ASSESSMENT OF POTENTIAL ENVIRONMENTAL BENEFITS OF USING SOLAR POWER FOR IRRIGATION PUMP IN BANGLADESH

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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LIST OF ABBREVIATIONS

A,B,C	Constants derived from measured local data
A D	Activity Data
BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
CdTe	Cadmium Telluride
CIS	Copper Indium Diselenide
DOE	Department of Environment
DSSTW	Deep Set Shallow Tube well
DTW	Deep Tube Well
EF	Emission Factor
EQ	Equivalent Weight
FMTW	Force Mode Tube Well
G	Irradiance
GHG	Green House Gas
H	Head of water
Hp	Horse Power
ICE	Internal Combustion Engine
IDCOL	Infrastructure Development Company Limited
IPCC	International Panel of Climate Change
IREDA	Indian Renewable Energy Development Agency
IRR	Internal Rate of Return
ITN-BUET	International Training Network Centre, BUET
LCL	Lower Control Limit
LLP	Low Lift Pump
MW	Mega Watt
NMIDP	National Minor Irrigation Development Projects
P	Power Generation
PV	Photo Voltaic
Q	Discharge
ROE	Rate of Exchange

STW	Shallow Tube well
TDS	Total Dissolved Solid
UCL	Upper Control Unit
UNDP	United Nations Development Program
USAID	United States Aid
WHO	World Health Organization
Wp	Watt Peak
X	Solar Radiation

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ABSTRACT

Bangladesh, the world's most densely populated nation (1099 persons / km^2 in 2010), having a population of 162.20 million in 2011 requires a constant food security to feed her huge population. During peak irrigation the whole country faces an acute energy crisis due to load shedding of 1248 MW. [3], Due to declined fuel availability and the price volatility caused by demand-supply gap, the attention must be centered towards renewable, readily available and non-polluting source like solar energy which is abundant in Bangladesh due to its geographical location. Bangladesh Energy Policy aims to achieve 5 % Renewable Energy of total energy by 2015 when total power generation will hit 13,000-14,000 MW and 10% Renewable Energy by 2020 when the total power generation will hit 22,000 MW. The average annual high speed diesel cost is 1,256 crore which produces 285,510 metric tons Carbon dioxide as GHG.

Though in practical environment is not given due attention in Bangladesh like advanced countries but gradually awareness is getting increased thinking consequences of the environment's degradation and afterward negative externalities to it. In Bangladesh perspective, not only environment can be given single point emphasis but economical and financial aspects are needed to give emphasis equally before undertaking any new system. CO_2 is considered as the baseline to measure the extent of the environmental degradation due to GHG. Other GHG are converted with equivalent weightage to it . It was observed that 13 millions of tons of carbon –di- oxide are generated (25 % of total generated GHG) due to the burning of the fossil fuel as hydro carbon while used behind irrigation purpose which ultimately placing impact on the climate change and subsequently adverse effect to the environment .

The current study will consider Dhaka-Keranigong area for the solar system based irrigation system, run by BUET. The current study will consider Boro rice which is grown during mid-January to late April. Boro is selected because of its crop-water requirement is high in comparison to wheat (6:1) [7]. During January-April period ground water level goes down, and there is hardly any rain to supplement irrigation. As boro rice is our staple food which captures more than two third of the total irrigated area (3869000 hac / 5602000 hectors). So if this project becomes at least in working level feasible than not only it ensure our food security but will also be applicable for other types crops whose crop-water demand is lesser and if not during boro season than due to Weathered advantage there will be supplement of water due to rain which augments the water supply to irrigation. This research will provide appropriate technological and management tools to the environmentalists and policy makers to formulate strategy of using solar power for irrigation pump in Bangladesh and take

appropriate measures to minimize degradation of environment caused by other conventional method.

At present farmers are getting 5% less cost of irrigation in comparison to conventional method. Individually this method is not recommended for the farmers but on co-operative alliance, this method will be economically and financially viable. Solar pump for short term economically and financially may not be viable but due to its long longevity (more than 20 years) it is well viable. Moreover technology is advancing to increase life span of PV panels and accessories to reduce its cost. In a test run by BUET at Keraniganj indicates that with local technology and accessories the cost can be reduced to a substantial level.

It is certain that fossil fuels are finite and will run out in course of time. Moreover burning of fossil fuel or hydrocarbon causes to emit GHG which is main responsible for climate change in the earth. So this is the right time to adopt renewable, green, sustainable method not only to secure our environment but also to secure our food for our future.

CHAPTER ONE

INTRODUCTION

1.1 General

In Bangladesh adaptation of irrigation techniques is reported to play a vital role in the improvement in the field of food grain. In this regard we need huge number of pumps in rural areas of the country for irrigation in upcoming days. Present pumps are mostly diesel engine operated where electricity from the national grid is not sufficient to maintain them properly. On the other hand, there is a great problem for grid connected irrigation pumps because supply of electricity in Bangladesh is not regular due to deficiency of electrical energy and electricity has not served in every irrigational zones of Bangladesh. Both diesel and grid operated pumps are generating huge amount of GHG which is very detrimental for the existence of our environment. Conventional irrigation system is dependent on fossil fuel or hydro carbon which is finite in nature. This is right juncture to think the alternative, renewable, green energy like solar energy which is abundant in nature. Alternative to the conventional method, solar energy is very suitable sustainable option.

Again in the conventional irrigation method, ground water is lifted and used to supply water directly to the crop fields. In Bangladesh, there are 68,000 villages and, each village has at least 10 irrigation farms. It is roughly estimated that the number of diesel engines in Bangladesh is more than 700,000, among which 200,000 are grid supplied electric pumps which consume 1685 MW electricity while on operation. Every year Bangladesh imports more than 36,26,000 metric ton of oil from other countries[4], which impacts the economy at a great extent [1]. In this situation the solar irrigations pumps will provide farmers access to clean energy and if patronized initially with subsidies through govt. and donor agencies than solar irrigation pump could be one of the most suitable alternatives to the present system. The World Bank has reported in a statement that reliance on costly diesel imports for irrigation puts a pressure on the country's foreign exchange and thirteen hundred solar irrigation pumps will save $3.2 million in foreign currency every year from replacement of diesel and use of clean and renewable energy. It will also contribute to improve farmers' livelihoods, increase climate change resilience of the agriculture sector and strengthen food security. Again, wider use of solar irrigation pumps will help the agriculture sector to reduce dependence on diesel imports. Smooth supply of water for irrigation will help to increase agricultural productivity. The solar irrigation pumps will enable us to save foreign exchange substantially. However, to popularize the solar irrigation pumps, investment in research and innovation is needed to bring down the upfront cost of the pumps.

1.2. Rationale of the Study

Shortage of energy in Bangladeshis is acute [2].20.36 % of total energy generated is utilized for peak irrigation [2].Total generation capacity of energy is 8275 MW which is 86.90 % of total requirement [3].Fossil fuel is the major source of energy in Bangladesh. Contribution of coal based power plant is 2.40 % (200 MW), Diesel and Furnace Oil is 26.13 % (2175 MW) while that of Gas based power generation is 68.83 % (5680 MW) and hydroelectric generation is 2.64 % (220 MW) [2,4].

During peak irrigation the whole country faces an acute energy crisis due to load shedding of 1248 MW [3]. Due to declined fuel availability and the price volatility caused by demand-supply gap, the attention must be centered towards renewable, readily available and non-polluting source like solar energy [5] which is abundant in Bangladesh due to its geographical location. Bangladesh Energy Policy aims to achieve 5 % Renewable Energy of total energy by 2015 when total power generation will hit 13,000-14,000 MW and 10% Renewable Energy by 2020 when the total power generation will hit 22,000 MW[6].

Introduction of solar energy for irrigation is observed in various places of Bangladesh like Tangail, Chapainawabganj, and Naogaon etc. The current study will consider Dhaka-Keranigong area for the solar system based irrigation system, run by BUET. The current study will consider Boro rice which is grown during mid-January to late April. Boro is selected because of its crop-water requirement is high in comparison to wheat (6:1) [7]. During January-April period ground water level goes down, and there is hardly any rain to supplement irrigation. As boro rice is our staple food which captures more than two third of the total irrigated area (3869000 hectors / 5602000 hectors) [4]. So if this project becomes at least in working level feasible than not only it ensure our food security but will also be applicable for other types crops whose crop-water demand is lesser and if not during boro season than due to Weathered advantage there will be supplement of water due to rain which augments the water supply to irrigation. So for food security we need to emphasize on its production. This research will provide appropriate technological and management tools to the environmentalists and policy makers to formulate control strategy of using solar power for irrigation pump in Bangladesh and take appropriate measures to minimize degradation of environment caused by other conventional methods.

1.3 Objectives of the Study

The main objective of the study is:

- To make a feasibility study on the potential environmental benefits of using solar power for irrigation pump in Bangladesh.

1.4 Scope of the Study

This Project paper will focus on the availability of solar energy in different locations of Bangladesh on the basis of daily solar radiation data, Sunshine Hour, comparison of the irrigational pump system on the basis of GHG operational emissions, comparison of the irrigational pump system on the basis of cost and payback period and finding out most suitable energy option for irrigation. Sunshine hour including radiation data of different locations of Bangladesh such as Bogra, Comilla, Dhaka, Dinajpur, Faridpur, Jessore, Khulna, Madaripur, Mymensingh, Rajshahi, Saidpur, Sylhet and Tangail from 2001 to 2010 were collected from Bangladesh Meteorological Department and comparison of the irrigational pump system on the basis of cost and payback period is done by visiting RDA(Rural Development Authority) at Bogra.

1.5 Limitations of the Study

This study might have following limitations:

- Due to non-availability of data on all locations of Bangladesh from BMD (Bangladesh Meteorological Department) study areas have been limited up to the data's available to them.
- Due to paucity of time, limited economic as well as human resources and non-availability of furnished data on the feedback of various solar pump, the outcome of the case study are deducted through analysis. Moreover, as this technique is in the beginning level, so feedback data are not available to any organization.

1.6 Organization of the Project Paper

This report presents the analysis, results and findings of the study in six chapters as shown below:

Chapter 1: **Introduction:** This chapter contains the general background and present status of the problem, objectives of the study, scopes of the study and the project paper organization.

Chapter 2: **Literature Review:** Compiles all relevant literatures related to the project paper.

Chapter 3: **Methodologies:** It describes the methodologies for this project starting with selection of case study areas to the display of information on the figures using 95% confidence statistical tools used. As a case study BUET run Keranigong Solar Power Irrigation Pump was considered for analysis.

Chapter 4: **Analysis of Data:** Here it provides a description of the analysis process adopted in this study.

Chapter 5: **Results and Discussions:** Presents the results of the analysis accompanied by discussions.

Chapter 6: **Conclusions and Recommendations:** Summarizes the whole study and provides some guidelines for further research in this area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Bangladeshis situated in the north-eastern part of south Asia is among the world's most densely populated nations (1099 persons/km^2 in 2010) with a population of 162.20 million in 2011[4]. Energy, and more explicitly electricity, is a prerequisite for the technological development, higher economic growth and poverty reduction of a nation. The future economic development of Bangladesh is likely to occur in a rapid growth due to proper supply of energy. The country has been facing a severe power crisis since its independence. Without creating much pressure on the conventional hydro carbon fossil fuel, various renewable sources like solar, hydropower, geothermal, tides, wind, biomass, and bio fuel can be effectively used in Bangladesh.

Solar energy is the most readily available and free source of energy in our country. Solar panels are the medium to convert solar power into the electrical power. Sun beam is absorbed with the PV panel materials and lightly held electrons are emitted from the atoms that they are bonded. This releases current, thus solar power is converted into electrical power. When PV cells are joined physically and electrically and placed into a frame they form a solar panel or PV module. Panels joined together form a solar array. The sunlight impinging on panels, i.e. irradiance or insulation (incoming solar radiation), is measured in units of watts per square meter (W/m2).We can use only 25% of sunlight radiation for PV module. The PV system power output (DC) has approximately a linear relationship to the insulation. It is notable that, Bangladesh Government has planned to produce 5% of total power generation by 2015 & 10% by 2020 from renewable energy sources like wind, waste & solar energy[8] .

