuration and estimates the total cost of installing and operating the system over the life time of the project. Since Hybrid system in this thesis is designed in standalone, the NPC, COE, operating cost for only designed power supply were calculated.

8.2 Optimization result:

When the 'calculate' button was pressed, HOMER takes a few moment for calculating and optimizing all given variables. After selecting 'categorized', HOMER shows the optimizing result shown in figure 8.1:

	PV (kW)	algae (kW)	biogs (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	algae (L)	Biomass (t)	algae (hrs)	biogs (hrs)
		2.0	2		$ 891	1,219	$ 16,473	0.145	0.91	392	28	1,185	8,759
	0.04	2.0	2	2	$ 1,165	1,247	$ 17,107	0.151	0.91	392	28	1,185	8,759
			5		$ 625	2,273	$ 29,678	0.262	1.00		68		8,759
	0.04		5	2	$ 899	2,301	$ 30,313	0.267	1.00		68		8,759
		4.2			$ 1,175	4,253	$ 55,541	0.490	0.00	6,112		8,759	
	0.04	4.2		2	$ 1,449	4,281	$ 56,176	0.495	0.00	6,112		8,759	

Figure 8.1: Optimization result of thesis

For categorized types, 6 combinations of hybrid system were found in result. The conventional combination consists of 2KW algae generator and 2KW biogas generator. There is no need of converter, hence there is no PV array system. In this category,

The initial capital cost = 891 $

Total net present cost (NPC) =16.473 $

Operating cost = 1.219 $/y

Cost of energy (COE) =0.145 $/KWh

Consumption of algae bio fuel = 392 Liter/year

Bio feedstock Consumption = 28 t/year

But the hybrid model in this thesis has PV system and converter also besides two generators. So our optimizing result is 2nd combination. In this combination we get the following value:

The initial capital cost = 1165 $

Total net present cost (NPC) = 17.107 $

Operating cost = 1.247 $/y

Cost of energy (COE) =0.151 $/KWh

Consumption of algae bio fuel = 392 Liter/year

Bio feedstock Consumption = 28 t/year

In this combination, it consists of 2KW algae generator, 2KW biogas generator, 0.4 KW PV, 2 KW inverter and 2 KW rectifier.

8.3 Cost summary:

From cost simulation, cash flow summary graph categorized by component was acquired. It shows us also NPC ($) for each component. Figure 8.2 shows the cost summary:
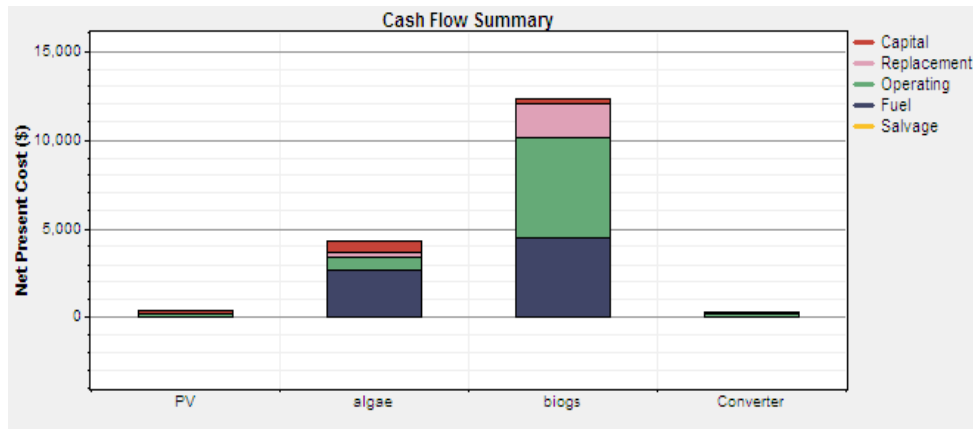
Figure 8.2: Cash flow summary

It also gives us some information as following below (from figure 8.3):