2.2 Current Situation

Growth in crop production in the country primarily depends on the irrigation development. Due to absence of adequate surface water in the dry season, irrigation is heavily dependent on groundwater. With the increased in groundwater use few factors limit crop growth in irrigated area. This are-

1. Expansion of irrigated area
2. Inefficient water distribution and

3. Inadequate supply limits crop growth in irrigated fields.

In Bangladesh, the cost of irrigation can be as high as 40% of a farmer's total production costs, and lack of timely irrigation leads to a 37% average decrease in yields of rice. Conversely, efficient irrigation can increase both the productivity and profitability of crops. To make a better irrigation system we need to improve efficiency to minimize irrigation water conveyance loss and to disseminate crop-specific water management knowledge. It is also important improving access to and promoting efficient, low-cost and smaller irrigation devices in the project areas. Moreover, most cases the conventional irrigation methods are to lift ground water and used to supply this water directly to the crop fields. Sometimes surface water is also used for irrigation. In both the cases, diesel and grid electric engines are used to power the pumps.

As we know in Bangladesh adaptation of irrigation techniques is reported to play a vital role in the improvement in the yield of food grain. It is worthwhile to note that the demand of diesel for irrigation has caused a miss - match in the demand for petroleum products. Bangladesh has small proven oil reserves, and thus imports much of its oil products. The average annual consumption of high speed diesel oil is 285,510 metric tons [4]. which cost is 1256 crore, which is 7% of total imported oil. Again most of which is used for operating irrigation equipment. The total subsidy for diesel for 2012 is estimated to be BDT 116.9 billion BDT (US$1.4 billion), which is the highest amongst the petroleum subsidies [8].

The price of diesel is increasing day by day due to increasing the oil price in international market which impacts Bangladesh's agriculture. If the oil crisis in Bangladesh becomes more severe, sufficient food cannot be produced and many people will starve due to want of food. In Bangladesh, there are 68,000 villages and each village has at least 10 irrigation farms. It is roughly estimated that the number of diesel engines in Bangladesh is more than 700,000 which are used for irrigation and consumes a lot of diesel fuel. So both the government and the farmers have to pay a huge amount of money for operating irrigation equipment which impacts our economy. On the other hand, there is a great problem for grid connected irrigation pumps. Electricity is a scarce service in Bangladesh. Natural gas, diesel oil, furnace oil, coal and hydro are the major types of fuel that are used in electricity generation in Bangladesh. Average annual consumption of furnace oil, which is mainly used as fuel for electricity generation, is 34,443 metric ton[4].

For a sustained development electricity production should be double than its annual GDP. For Bangladesh as this thumb rule was not followed so growth faced a real obstacle due to lack of power generation in every year. Supply of electricity in Bangladesh is not regular due to deficiency of electrical energy. Supply of electricity to grid connected irrigation pumps remain uncertain due to demand-supply gap. During dry season's Irrigation the whole country faces an acute crisis due to load shedding of 1248 MW. Due to declined fuel availability, their predicted gradual extinction in the next few decades and the resultant price volatility due to demand-supply gap, the attention must be centered towards renewable, readily available and non-polluting method like solar energy which is abundant in Bangladesh due to its geographical location.

2.3 Types of Irrigation

Four irrigation systems can be identified in Bangladesh. These are –

1. Private owned and operated minor (small-scale) irrigation comprising of shallow tube wells (STWs), deep tube wells (DTWs), low-lift pumps (LLPs) and hand tube wells (HTWs).
2. Public managed irrigation, which consists of primary pumping plants, gravity diversion through major canals and secondary lifting by LLPs (large-scale irrigation),
3. Public developed and community managed small scale irrigation comprising low-lift pumps and gravity diversion.
4. Private managed non-mechanized and traditional irrigation by indigenous method from adjacent low-lying areas to crop fields.

The private owned and operated irrigation covers almost four- fifth, publicly managed irrigation about one-fifth (BBS, 2008, MOS, 2005 and IWRMU, 2003 and SSWRDSP, 2010). Small-scale equipment such as LLP with power- operated centrifugal pump drawing water from rivers, creeks and ponds. STW with a motorized suction mode pumping unit, DTW with power-operated force mode pumping unit, manually operated pumps extracting water from a shallow tube well and traditional methods are mainly used to irrigate cropped land in the country. Currently, STWs, LLPs and DTWs cover about 62 percent, 17 percent and 15 percent of the total irrigated area, respectively (Rahman, 2009 and BBS, 2008).Gravity and traditional irrigation covers about 3 percent each. Almost 90 percent of the STWs and LLPs are diesel operated. On the other hand, 80 percent of DTWs are electricity operated (DAE, 2008). Data on the country-wide irrigated area show that annually about 5.6 million ha is cultivated with irrigation (BBS, 2008). Of this 87 percent is irrigated in the dry, 7 percent in the post-monsoon and 6 percent in the pre-monsoon seasons. Crops in the post-monsoon seasons require supplementary irrigation. The irrigation rate or the ratio of irrigated area to the total cropped area is 0.36.

2.4 Disadvantages of diesel driven pump are:

-The equivalent cost of diesel per kWh is very expensive.

-They are less convenient to operate and automate.

-The pump/motor provided combination takes up more than electrical system.

-Carrying of fuel to the operational sites in a continuous process and a logistic problem.

-Tanks for fuel storage and delivery access must be provided.

-Extra controls for runway engine condition may be needed.

-Spill containment and leak defection may be an issue.

-The diesel motor produces noise pollution and GHG.

-Maintenance is costly and required more frequently.

2.5 Parameters for selection of Energy Source

Efficient irrigation depends on good system design and good management. Mode of irrigation is a, major part for the selection is an important part of the design process. The good practice to compare the pumps cost is to calculate the Life Cycle Cost of the energy source and Life Cycle Cost components are as under,

1. Initial cost or Purchase cost or Upfront Cost.
2. Operation cost (diesel, fuel transportation, labor etc).
3. Maintenance and Replacement Costs (Repair, replacements of diesel engine, Pump and its parts).
4. Environmental costs (Spills, contaminations, leakages, noise and emissions).
5. Disposal cost (Pump cost when it is disposed off to buy new Pump).

The more efficient the selection of the type of irrigation, the more profit returned per investment spent on irrigation system. There are both merits and demerits for the choice. Considering the above factors, keeping a system of energy source as baseline, the other opted method can be compared with baseline and a suitable decision can be sought through analysis based on the software named RETScreen, clean energy software available at http://www.retscreen.net/ang/home.php.

2.5.1 Advantages:

-Savings in energy charges.

-Possible savings in electricity supply capacity charges.

-Lower overall annual costs of pumping.

-Lower maintenance.

-Longer life of equipment.

-Better matching of pump of system demand.

-Better and more efficient irrigation system.

-Reduced chance of over pumping wells.

-Easier to start to control

-Cleaner environment and less risk of adverse climate change.

2.6 For Bangladesh Perspective Advantages:

According to World Bank in 2007 Bangladesh produces 0.3 t/capita of GHG and overall produces 56,153 kt which is 0.17 % of total GHG produced around the world. Though the emission is not that significant in compared to the other developed nations but even though to make our environment healthy and to produce positive role in reduction of carbon emission, introduction of solar energy as renewable source will play a vital role. After economic analysis it is shown that Photovoltaic pumping system for irrigation in Bangladesh is more feasible than Diesel engine pumping system in long term basis though for short term basis visibaby not feasible but if we take intangible environmental benefits into consideration than for short term economical and financial non- benefits can be overcome. In economic point of view PV –pumping system for only one season irrigation is a little bit higher than the diesel engine pumping system due to high cost of PV module and its components. For two or three seasons irrigation PV- pumping system is lower than diesel pumping system. If the price of PV –module and its components reduces or these are produced locally, then PV-pumping system will be more feasible [1]. Bangladesh is blessed with human resources which is now a day's considered to be blessings, not a curse. To maintain that huge population with food security is vital to ensure sustainable growth. As Bangladesh is dependent on imported gradual deplorable hydro-carbon to be the main source of it's energy, so due to any geo-politics on oil may adversely affect Bangladesh's food security. To be pro-active and self sustained we need no start such a measure which not only will get rid off from others' involvement but will also ensure in self sufficiency in food grain production. Otherwise, being world citizens in no way we can neglect our role to make this earth environmentally friendly and sustainable for future generations.

2.7 Disadvantages

-Solar power disadvantages are actually not so plentiful. In fact, there's only one notable disadvantage to solar power that one can think of. That disadvantage is that the sun doesn't shine 24 hours a day. When the sun goes down or is heavily shaded, solar PV panels stop producing electricity. If electricity is needed at that time, some other sources have to be used to get electricity. In other words, irrigation cannot be 100% powered by solar panels. At the very least, batteries are needed to store electricity produced by solar panels for use sometime later. For irrigation purpose if water is stored in reservoir than it can be used during night or when irrigation demand is more than it produces during sunshine hour.

2.8 Key Issue

The use of solar water pump is getting momentum in Bangladesh. According to IDCOL around 1500 solar pump will be installed by 2016 which will save 5100 tons of diesel which costs 41 crore tk. Diesel is a costly fuel, which is difficult to procure in rural areas and results in significant carbon emissions. Grid power-based systems, on the other hand, face the issue of poor energy supply. Moreover, both diesel- and grid power-based pumps deplete the water table excessively by pumping heavily at short intervals. In comparison, solar pumps can play an important role in reducing carbon emissions and increase access to groundwater for farmers. However, there are several constraints in the wide-scale adoption of these systems. High upfront costs pose a major challenge for the acceptance of solar water pumping systems. Also, banks are not comfortable about providing loans for such systems. Other issues such as procedural delays in the disbursement of subsidies and theft of solar panels may be a hindrance to adoption in some areas.

2.9 Diesel burning and carbon emission:

As with the 1996 Guidelines and IPCC Good Practice Guidance the most common simple methodological approach is to combine information on the extent to which a human activity takes place (called activity data or AD) with coefficients which quantify the emissions or removals per unit activity. These are called emission factors (EF). The basic equation is therefore mentioned in equation 1

Emissions = AD • EF ………………………………… (1)

Emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ashes etc.) are relatively unimportant.

Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of fuels combusted and the averaged carbon content of the fuels.

2.10 The relationship between CO_2 emissions and Diesel consumption works like this:

- 1 liter of diesel typically weighs 0.83 kg(the density range is 820-845kg/m3 in Europe and up to 860 kg/m3 elsewhere)
- About 87% of this is carbon, so 1 liter of diesel contains 0.83*87%= 0.722 kg of carbon.
- Each atom of carbon weighs 12 atomic unit. When it combines with atoms of oxygen in the combustion process it becomes CO_2 which weighs 44 atomic units. The 0.722kg of carbon in the original then becomes 0.722*44/12=2.65 kg of CO_2.
- So one liter of diesel fuel produces about 2.65 kg of CO_2.

Bangladesh imports 27,29,477 metric ton JP-1, kerosene, petrol, octane and diesel are 11,81,097 metric ton of crude oil, total 39,10,574 metric ton which produces 186,69,460 metric ton of CO_2. Carbon pricing is to force emitters to pay at least part of the cost of the negative externalities (pollution cost) caused by CO_2 emission. The source of these negative externalities for CO_2 is assumed to be climate change issue since CO_2 is a known GHG and general index to indicate the extent of GHG emissions. Though PPP (Polluters Pays Principal) the carbon pricing varies in average $ 20/ metric ton, the amount of carbon di-oxide is produced of the oil burnt in Bangladesh; the price of that CO_2 is 2,960 crore BDT.