The O&M cost for system = 6,663 $

Fuel cost = 7,101 $

Salvage cost = -65 $

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	182	53	153	0	-30	359
algae generator	620	287	757	2,607	-3	4,268
biogas gen	271	1,865	5,598	4,494	-24	12,204
Converter	92	38	153	0	-7	277
System	1,165	2,243	6,663	7,101	-65	17,107

Figure 8.3: Cash flow of the system

8.4 Electrical energy produced in the HRES:

From the simulation, the production of electrical energy for each component was estimated. Such as:

Total energy produced annually by PV array = 57 KWh/y (1%)

Total energy produced annually by algae bio fuel = 810 KWh/y (8%)

Total energy produced annually by biogas = 8,681 KWh/y (91%)

Total energy produced annually by the HRES = 9549 KWh/y

We also estimated the total energy consumption by load which is 8869 KWh/y.

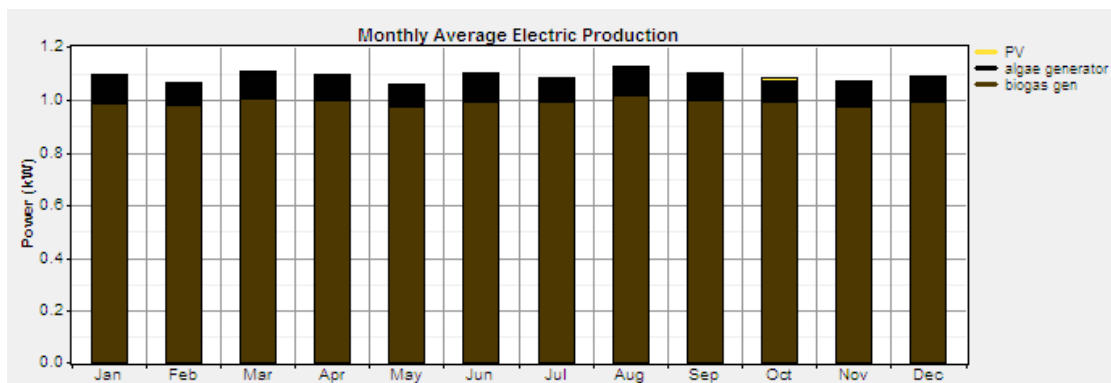Monthly average electric production figure 8.4 is given below:

Figure 8.4: Monthly average electric production

8.5 Solar power system:

From simulation, the maximum output power, minimum output, capacity factor, DMap etc were also estimated.

The nominal capacity of PV array = 0.0400 kW

The mean electrical power output of PV array over a year = 0.01 kW

The capacity factor = 16.4 %

Total electric power output of PV array over a year = 57.4 kWh/yr

The number of hours in the year that PV array produced power = 4,375 hr/yr.
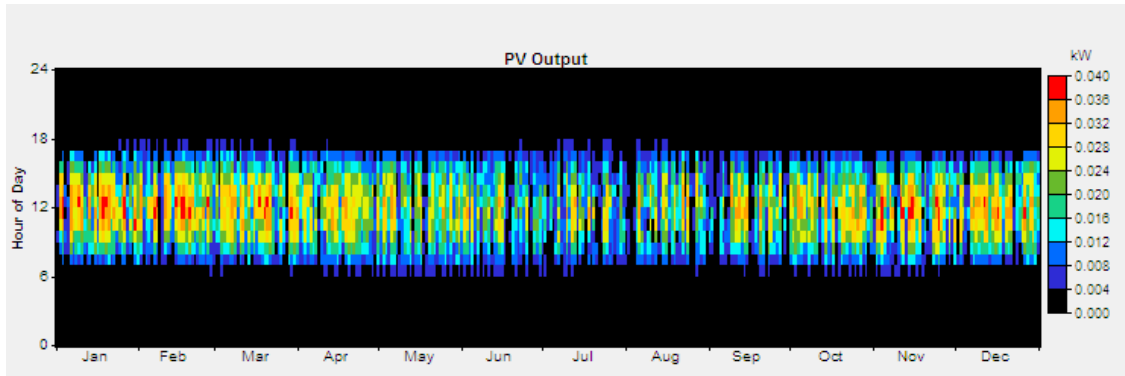
The DMap is given below in figure 8.5:

Figure 8.5: DMap for PV array

DMap indicates that PV array gives more power in January to March and November to December months. It also shows us that PV gives output 6.00 to 18.00 hours in a day most time.