2.11 Energy Policy of Bangladesh

- The objective of Bangladesh renewable energy policy are
- Harness the renewable energy resources and disseminator of renewable energy technologies in urban areas.
- Enable, encourage and facilitate both public and private sector investment in renewable energy project
- Develop sustainable energy supplies to substitute indigenous non-renewable energy supply.
- Scale up contributions of renewable energy to electricity contribution.

- Scale up contributions of renewable energy both to electricity and to heat energy.
- Promote appropriate, efficient and environment friendly use of renewable energy.
- Train facilitates the uses of renewable energy at energy level of energy usage.
- Create environment and legal support to average the use of renewable energy.
- Promote development of local technology in the field of renewable energy.
- Promote clear energy for Clear Development Mediums (CDM) and
- Achieve the targets for developing renewable energy resources to meet five (5%) percent of the total power demand by 2015 and then 10% by 2020.

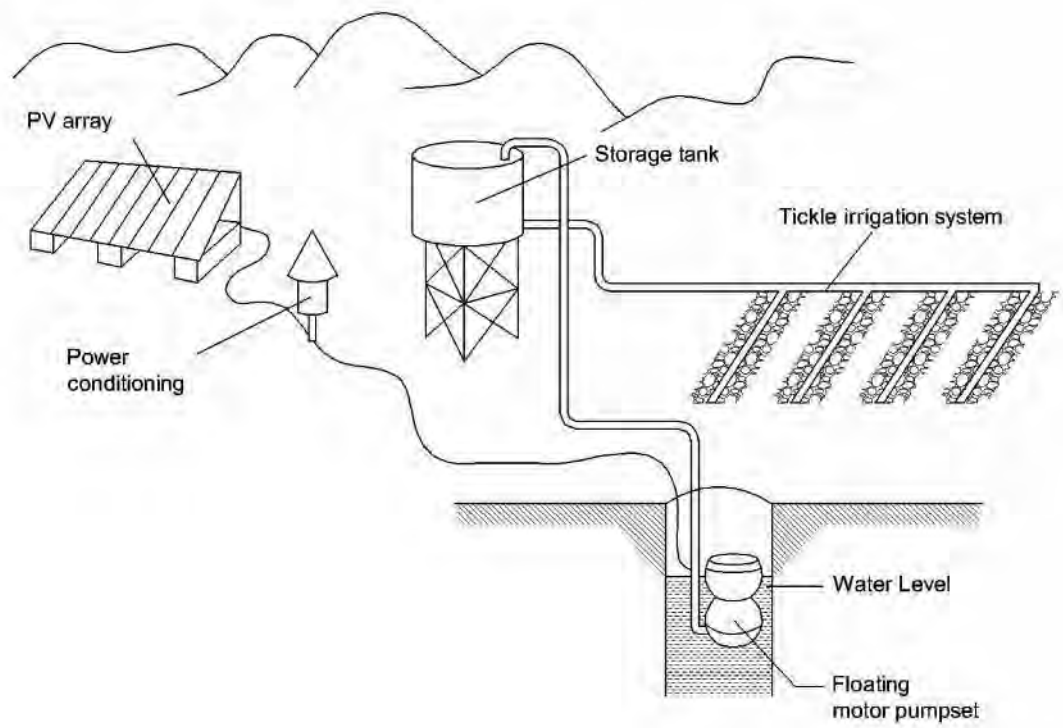
2.12 Introduction of Solar Pump

2.12.1 Description

Solar pumping is an important application of photovoltaic system which does not necessarily need battery storage. It is a pump running on the power of the sun. Solar water pumps were first introduced for water provision in off-grid areas. The technology has developed around many different designs and in some water pumps the reliability and maintenance requirements have improved over the initial pumps introduced to the market. Solar pumps are easy to install, require no nonrenewable energy, operate autonomously and are generally “good” for the sustainability of boreholes due to their low extraction volumes spread over eight to ten hours a day. The initial capital cost is high due to the cost of the photovoltaic modules. The maintenance requirements differ and range between annual and five year maintenance intervals. A perceived limiting factor of solar pumps is that they do not easily cater for fluctuating water demands or increased water demand although solutions for this are being offered.

Solar pumps are used principally for two applications: Village water supply (including live stock watering) and irrigation. These two applications have very different demand patterns: Villages need a steady supply of water, whereas crops have variable water requirements during the year.

A solar pump for village water supply is shown schematically in fig 2.1.Note that water has to be stored for periods of low insulations.


PV array
Storage tank
Tickle irrigation system
Power
conditioning
Water Level
Floating
motor pumpset

2.12.2 Components

Unlike a normal pump (such as positive displacement pumps), the solar powered pump is actually a more or dictionary phrase than a technical one. It is also used to describe that there's a pump, being powered by another device (such as solar panels), being powered by the renewable electricity generated from the sun (solar electricity).

A solar powered pump consists of four parts:

- The actual fluid pump [that actually moves (pumps) gases or liquids under pressure].
- The controller (adjusting speed and output power according to input from solar panels).
- The engine (usually an electric motor).
- The energy source being powered by the sun, usually photovoltaic cells (solar panels).

Solar array (photovoltaic cell, solar panels) taken up to 50%-80%of the whole setup cost, which is the most expensive part. There are two major types of solar pumps, DC (direct current) and AC (alternating current),

DC solar pump:

- Powered output up to 2 KW
- Suitable for small applications (garden fountain, landscaping)
- Relatively low-priced (require slightly less solar panel)
- Low compatibility (only selected controlled work by selected motor)

AC solar pump: A solar pump pumping inverter is needed in AC solar pump setup. The inverter converts DC generated from solar array to AC to drive the pumps in the meantime (as the controller) to control output and speed**.** Flow chart for PV array to pump & motor in solar Irrigation is shown figure 2.2.

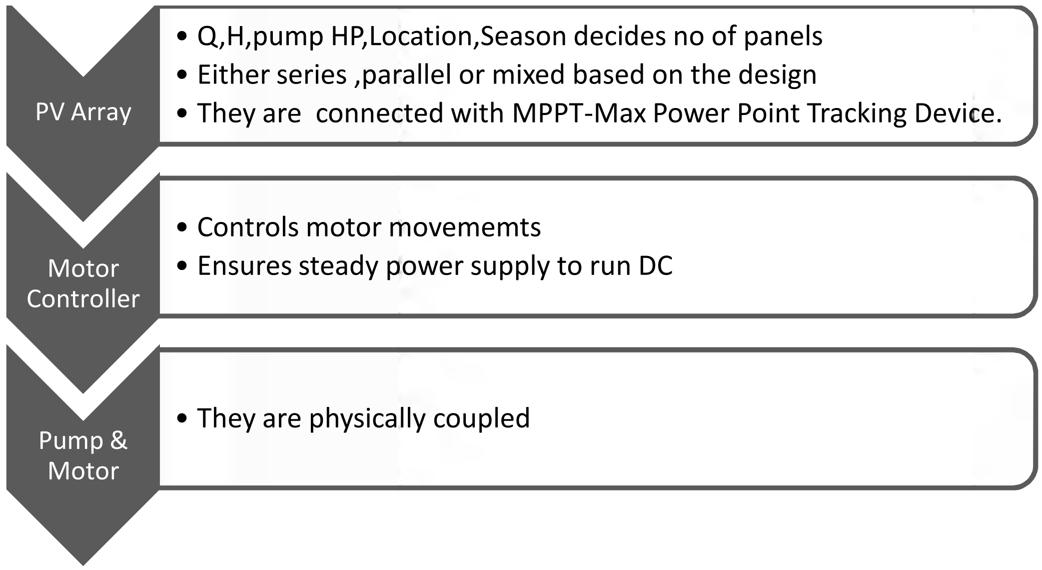


Figure 2.2: Flow Chart for PV Array to Pump & Motor in Solar Irrigation

Note: MPPT is very costly and to replace it by doing manually each after 3-4 hours to harness maximum radiation .It has to be noted that if MPTT is done either mechanically or manually carried out almost 33% efficiency is increased.

The majority of inverters for PV applications can be classified into three main categories. Variable frequencies inverters are used for stand- alone drive/ shaft power applications, almost exclusively in PV pumping systems. The remaining two main inverter categories are suitable for the grid connection of PV power plants. Self –commutating fixed frequency

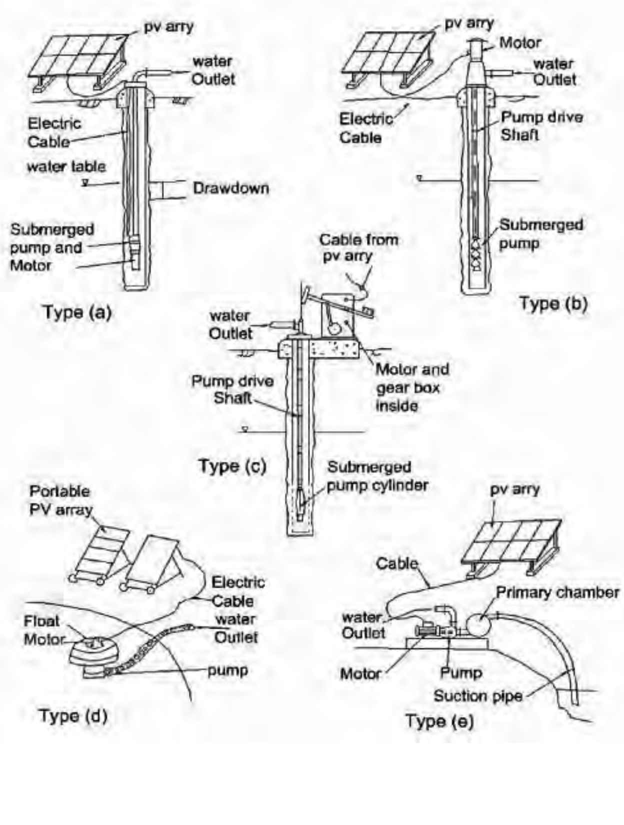
Inverters are able to feed an isolated distribution grid and if equipped with special paralleling control, also a grid supplied by other parallel power sources. Line commutated fixed-frequency inverters are able to feed the grid only where the grid frequency is defined by another power source connected in parallel.

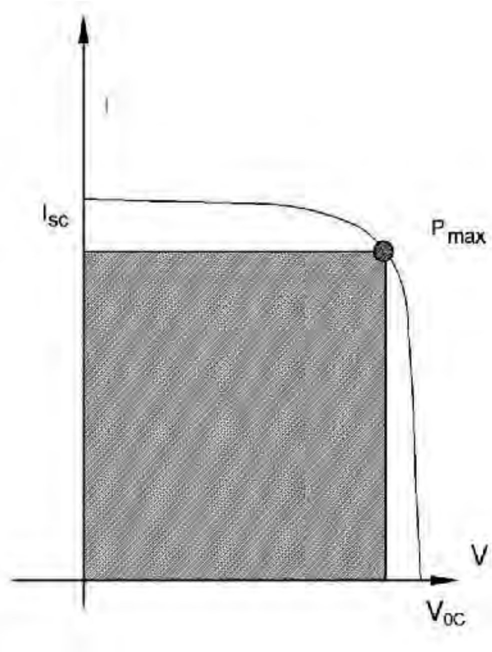
The inverter will not work if such external frequency reference is lacking. The efficiency of the inverters usually depends on the load current being a maximum at the nominal output power. It can be as high as 95% but will be lower (75-80%) if the inverter runs under part load.

2.12.3 The Technology

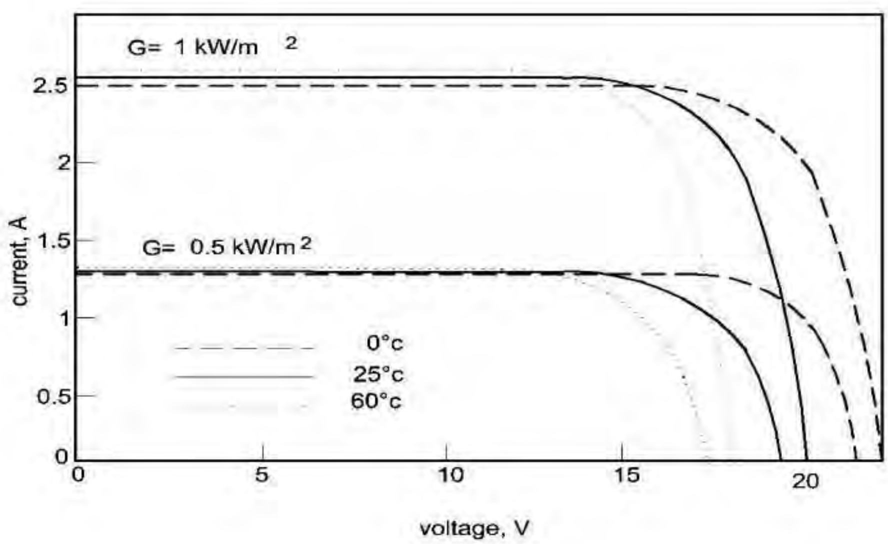
Systems are broadly configured into five types and pictures of different PV pump system is shown in figure 2.3:

(a) Submerged multistage centrifugal motor pump sets are probably the most common type of solar pump used for village water supply. The advantages of this configuration are that it


pv arry
water
Outlet
Electric
Cable
water table
Drawdown
Submerged
pump and
Motor
Type (a)
pv arry
Motor
water
Outlet
Electric
Cable
Pump drive
Shaft
Submerged
pump
Type (b)
Cable from
pv arry
water
Outlet
Motor and
gear box
inside
Pump drive
Shaft
Type (c)
Submerged
pump cylinder
Portable
PV array
Electric
Cable
water
Outlet
Float
Motor
pump
Type (d)
pv arry
Cable
Primary chamber
water
Outlet
Motor
Pump
Suction pipe
Type (e)



I
Isc
Pmax
V
V0C


G= 1 kW/m 2
G= 0.5 kW/m 2
2.5
2
1.5
1
0.5
0
current, A
0°c
25°c
60°c
0
5
10
15
20
voltage, V

2.14 Radiation- Power generation relationship:

The sunlight impinging on panels irradiance or insulation (incoming solar radiation), is measured in units of watts per sq. meter (w/m^2) .we can use only 25% of sunlight radiation for PV module. The PV system power output (DC) has approximately a linear relationship to the isolation. Using the solar radiation available on the tilted surface the hourly energy output of the PV generator can be calculated according to following Eqn (3)

$$P=AX^2 +Bx+ C \text{ (in watts} \quad \text{Eqn (3)}$$

Where, X= solar radiation,

P= Power generation (w)

And A, B, C are constants which can be derived from measured data. By using above formula we can predict solar power generation at any solar radiation. This is also useful in estimating the suitable solar photovoltaic panels for required load.

2.15 Weakness and opportunity

The nature of the absorption process also indicates how a part of the incident photon energy is lost in the event. Indeed, it is seen that practically all the generated electron-hole pairs have energy in excess of the band gap. Immediately after their creation, the electron and hole decay to states near the edges of their respective bands. The excess energy is lost as heat and cannot be converted into useful power. This represents one of the fundamental loss mechanisms in a solar cell.

The several hundred micrometers of silicon are necessary to absorb all the above-band gap light but few micro-meters of a direct gap material (for example, GaAs) are sufficient for this purpose.

Solar panels are made of some heavy metals like cadmium but as solar PV are recycled so this weakness is overcome without degrading the nature.

Opportunity in Bangladesh about solar energy is enormous. Already IDCOL (Infrastructure Development Company Limited) is going to install 1400 solar power irrigation project through micro credit system which will be financed by donor agencies like USAID, UNDP, EU, WB, ADB etc. Total expenditure will be distributed like 40% on credit, 40% as grant as 20% on equity basis. Due to this subsidized system it will be popular as 40% of total cost has not to be bearded by the beneficiaries. For example earlier farmer used to pay as cost of irrigation

¼ of total paddy produced and now they pay only 1/5 of total paddy produced after installation of solar irrigation pump in Tangail (source: Interview with farmers).

2.16 Solar panels for irrigation

There are some 2,702,000 acres covered by 700,000 pumps consuming around 750 MW electricity and huge amount of diesel. We can replace then all with solar panels. Individual solar panels for irrigation may not be cost effective. if we can install in mini-grid, than it can provide light to the village at night and pump water in the day time. The solar mini grid could also be connected to main power grid to reduce load shading and transmit the extra electricity to the grid.

2.17 Sizing

Sizing of solar pumps is determined by the hydraulic energy required:

Hydraulic energy (kWh/day)

=volume required (m 3/day) × head (m) × water density ×gravity

=0.002725×volume (m3/day) ×head (m)

Solar array power required (kW)

= (Hydraulic energy required (kWh/day))/ (Average daily solar irradiation (k W-h/m^2 day) × F×E)

Where F is the array mismatch factor equal to 0.85 on average, and E is the daily subsystem efficiency, typically between 0.25 and 0.4.

Flow Chart for selecting PV Panel for Irrigations is shown at below in figure-2.6.

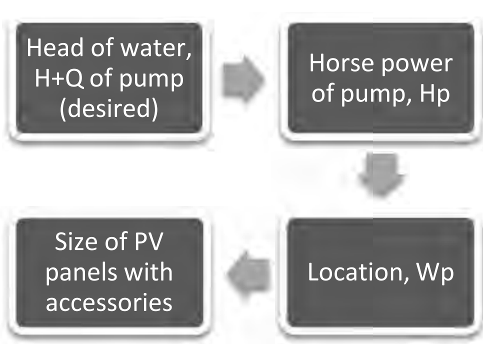


Figure 2.6 Flow Chart for selecting PV Panel for Irrigations

2.18 Advantages of Solar Pump Design

In Bangladesh per watt peak cost is 70-80 Taka and gradually reducing due to competitive and advancement of technology.

1. Expansion of renewable energy.
2. Reduction of carbon emission.
3. Reduction of deficiency of energy.
4. Improvement of human resources through transfer of technology.
5. Solar energy is cost effective in term of non- curable cost such as no electricity bill, so no periodic shut down.
6. In long term financial analysis it is viable.
7. Sustainable and unlimited access to energy, due to its energy source is sun.
8. Independent from the electrical grid and therefore usable in remote rural areas that are difficult to reach preferably closes to the water source and thus reducing cable length.

9. Low operating cost: One of the important advantages is the negligible operating cost of the pump. Since there is no fuel required for the pump like electricity or diesel, the operating cost is minimal.

10. Low maintenance: A well-designed solar system requires little maintenance beyond cleaning of the panels once a week. Most vendors provide the post-installation service through trained technicians for every cluster, so that the farmers don't need to worry about availability of spares or other related problems.

11. Harmonious with nature: Another important advantage is that it gives maximum water output when it is most needed i.e. in hot and dry months. Slow solar pumping allows us to utilize low-yield water sources.

12. Flexibility: The panels need not be right beside the well. They can be anywhere up to 20 meters away from the well, or anywhere you need the water. So, it offers freedom regarding the placement of panels. These pumps can also be turned on and off as per the requirement, provided the period between two operations is more than 30 seconds.

13. This system does not generate pollution, because the sun is a clean energy source.
14. Long life span, high reliability, over 20 years lifetime.
15. Easy and quick installation.
16. Automatic system options to adapt the system to the different seasons.
17. There is no need for batteries.
18. This is environmentally friendly producing no GHG and noise pollutions.

2.19 Limitations

The main limitation of solar pump about the price of installation is high in compression to diesel and grid pump for short term benefit. The other limitations are listed below:

1. Low yield: Solar pumping is not yet suitable where the requirement is very high. The maximum capacity available with solar is very low. However, the output of the solar DC pump is more than a normal pump.

2. Variable yield: The water yield of the solar pump changes according to the sunlight. It is highest around noon and least in the early morning and evening. This variability should be taken into consideration while planning the irrigation.

4. Water quality: As with any other pump, solar pumps work best if the water is clean, devoid of sand or mud. However, if the water is not so clean, it is advisable to clean the well before installation or use a good filter at the end of the immersed pipe.

5. Theft: Theft of solar panels can be a problem in some areas. So the farmers need to take necessary safety precautions. Ideally, the solar system should be insured against theft as well as natural hazards like lightning.

6. Weather: As Bangladesh is susceptible to nor-wester wind so, if not installed with proper anchorage than likely chances of up-rootmrnt and become flying debris during the storm.

7. Storage: Water storage is required for cloudy periods.

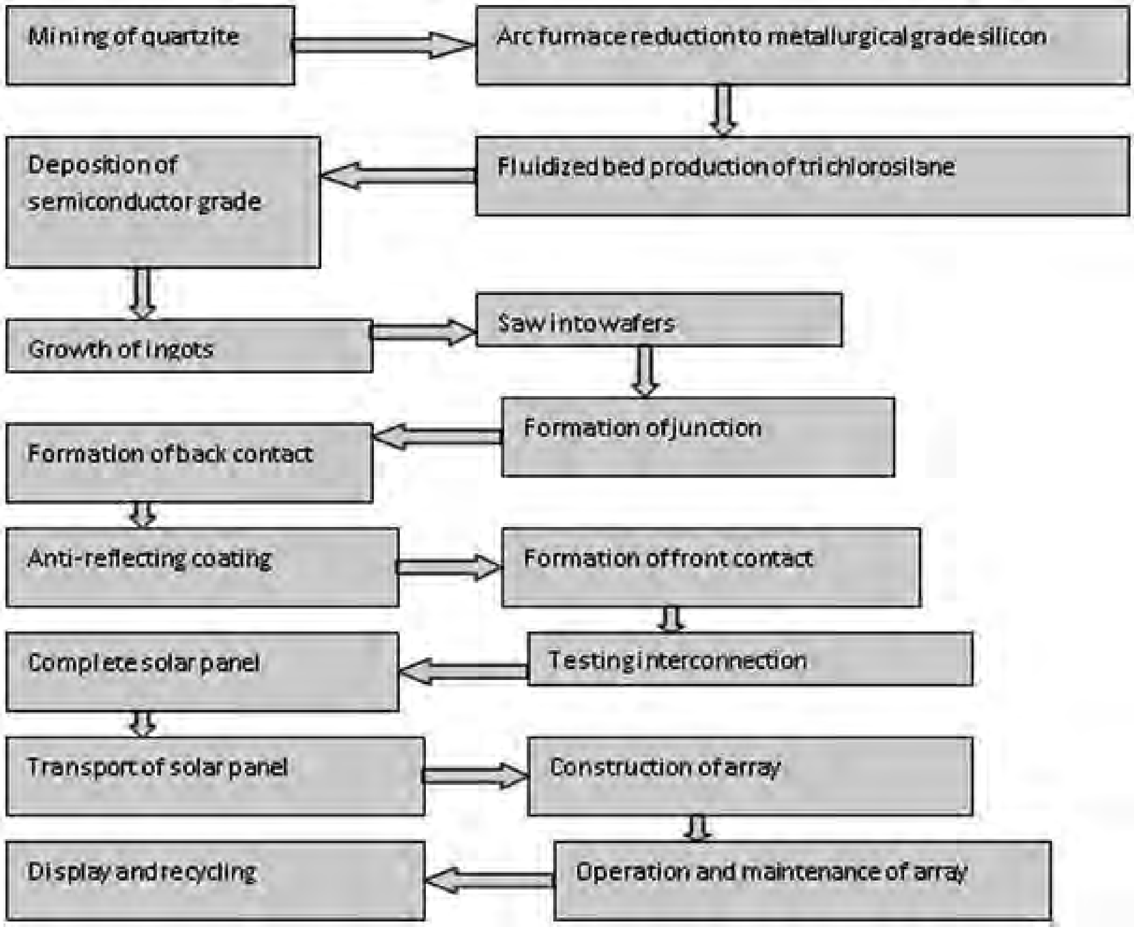
8. Repair: Repair often requires skilled technicians.