8.6 Algae bio fuel based power system:

From simulation, the operational life of generator, fixed generation cost, marginal generation cost, maximum minimum electrical output, fuel consumption, DMap etc. were estimated. All output data from simulation are shown by figure 8.6 to 8.8:

Generator output properties:

Quantity	Value	Units
Hours of operation	1,185	hr/yr
Number of starts	547	starts/yr
Operational life	12.7	yr
Capacity factor	4.62	%
Fixed generation cost	0.173	$/hr
Marginal generation cost	0.130	$/kWh

Figure 8.6: Algae generator properties

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Electrical power output:

Quantity	Value	Units
Electrical production	810	kWh/yr
Mean electrical output	0.684	kW
Min. electrical output	0.600	kW
Max. electrical output	2.00	kW

Figure 8.7: Electrical power output from algae generator

DMap:

Figure 8.8: DMap for algae generator
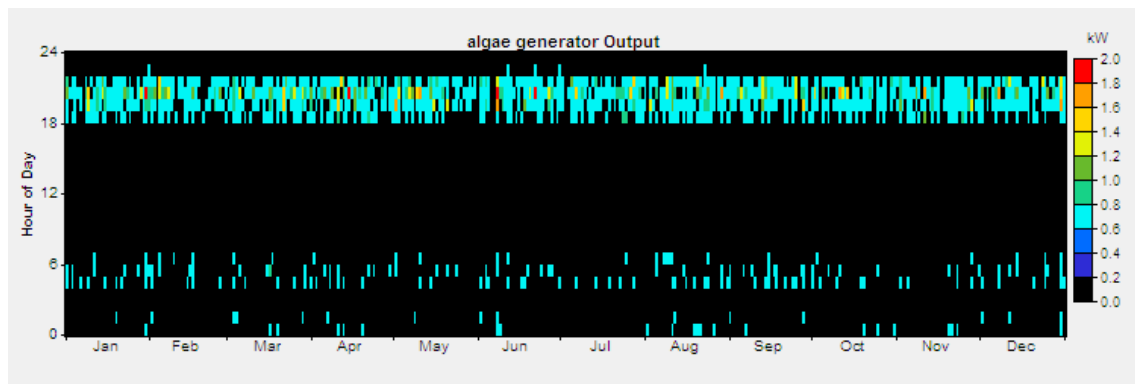
DMap shows us that algae generator is barely working. Most of the operating time is 18.00 to 22.00 hours in a day.

8.7 Biogas based power system:

From simulation, the operational life of generator, fixed generation cost, marginal generation cost, maximum minimum electrical output, fuel consumption, DMap etc. were estimated. All output data from simulation are shown by figure 8.9 to 8.11:

Biogas generator properties:

Quantity	Value	Units
Hours of operation	8,759	hr/yr
Number of starts	2	starts/yr
Operational life	1.71	yr
Capacity factor	49.5	%
Fixed generation cost	0.103	$/hr
Marginal generation cost	0.00446	$/kWh

Figure 8.9: Biogas generator properties

Electrical power output:

Quantity	Value	Units
Electrical production	8,681	kWh/yr
Mean electrical output	0.991	kW
Min. electrical output	0.600	kW
Max. electrical output	2.00	kW

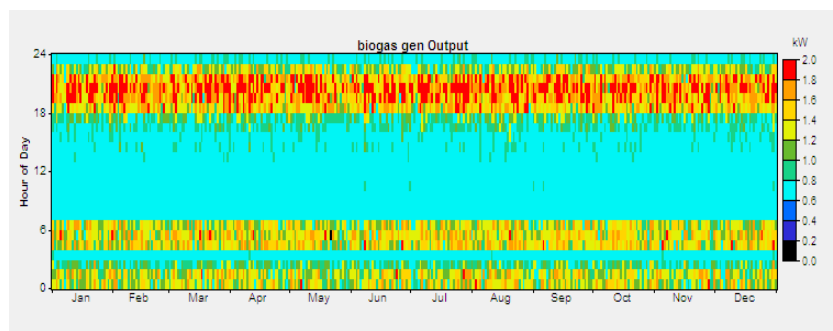Figure 8.10: Electrical power output from biogas generator

DMap :

Figure 8.11: DMap for Biogas generator

DMap shows us that biogs generator is actually operating all time of days in year. But peak demand hours from the generator is 18.00 to 22.00 and off peak hours is 7.00 to 17.00.

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8.8 Simulation result of converter :

From simulation result, capacity ,mean output, maximum and minimum output, capacity factor, operating hours in a year, losses etc of converter(inverter) were estimated. All figures are given below from figure 8.12 to 8.13:

Converter's electrical quantity :

Quantity	Inverter	Rectifier	Units
Capacity	2.00	2.00	kW
Mean output	0.00	0.00	kW
Minimum output	0.00	0.00	kW
Maximum output	0.03	0.00	kW
Capacity factor	0.1	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	1,714	0	hrs/yr
Energy in	14	0	kWh/yr
Energy out	13	0	kWh/yr
Losses	1	0	kWh/yr

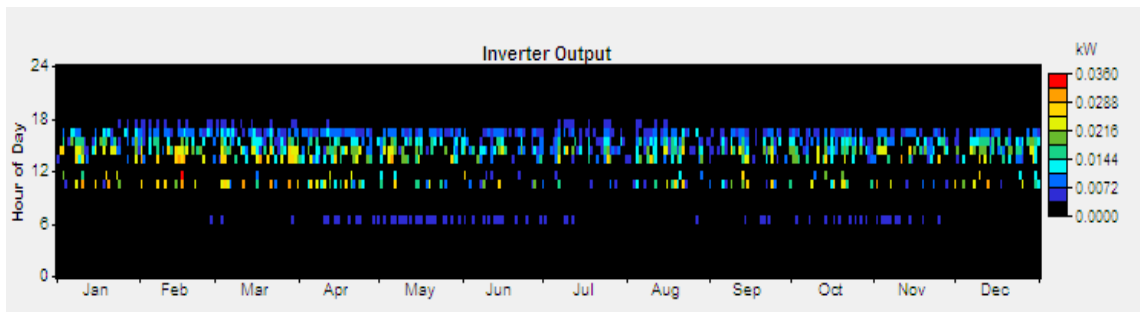Figure 8.12: Power and converter's properties

DMap for Inverter:

Figure 8.13: DMap for Inverter

DMap shows that the main operating time of inverter is 12.00 to 18.00 hours. And inverter's output is around 0.0072 to 0.0144 KW .

Chapter 9

Sensitivity analysis

9.1 What is Sensitivity:

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs. Ideally, uncertainty and sensitivity analysis should be run in tandem [40]. Sensitivity analysis can be useful for a range of purposes, including

1. Testing the robustness of the results of a model or system in the presence of uncertainty.

2. Increased understanding of the relationships between input and output variables in a system or model.

3. Searching for errors in the model (by encountering unexpected relationships between inputs and outputs).

4. Model simplification – fixing model inputs that have no effect on the output, or identifying and removing redundant parts of the model structure.

9.2 Sensitivity in HOMER:

Sensitivity analysis by entering multiple values for a particular input variable can be performed. HOMER repeats its optimization process for each value of that variable and shows how the results are affected. A sensitivity analysis can be referred to as one-dimensional if there is a single sensitivity variable. If there are two sensitivity variables, it is a two-dimensional sensitivity analysis and so on.

In HOMER we can enter different values of capital cost, replacement cost, O&M cost, price of fuel, source availability, environmental factor, operating time etc. to analyze sensitivity to the model of the system. This type of analysis can represent the effects or relationship of different variables.