9. High initial capital cost: High initial capital cost required which is burden for farmers like Bangladesh.

2.20 Effect of Hazardous Materials

The commercial standard PV module uses solar cells made from wafers of silicon, usually 0.3mm thick 10 cm×10 cm in area. A simplified fuel cycle of silicon solar cells from ‘cradle to grave’ is shown in fig. 2.7. The ingots may be either Czochralski-grown single crystals or directionally-solidified multi-crystalline cubes. For the latter the third and fourth steps of fig 2.7 may be replaced by less costly steps yielding ‘solar grade’ silicon rather than the semiconductor grade material.

Each of the steps shown in fig 2.7 has inputs of energy and materials and requires capital equipment, and each also has potential hazards associated with it. The first step is a standard mining operation with associated hazards to the miners and inputs to diesel fuel and machinery. Metallurgical grade silicon is made in large quantities for the steel industry, with a small fraction going as input to the semiconductor industry. The major emission of this


Mining of quartzite
Arc furnace reduction to metallurgical grade silicon
Fluidized bed production of trichlorosilane
Deposition of semiconductor grade
Growth of ingots
Saw into wafers
Formation of junction
Formation of back contact
Anti-reflecting coating
Formation of front contact
Testing interconnection
Complete solar panel
Transport of solar panel
Construction of array
Operation and maintenance of array
Display and recycling

production rate. Thus for the 1990 crystalline silicon PV technology in small scale production, the CO_2 emission is around 400,000 tonnes per gigawatt –year of energy output. This compares with the CO_2 output from the most modern and efficient coal-fired plant of 9 million tonnes per gigawatt-year of energy output. Boiling water reactors have been estimated to emit about 75,000 tonnes of CO_2 per gigawatt-year (Palz and Zibetta, 1991), mainly from the fuel production steps,

There are a number of technologies for PV cells other than those using wafers of silicon. Thin multcirystalline films of silicon on ceramic substrates and thin polycrystalline films of copper indium diselenide (CIS) and of cadmium telluride (CdTe) are the three most promising technologies for efficient low-cost modules and all seem likely to be in commercial production within next 2-4 years. An excellent review of the scientific, technical, economic and environmental issues associated with these three materials has been given by Zwiebel (1990).

The environmental impacts of the thin-film silicon cell are similar to those of the wafer silicon cell, but reduced in magnitude because of the smaller volume of silicon used. The CIS cell has a potential hazard in the hydrogen selenide used in its manufacture. A report on CIS manufacture by Moskowitz et al. (1990) has concluded that hydrogen selenide can be used safely provided that adequate safety precautions are adopted. There are proposals for the production of CIS which involve the use of solid selenium rather than hydrogen selenide (Badawi et al., 1991) which would largely obviate this hazard.

Both CIS and CdTe cells have a window layer of cadmium sulphide, so both types of cell could potentially present a hazard from cadmium. Cadmium hazards arise in the refining stage, with emissions of cadmium oxide dust; emissions of cadmium-containing PV modules were involved and from possible leaching of cadmium from modules discarded at the end of their working life. In all of these cases, the control strategies are well established in industry, and the magnitude of the hazard is in proportion to the amount of cadmium present in the cells.

In CIS modules, the amount of cadmium is used about 0.04g/m², equivalent to 400 g per MWp of output. This tiny amount of material is easily controlled during manufacture ,whilst cadmium evaporated from module on a building which caught fire would pose a negligible hazard to anyone far enough from the fire to avoid being burnt to death. Careless disposal of large numbers of CIS modules in one location could pose a hazard from leaching of cadmium and selenium into ground water. However, the scarce indium and regulations on the disposal of cadmium and selenium products would lead to recycling of the modules and reuse of the indium, cadmium and selenium.

The PV modules using CdTe cells would contain much more cadmium (about 5 g/m²) than those using CIS cells, and the potential hazards are correspondingly higher. It is clearly beneficial to use a manufacturing process with a high utilization of cadmium feedstock, and the success of electrochemical deposition as a production technology gives the opportunity for such a process. Copper Indium Diselenide Fuel Cycle is described in figure 2.5 at below

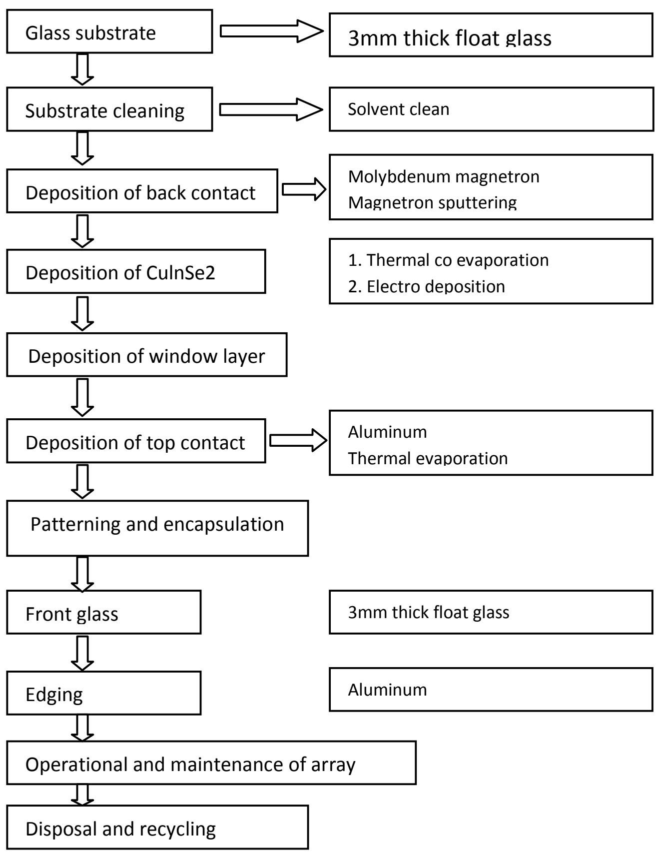


Figure 2.8 Copper Indium Diselenide Fuel Cycle

The CO_2 emissions estimated for the various current PV cell technologies are shown in table 6.2, along with an estimate of values which might be typical of 2020 PV technology.

The waste Cadmium and tellurium from the manufacturing plant can be economically recycled and emissions reduced to very small levels even for 100 MWp per annum production rate. Cadmium dust which might be present in the manufacturing plant could present a chronic hazard to personnel. However, the monitoring and control of such dust is well established in existing industries where cadmium is used and no additional problems can be foreseen for PV manufacture.

The quantity of cadmium in the CdTe modules increases the potential hazards during operation and disposal compared to those with CIS cells. In operation, the modules can leak cadmium into the environment only if they are broken or subject to high temperatures. Broken modules use little hazard as the area of cadmium exposed by even a break across the entire module would be less than $3mm^2$, and broken modules would be replaced quickly in routine maintenance. A fire in a building clad with CdTe modules could pose some hazard, although for small areas the hazard would be significant only for those so close to the fire as to suffer far greater hazards from smoke and flames. A large building having a large area for PV cladding could emit cadmium vapor turning to cadmium oxide dust into the smoke plume. Moskowitz et al. (1990) have studied this issue and conclude that standard fire safety procedures would protect the population from this cadmium hazard, just as they protect them from the carcinogens in the smoke plume.

Disposal of CdTe modules may need to be controlled more strictly than for CIS modules, and recycling of materials is more important both for environmental reasons and for the value of the cadmium and tellurium. The technological problems associated with this recycling appear to be readily solvable at low cost.

Table 2.1 Hazardous emissions from photovoltaics

Material	Production	Operation	Disposal
Silicon	Silica dust Silanes Diborane Phosphene Solvents		
Copper indium Diselenide	Hydrogen Selenide Cadmium oxide Cadmium dust Selenium Solvents	Cadmium Selenium (in a fire)	Cadmium Selenium (if not recycled)
Cadmium Telluride	Cadmium oxide Cadmium dust Tellurium Solvents	Cadmium Tellurium (in a fire)	Cadmium Tellurium (if not recycled)

It is interesting to note that the amount of cadmium contained in the CdTe modules needed to generate energy of say, 1 GWh over their lifetime is about equal to the cadmium emitted from the smoke- stack of a typical coal fired station whilst generating the same 1 GWh of electrical energy. Very little of the cadmium in the PV modules would be lost into the environment, so the PV plant is cleaner, even for cadmium emissions, than a coal fired power station.

2.21 Fuel Cycle, Environmental burdens and impacts

A detailed analysis of the fuel cycles of different energy systems is needed to determine the external costs incurred during the various stages of the fuel cycle process and to internalize technologies . This in turn facilitates a one-to–one comparison of different competing technologies on an even footing. Based on these data, informed policy actions /choices either encouraging or limiting particular energy options, can be taken. A Linkage between fuel cycles external costs in described in figure 2.6 at below.

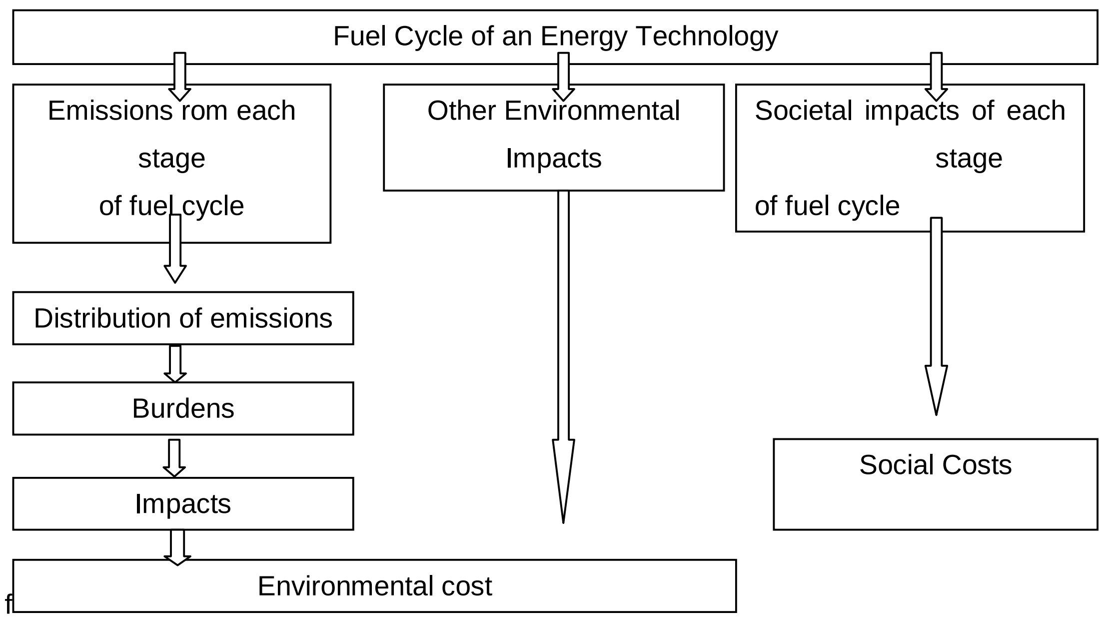


Fig 2.9 Linkage between fuel cycle and external cost

2.22 Environmental Costs of Photovoltaic

Carbon Dioxide Emitted in the Production of PV Modules (In Units of Kilo Tons per Gigawatt-Year) are described in tabular form in table 2.2 at below.

Table 2.2: Carbon Dioxide Emitted in the Production of PV Modules

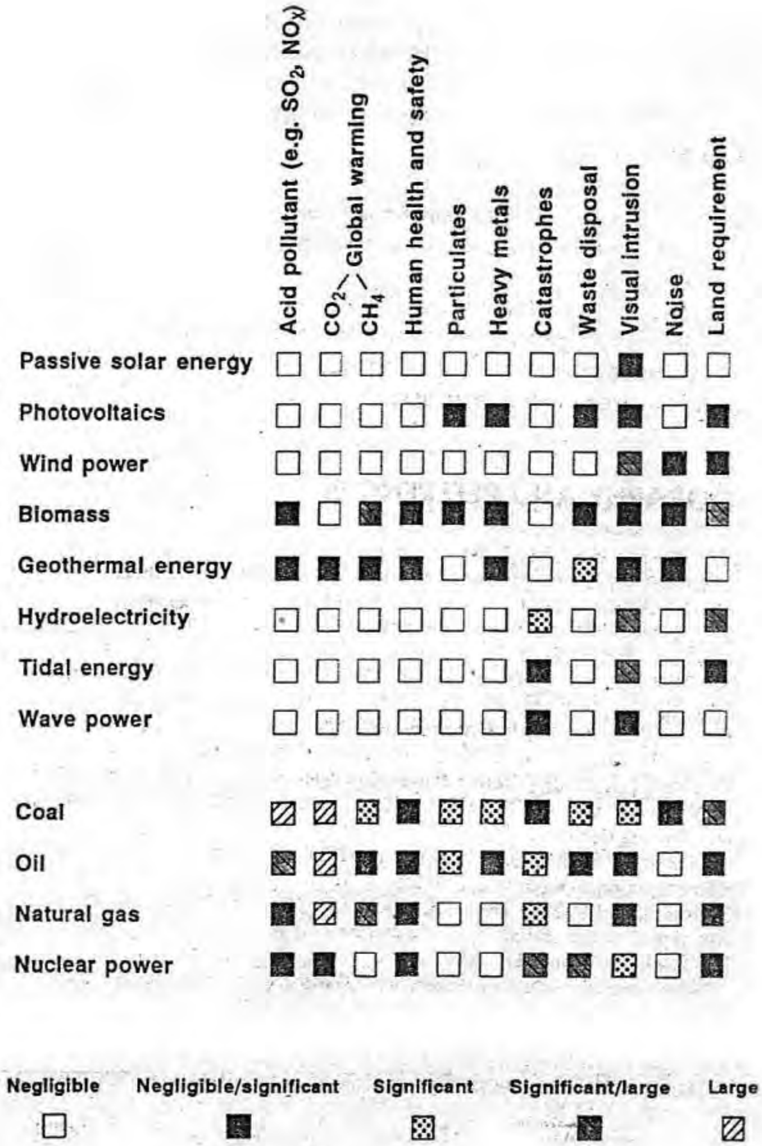
(In Units of Kilo Tons per Gigawatt-Year)(Markvart Tomas, Solar Electricity, Table-6.1)

Cell material	Production scale	Efficiency (%)	Lifetime (years)	CO_2 Kt $GW^{-1} yr^{-1}$
Monocrystalline silicon	Small Large	12 16	20 30	400 150
Multisilicon crystalline	Small Large	10 15	20 30	400 100
Thin-film silicon	Small large	10 15	20 30	130 50
Thin-film polycrystalline materials	Small large	10 14	20 30	100 40
Future (2020) Multifunction	large	30	30	24

.

2.23 Environmental effects of different energy technologies

Environmental costs arise from many factors and a valid comparison of the external costs of different energy sources must include all of these factors. There has been significant effort in Europe and USA to derive the external costs of electricity generation (Hohmeyer and Ottinger, 1991) and there is a growing consensus on the methodologies used in these calculations and on the external costs associated with the various technologies. Baumann and Hill (1991) have briefly reviewed these methodologies and have produced a matrix which allows a qualitative comparison of the magnitudes of the various components of the external costs for the various energy technologies. This matrix is shown as Fig-2.7, and it is clear that PV is the most environmentally benign of all electricity generation that technologies presently envisaged for large –scale use throughout the world



Acid pollutant (e.g. SO2, NOx)
CO2
CH4
Global warming
Human health and safety
Particulates
Heavy metals
Catastrophes
Waste disposal
Visual intrusion
Noise
Land requirement
Passive solar energy
Photovoltaics
Wind power
Biomass
Geothermal energy
Hydroelectricity
Tidal energy
Wave power
Coal
Oil
Natural gas
Nuclear power
Negligible
Negligible/significant
Significant
Significant/large
Large

review technical problems encountered and suggest solutions. The end-users are highly satisfied with the pumps and their operation. The pilot project demonstrated the great potential of PV energy in Indian agriculture [9].

In 2006/ 07 India's agricultural sector accounted for 22% of the total electricity consumption, up from 10% in the 1970s. There are about 21 million irrigation pump sets in India, of which about 9 million are run on diesel and the rest are grid-based. For huge loss, the Gujarat government introduced the Jyotigram Yojana, a programme that seeks to provide a reliable supply of power for agricultural and domestic purposes in rural areas. The program has a plan for the deployment of various solar PV applications, including water pumping systems. However, the deployment has been sparse thus far, with only 7,334 solar PV water pumps having been installed across the country as of March 2010 [9]. Water demand for irrigation is correlated to bright sunny days. Even so, small buffer storage might be needed to replace diesel satisfactorily. A solar PV water pumping system consists of a PV array, motor pump and power conditioning equipment, if needed. The power conditioning equipment is used to stabilize the fluctuating electrical energy output of the array. Depending on the total dynamic head and the required flow rate of water, the pumping system can either be on the surface or submersible and the motor can run on either alternating current (AC) or direct current (DC). For AC pumping systems an inverter is required. Ratings of pump sets are chosen depending on the water requirements, size of field, total dynamic head, type of irrigation (drip irrigation, use of sprinklers) and so on [10]. In Sri Lanka SAWM Project- phase I of the Ministry of Agriculture Development and Agrarian service which was launched in 2005.

-Delivered 5085 solar powered drip irrigation systems to farmers in the dry zone of Sri Lanka under a subsidized loan scheme to

- help them better manage their irrigation techniques,
- boost productivity
- reduce CO_2 emissions[12].

2.25 Opportunities in Bangladesh

Unlike conventional diesel or electrical pumps, solar photovoltaic (PV) pumps are powered by an array of solar panels. Solar PV pumps are designed to operate on DC power produced by solar panels. These pumps are gaining popularity all over the Bangladesh, especially in the areas where electricity is either unavailable or unreliable. Solar PV pumps are becoming a preferred choice in remote locations to replace hand-pumps, grid-connected electrical pumps and diesel pumps. In such places, solar PV pumps are even economically viable in comparison to conventionally run pumps.

Bangladesh is blessed with abundant solar energy and if harvested efficiently. There is need to come together and take initiative to create technologies for a greater use of these sources to combat change by reducing the emission of GHGs.

Bangladesh is situated between 20.30 and 26.38°N latitude and 88.04 and 92.44°E longitude, which is an ideal location for solar energy utilization. Daily global solar radiation varies between 5 and 7.5 kWh/m2/day. Solar PV technology is an important emerging option for electricity generation. So, densely populated tropical country like Bangladesh could be electrified by PV grid system using the inexhaustible and pollution free solar energy. Compensation of electricity shortage and reduction CO2 emission would be done by introducing solar energy sources for electricity generation in mass scale [13].

2.26 Example of solar pump implementation in Bangladesh: Bangladesh's first solar-powered irrigation pump, with a capacity of 11 KW, was installed in 2009 in the northern district of Naogaon by Grameen Shakti, a micro-finance institution that is supporting the expansion of renewable energy in rural areas. At present the pump lifts 400,000 liters of water each day from 100 meters below ground, which will increase to 500,000 liters during longer summer days. It allows farmers to irrigate their lands for a reasonable price. The government estimates that, once all the pumps are in place, their solar panels will save 675 MW hours of electricity per day, cut imports of diesel fuel by 47,000 tons per year, saving $45 million annually, and reduce carbon dioxide emissions by an annual 126,000 tons.

CHAPTER THREE

METHODOLOGIES

3.1 Introduction: The objective of this project is to estimate solar energy availability at various regions of Bangladesh, conduct a comparative study of Grid (based on diesel), Diesel and Solar irrigation pumps on the basis of GHG operational emission and estimate and compare of cost and payback period of diesel, grid and solar electricity based irrigation system at various zones of Bangladesh. Here the data of solar radiation and sunshine hour of 13 geographically dispersed areas of Bangladesh such as Bogra, Comilla, Dhaka, Dinajpur, Faridpur, Jessore, Khulna, Madaripur, Mymensingh, Rajshahi, Saidpur, Sylhet and Tangail from 2001 to 2010 is collected from Bangladesh Meteorological Department and comparison of the irrigational pump system on the basis of cost and payback period is done by visiting RDA (Rural Development Authority) at Bogra.

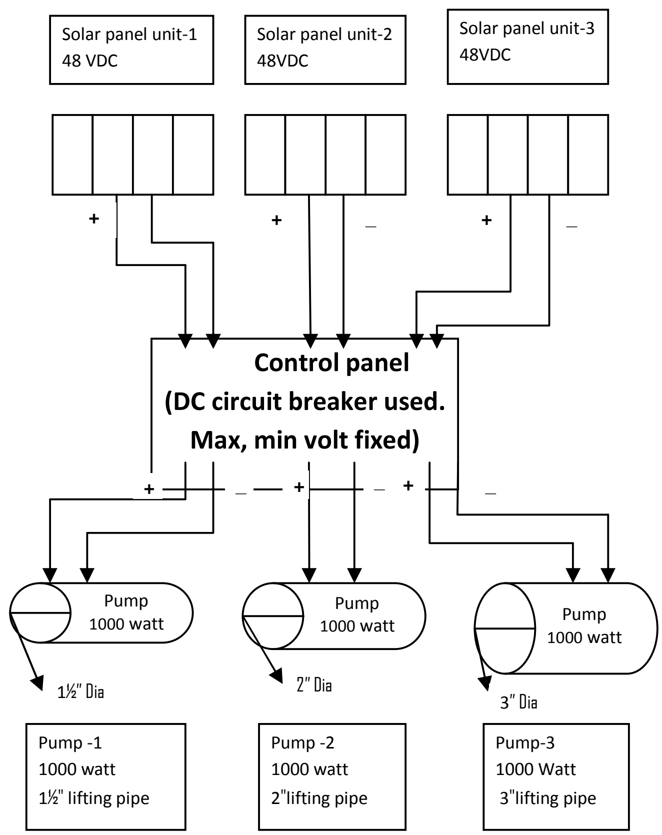


Fig 3.1 Flow chart of Keranigong Solar power pump

3.2 Case Study: **Keranigonj solar irrigation pump**

The water irrigation system designed allows its users to distribute water in areas that are difficult to reach, in a convenient and simple way. The solar irrigation system is an innovative solution that works independently of the electrical grid and therefore is very useful in rural areas that do not have access to the electrical grid.

According to analysis above is shown a solar pump design. Flow chart of Keranigong Solar power pump shown if figure 3.1. There are 3 solar units, 3 pumps and a control panel. Each unit of solar panel contains four panels (12v) and capacity of total panel array is 3 kWp. Solar panel units and motor lifting three pipes are connected to the 6" main bore well which depth is 120 feet and the static water level is 20 to 25 feet. The case study was carried out on Boro rice which is produced at the mid of the January to mid of the April. The Pilot project was carried out on 4 Bighas of land at keranigong, Dhaka.
This design committed to contribute to sustainable agriculture development, where the use of fossil fuels can be reduced by using solar energy systems.

3.2.1 System elements

- Solar system: This elements converts the solar energy into electrical energy
- Centrifugal pump: This element distributes the water by pumping it from one place to another, using the necessary energy or the adequate level of flow and pressure.
- Control panel: The control panel allows the users to adjust the received current from the solar panel to the rotation speed of the water pump.
- Tank: There is the option of installing water to be able to also use the irrigation system during periods when the sun radiation not received sufficiently or during hours of darkness of night.

3.2.2 Working principle:

These motors will start to work at minimum 24v.
From 7am-12 pm: At the starting of the day when solar panel start to get charging at least one motor will start to run.