9.3 Sensitivity analysis of HRES:

In this thesis, sensitivity was analyzed for only biomass and algae fuel prices. For biomass variable prices were entered because of fluctuating of biomass price in market .These values are shown in figure 9.1:

Biomass (Price ($/t))
12.500
11.800
12.000
12.100

Figure 9.1: Sensitivity value for biomass

For algae fuel, variable prices because of fluctuating of algae biofuel price in market were entered. These values are shown in figure 9.2:

algae (($/L))
0.520
0.510
0.528
0.531

Figure 9.2: Sensitivity value for algae bio fuel

After entering all sensitivity value, we ran HOMER for sensitivity calculation. It took a while for simulation.

9.4 Sensitivity results:

In homer software, there are two dimensional graph system. Graphs are four types. They are:

- Optimal system type.
- Surface plot.
- Line graph.
- Spider graph.

In optimal system, biomass price was in X-axis and algae fuel price in Y-axis. For surface plot the assumption remained same. On the other hand for line and spider graph, different values of biogas and algae fuel price can be entered for analysis.

Sensitivity analysis shows many important factor's result from the graph with variation of biomass and algae fuel price. Levelized cost of energy and total net present cost are two very fundamental factor of any HRES. So all the graphs of COE and NPC are given in figure 9.3 to 9.6:
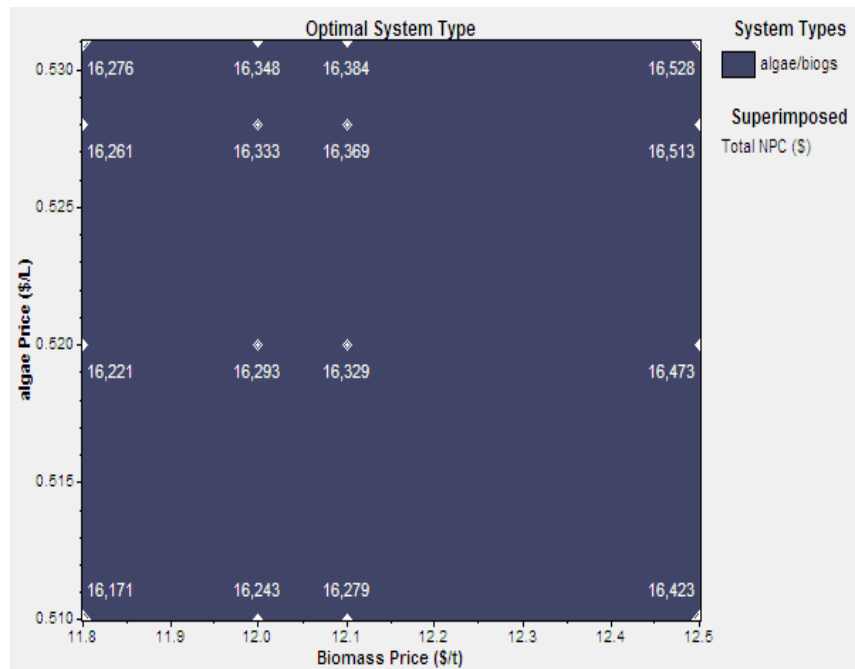

Figure 9.3: Optimal system type

Figure 9.3 shows the different optimum NPC ($) for two dimensional variable. Here two dimensional variable are biomass price and algae fuel price. It is actually a superimposed graph for NPC.
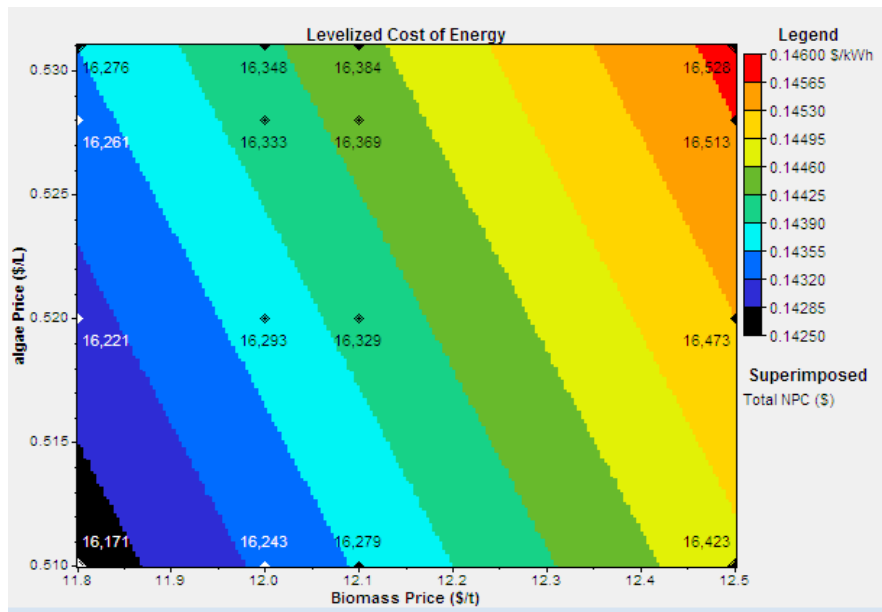
Figure 9.4: Levelized cost of energy (surface plot)