From 12pm-3pm: At the middle of the day solar panel will be charged more than earlier and two motors can be run equally.

From 3pm-6pm: Solar panel can have its peak value at this time and can run three motors easily.

Moreover if motors lift more water than we need can preserve water by installing a tank for further purposes. In a solar panel due to the array of PV panels the voltage attains a constant level stating from beginning up to end. The variable parameter is current. When the sunshine or radiation is rising that time production of Current is less so capable of running one motor and subsequently two and three at a time. This system has been installed with the intention to obtain optimum discharge in any time of the day.

The schematic figure of the Keraniganj solar run irrigation pump is shown in figure-3.1 in below:

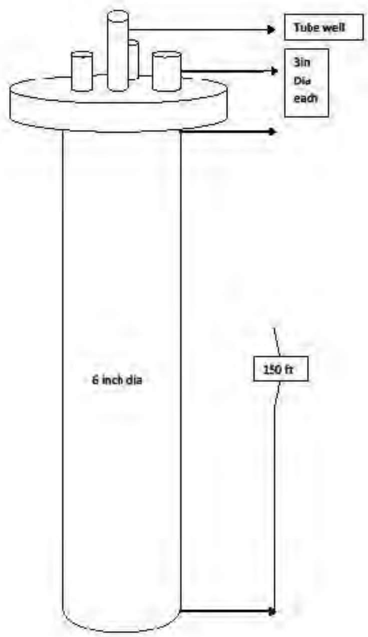


Figure 3.2 Keraniganj Solar Power Irrigation Pump Boring and Variable Pipes

3.2.3 Data of Motor and Pump Performances: The data of the Keraniganj solar power irrigation's motor & pump performances are shown in the tabular forms in tables-3.4, 3.5 & 3.6

Table 3.1-Motor & Pump-1(14-2-2011)

Time	RPM	Flow, Q Gal/15 mins
9:00	1558	-
9:15	1640	80.1
9:30	1604	81.9
9:45	1627	84.0
10:00	1672	86.0
10:15	1510	89.9
10:30	1697	92.2
10:45	1595	99.2
11:00	1651	100.0
11:15	1636	102.6
11:45	1641	104.7
12:00	1651	107.3
12:15	1609	108.2
1:00	1619	111.1
1:15	1612	113.6
1:30	1432	115.6
1:45	1315	117.1
2:00	At 2:00 pm as pump 2& 3 worked simultaneously , so to extract maximum yield pump 1 was kept stopped	
2:15		
2:30		
2:45		
3:00		
3:15		
3:30		
3:45		
4:00		
Total		**1494.3 gal/day**

Table 3.2-Motor& Pump -2(24-2-2011)

Time	RPM	Flow, Q Gal/15 mins
9:00	2027	-
9:15	2035	333.2
9:30	2116	335.6
9:45	2099	338.6
10:00	1916	341.5
10:15	1942	344.1
10:30	1942	346.2
10:45	1956	348.6
11:00	1960	351.6
11:15	1704	354
11:45	1697	355.1
12:00	1627	357.1
12:15	1657	360.5
1:00	1705	362.6
1:15	1712	366.5
1:30	1627	368.6
1:45	1711	373.2
2:00	1681	376.1
2:15	1707	378
2:30	1690	380
2:45	1699	382
3:00	1723	384.1
3:15	1575	386.3
3:30	1516	388.2
3:45	1495	389.9
4:00	1784	391.9
Total		**9,093.5 gal/day**

Table 3.3 -Motor & Pump -3(14-2-2011)

Time	RPM	Flow, Q, gal/15 mins
9:00	1884	-
9:15	1987	665
9:30	1976	667
9:45	1968	668
10:00	1998	671
10:15	1812	673
10:30	1770	674
10:45	1730	675
11:00	1773	677
11:15	1810	678
11:45	1697	682
12:00	1835	684
12:15	1757	685
1:00	1809	689
1:15	1796	691
1:30	1804	692
1:45	1785	695
2:00	1774	696
2:15	1728	697
2:30	1716	699
2:45	1647	701
3:00	1567	702
3:15	1777	705
3:30	1770	706
3:45	1666	707
4:00	1499	709
Total		**17,188 gal/day**

Note: While performing the experiment found that keeping the voltage in static condition, if current increases then discharge also increase and vice versa. With a fixed rpm of the motor, the discharge will remain the same but rpm of the motor do no remain same due to mechanical loss due to friction, electrical loss due to magnetic flux created by the v & i. That's why it was found that though the rpm increased but correspondingly discharge did not increase due to above causes discussed .During low insulation in the morning only motor -1 was acting due to the smaller size of the discharge pipe but when insulation increased, both motor-2 & 3 could operate simultaneously. In the case study it was suggested that operator's judgment to extract maximum yield, is very important. Total yield in Keraniganj demonstration test was 27,775 gal/day (= 108,322 lit/day) which is much more that daily requirement for a boro rice irrigation requirement for a 4 bigha of land.

Table 3.4 Greenhouse Gas Emission Reduction Analysis-Photovoltaic Projects

GHG operational emission based on IPCC guidelines for national greenhouse gas inventories are given in table 3.6 in below [24]:

Background Information						
Project Information Project name-PRE-RSF Pump Project Project Location-Dhaka			Global Warming Potential of GHG 1 tonne CH4 = 21 Tonne CO2 (IPCC 1996) 1 tonne N2O = 310 Tonne CO2 (IPCC 1996)			
Base Case Electricity System(Baseline)						
Fuel type	Fuel mix (%)	CO2 emission Kg/GJ	CH4 emission Kg/GJ	N2O emission Kg/GJ	Fuel conversion efficiency (%)	GHG Emission (t CO2/MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	12.3%	2.192
Proposed Case Electric System(Photovoltaic Project)						
Fuel type	Fuel mix (%)	CO2 emission	CH4 emission	N2O emission	Fuel conversion efficiency (%)	GHG Emission (tCO2/MWh)
Electric system Solar	100.0%	0.0	0.0000	0.0000	75.0%	0.000

GHG Emission Reduction Summary				
Electrical System	Base case GHG (tCO2/MWh)	Proposed case GHG emission factor (tCO2/MWh)	End use annual energy delivered (MWh)	Annual GHG emission reduction (tCO2)
	2.192	0.000	7.221	15.83
			Net GHG emission reduction tCO2/MWh	15.83

From the above chart it is found that using diesel as fuel causes net GHG emission of 2.19 kg/GJ. On the other hand solar pump system causes GHG emission of 0.00(Kg/GJ). It indicates that on GHG emission point of view the most suitable energy option for irrigation is PVP system.

3.2.4 Cost of PV Irrigation Pump

As solar powered pump is sponsored by IDCOL and donor agencies, so 40% of total cost is given as grant to encourage micro credit investor to collect less tool of cost of irrigation. DuringTangail visit it was observed that farmers earlier used to give ¼ of crop produced but now after solar power installation introduction they give 1/5 of crop produced. So as a result of new method farmers save (1/4-1/5) =1/20 crop produced.

3.2.5 Unit Electricity Cost

Probably the most valuable figure for comparing two electricity-generating systems is the net cost of generating each kilowatt-hour during the lifetime of each system. This can be determined from the ALCC as follows:

Electricity cost ($/kWh) = ALCC ($/year)/Electricity supplied (kWh/year)

The electricity supplied each year can be estimated as:

Electricity per year = I × AEm × Es × 365 kWh

Where I = average annual irradiation in kWh/sq-m/day

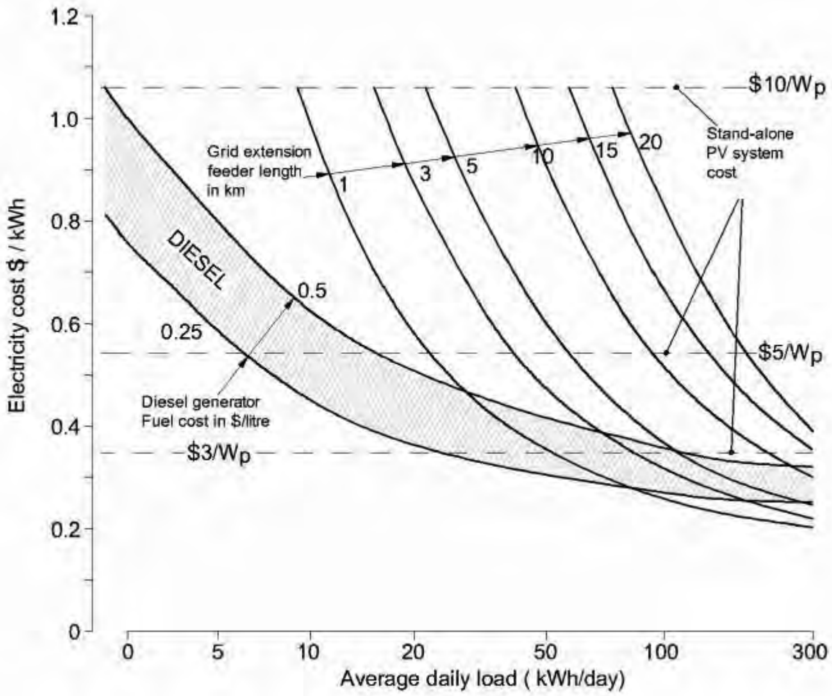
A = array area in m

E_m = module efficiency

E_s=system efficiency

365 = days in a year

When comparing two systems, it is often usual to see how the unit electricity cost varies depending on the size of the system, or to examine the effect of varying the module price, or the diesel fuel price. An example comparing the electricity cost of PV with that of diesel or an extension of the grid is shown in figure- 3.3.


1.2
1.0
0.8
0.6
0.4
0.2
0
Electricity cost $ / kWh
0
5
10
20
50
100
300
Average daily load (kWh/day)
$10/Wp
$5/Wp
$3/Wp
Grid extension
feeder length
in km
1
3
5
10
15
20
Stand-alone
PV system
cost
DIESEL
0.5
0.25
Diesel generator
Fuel cost in $/litre

CHAPTER 4

ANALYSIS OF DATA

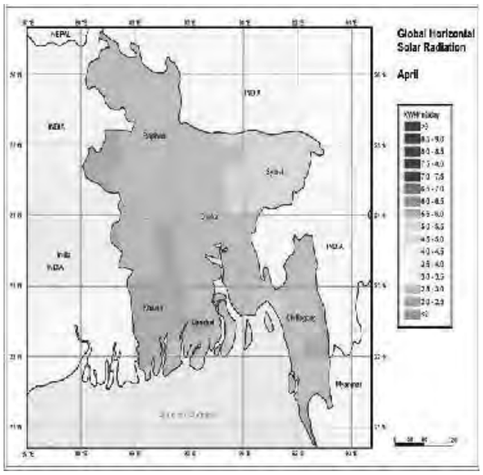
4.1 Introduction

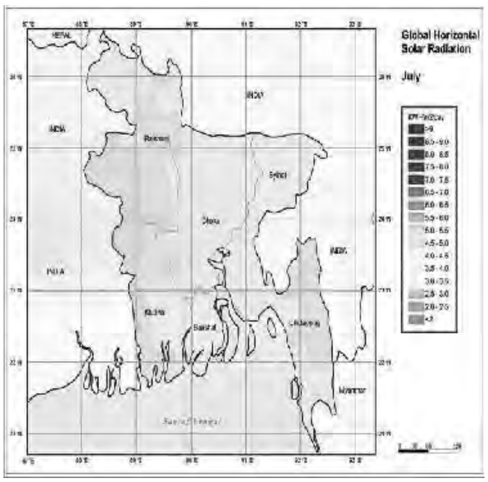
The designed water irrigation system allows its users to distribute water in areas that are difficult to reach, in a convenient and simple way. The solar irrigation system is an innovative solution that works independently of the electrical grid and therefore is very useful in rural areas that do not have access to the electrical grid. This system can contribute to sustainable agriculture development, where the use of fossil fuels can be reduced by using solar energy systems. The solar irrigation system allows its users to level amount of solar energy that is obtained with the amount of energy that is needed to distribute the water through an electronic control system, so that the irrigation can be performed in an optimal way. This chapter describes in details about the analysis part of the total project work covering the important aspects like solar radiation and sunshine hour in different zones of Bangladesh and quantity of CO_2 emission.