Figure 9.4 shows the different COE ($) for two dimensional variable. Here two dimensional variable are biomass price and algae fuel price. It is actually a superimposed graph for NPC. In this graph different color of spectrum indicates different COE per KWh.

Figure 9.5: COE and NPC plot (line graph)
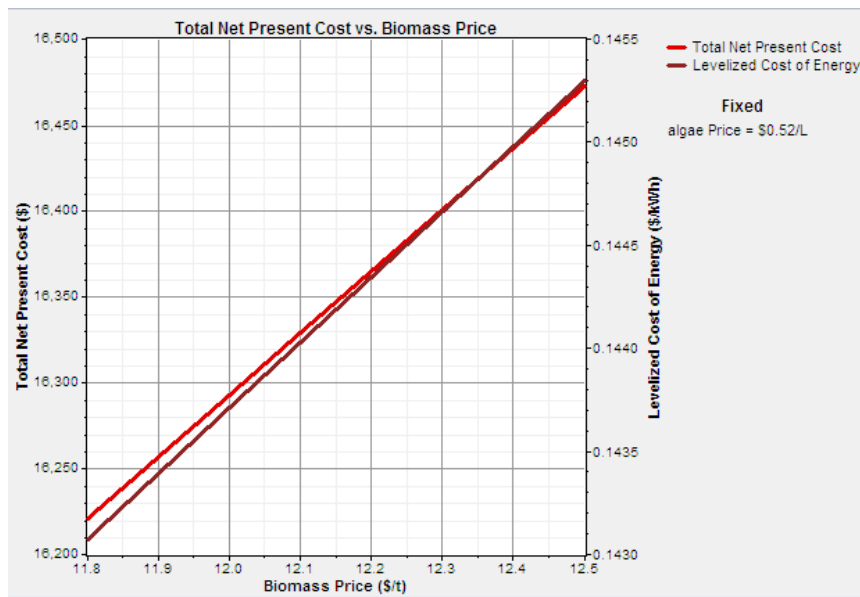
Figure 9.5 shows NPC line and COE line for variation of biomass price. But in here, algae fuel price is fixed ($0.52/liter).
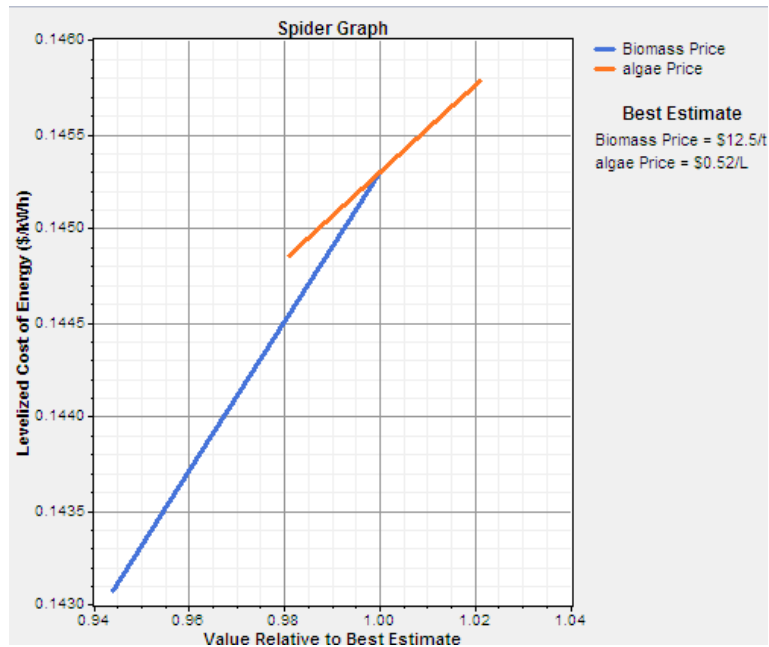
Figure 9.6: Levelized cost of energy (spider graph)

Figure 9.6 shows the spider graph of levelized cost of energy. When COE is $0.145/KWh, the line of biomass price and algae fuel price intersects. So the optimum levelized cost of energy (COE) is $0.145/KWh.

Chapter 10

Conclusion and Recommendation

10.1 Conclusion:

In the modern civilization electricity has become one of a basic need. Severe scarcity of power in Bangladesh has become a threat to the economic development. In rural area, where grid connection is not feasible or grid extension is not available, alternate electric sources like biogas, algae bio fuel and solar PV can be the potential solutions. Though renewable energy system technologies already has existed but only one renewable energy based system cannot supply entire load and also financially less viable.

All the information of this thesis has been collected from the most relevant papers on the design, simulation of the hybrid systems. Homer software was used to determine the cost analysis and hybrid configuration. In this search for a technically feasible and economically viable hybrid solution for off-grid electricity supply to four houses in Tongi were simulated. This study took three off-grid home energy systems, a biogas generator, an algae fuel generator and solar PV system, and compared them along two different criteria:

1. Cost analysis

2. Environment impact

Firstly, the results indicate that the stand-alone hybrid renewable energy system composed of 0.04 kW PV array, a 2 kW biogas generator, a 2 kW algae fuel generator and a 2 kW inverter can supply 24 kWh/d energy consumption with a peak demand of 4.3 kW in this study. The NPC of the system is $17,107, COE is $0.151/KWh, operating cost is $1,247/year during projection period of 25 years.

Secondly, the Hybrid system is totally eco-friendly. The algae cultivation reduces CO_2 in the air. Human, animals, industrial, residential wastes are used in producing biogas. Sunlight is not wasted. So we can say this HRES provides us a fresh environment which does not pollute environment on the contrary.

Renewable energy sources discussed above can help Bangladesh produce more power. With the help of these resources Bangladesh can export electricity meeting the internal demand in the future. Therefore, the Government and the Private sector should work hand in hand to emphasize more on renewable energy source to produce electricity to solve our power crisis problem.

10.2 Recommendation:

There has some future works which can be modified, improved, deeply analyzed in this thesis. There have also some limitations in this thesis. So some future works are recommended in below:

1. In this thesis, HRES is designed in off grid mode. But it can be done in on grid mode also. It can be also designed as backup power system.
2. Algae bio fuel production is very easy in Tongi. But extraction and harvesting is expensive. So price of algae fuel goes high. So further study is required to reduce the price of algae bio fuel and make it available.
3. All technical universities and research institutes should be active in researching of algal biodiesel.
4. Bangladesh may try to acquire technology which may produce food, fuel and chemicals from biomass.
5. Algae can be used in wastewater treatment technology. So industrially production of bio fuel from algae in a large scale is possible.

6. In this thesis, Solar PV is shown as less efficient power system. So improvement of solar energy in a large scale can be implemented in future works.

7. Installation cost may be reduced so that net present cost becomes lower to rural area in Bangladesh.

8. Biomass is available in rural area. But plantation, operating and maintaining cost must be reduced.

9. Environmental factor, risk, variation of natural resources is not considered in this thesis. So those factors can be discussed to get better output and analysis.

10. Cost simulation and modeling a Hybrid system can be also determined by other software like MATLAB, PVSyst, LINDO, PSCAD etc.

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