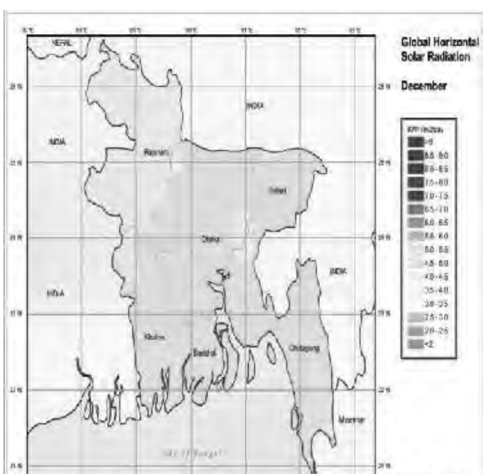
4.2 Solar Radiation and Sunshine Hour

The effectiveness of solar irrigation pump largely depends on the sunshine hour and solar radiation of a particular region. Monthly records of solar radiation (from January- December) of different districts of Bangladesh have reported and given in Appendix-B. Basing on these records, a comparison on the quantity of solar radiation can be made and the effectiveness of the designed solar irrigation pump can be assessed.

4.2.1 Monthly solar radiation: To get a preliminary idea the global horizontal solar radiation pattern is based on the monthly solar radiation data as given in Appendix A. Here, the average solar radiation has been recorded in April is 5.5-6 KWH/m2/Day, in July it is 4-4.5 KWH/m2/Day and in December it is 4.5-5.0 KWH/m2/Day. Figure 4.1, 4.2 and 4.3 show the variations of monthly solar radiation of Bangladesh representing three main crop seasons such as summer, rain and winter.


Global Horizontal
Solar Radiation
April
NEPAL
INDIA
Dhaka
Chittagong
Myanmar


Global Horizontal
Solar Radiation
July
NEPAL
INDIA
Dhaka
Sylhet
Khulna
Myanmar


Global Horizontal
Solar Radiation
December
NEPAL
INDIA
Dhaka
Khulna
Chittagong
Myanmar

4.2.2 Daily Radiation Pattern: The daily radiation pattern of Dhaka city and other district are based on the annual total radiation data whose 95% confidence level value has been given in Appendix-B For Dhaka the LCL radiation of January, 2011 has been recorded as 1.86 kWp m^2/d and UCL has been recorded as 2.1 kWp m^2/d .

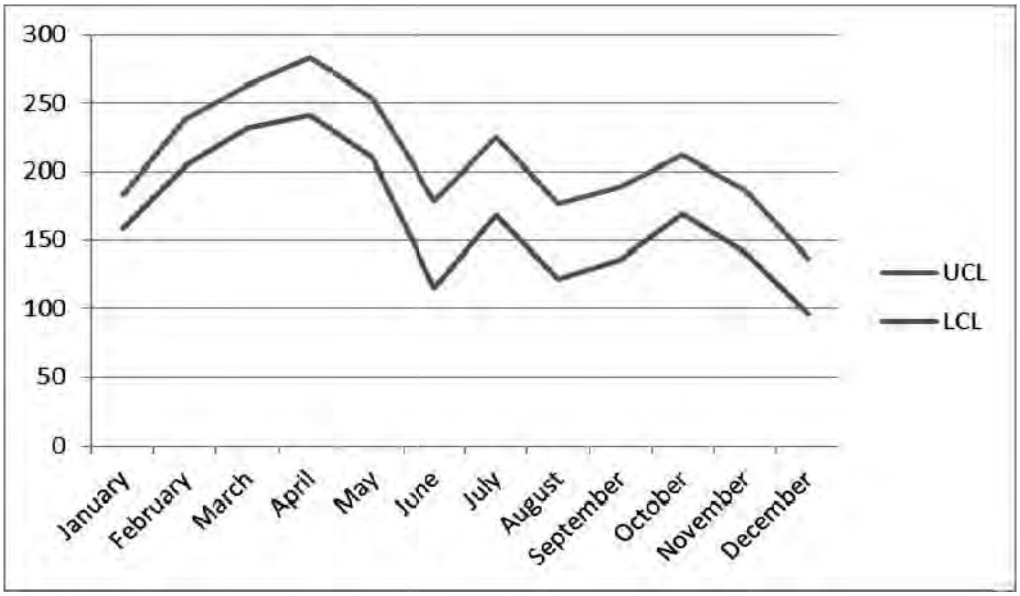


Figure 4.4 Figure of Monthly Solar Radiation of 2011 of Dhaka city (unit-cal/sq-cm/day)

4.3 Daily sunshine hour pattern in Dhaka city: The 10 year's daily sunshine hour pattern of Dhaka city is based on the annual total sunshine hour data whose average value has been given in Appendix C. Here the minimum sunshine hour has been recorded as 5.21935484 in the year of 2003 and maximum was 7.93870968in the year 2001.

4.3.1 Pattern of Dhaka City from 2001 to 2010(January)

Basing on the average monthly sunshine hour of10 years, a general trend can be developed. Figure 4.5 shows about the daily sunshine hours in January (10 years data considering in Dhaka City). Figure 4.6 shows the variation of average sunshine hour per month. The variation of sunshine hour also can be obtained from the difference of UCL and LCL, which is shown in table 4.5. Here UCL and LCL represent the upper control limit and lower control limit of daily sunshine hour which accuracy is 95%.

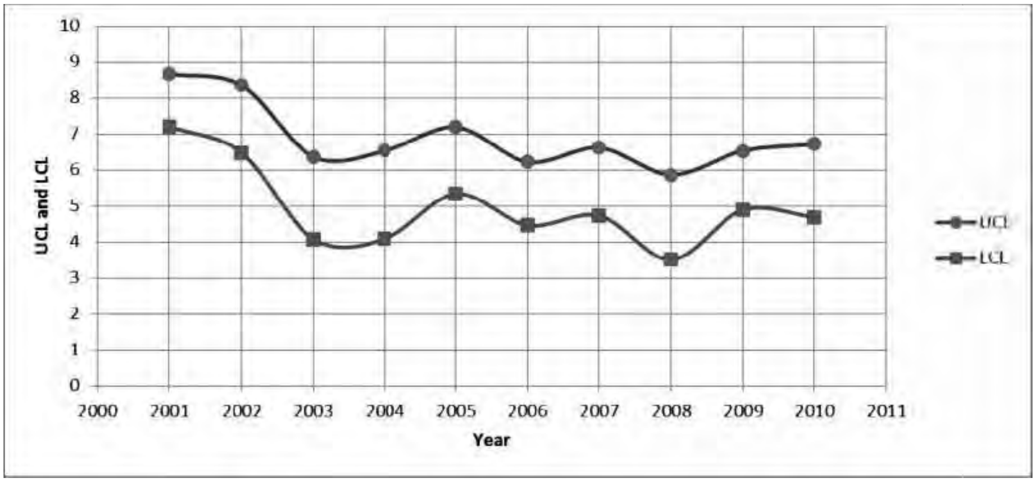


Figure 4.5 Daily Sunshine Hours in January

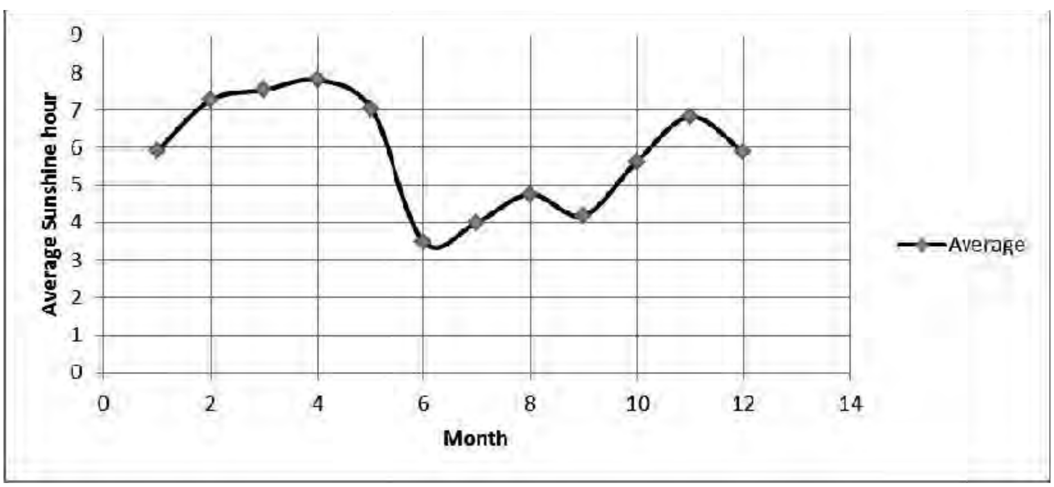


Figure 4.6 Average Sunshine Hour Variation per Month of Dhaka City.

4.4 CO_2 emission:

Table 3.5 shows that Greenhouse Gas (GHG) Emission Reduction Analysis in Photovoltaic Project. It is observed that when Diesel (#2 oil) is used as fuel CO_2 emission is 74.1 kg/ GJ, CH_4 emission is 0.0020 Kg/ GJ, N_2O emission is 0.0020 Kg/ GJ and total GHG emission is 2.19 tCO2/MWh. On the other hand, when solar pump is used CO_2, CH_4 and N_2O emission

Segment	1	2	3	4
Area within segment	1Bigha	1Bigha	1Bigha	1Bigha
Day of Irrigation	1	2	3	4

1.Place name:	Savar, Hemayetpur Solar Powered Irrigational Pump
2. Established by:	RAHIM AFROZ
3. Grid resistance	Northing= 23˚46’ 3” Easting = 90˚ 15‘58”
4. Command Area	20 acre
5. No of pipe delivery	3“
6. PV Panel	32×5=160nos Each panel WP=75 WP, so total=160×75=12 kw
7. System voltage	32(no of panel)×12=384 v
8. Amp=	n/a
9. Hp	5-7.5 Hp
10.Pump	Dc pump, Lorentz
11.Static Head	65‘
12. Pump controller	is introduced
13. Total expenditure	32~35 lac in year 2007
14. Interval of irrigation	3~4 days interval

1.Place Name	Tangail, Nagar Jalfai, Polli Biddut Office
3.Established By	RAHIM AFROZ
4.Grid resistance	Northing= 24˚ 14‘ 33” Easting = 89˚56‘ 35”
5. Command Area	15 acre
6.Pv Panel	28 PV panel
7. Wp	3.36 kWp
8. Diameter of Discharge Pipe	3“
9.System Voltage	168 v
10.Layer,water	30‘
11.Hp	5 Hp
12.Pump	DC pump
12.Static Head	80‘
13. Pump Controller	is introduced
14.Expenditure	n/a

Table 4.3: Information Regarding Visited Installation of Solar Powered Pump

1.Place name:	Pukuriapara, Nachol,system type:1800 Wp	Bandhupara, Porsha,system type:1200wp,13000 litre/day	Soyedpur, Potnitola, system type:1200 Wp,13000	Sitoldanga, Sapahar, system type: 1800Wp, 26,000 Litre/day
Overhead pipe	3“ diameter and 35 foot from ground	1.5“ diameter and 35 foot from ground	1.5“ diameter and 35 foot from ground	1.5“ diameter and 35 foot from ground
Total original boring depth	128 foot			162 foot
Measured boring depth by us	126 foot	97 foot	74 foot	156 foot
Pump	121 foot from	92 foot from ground	69foot from ground	131 foot from

depth	ground			ground
Instructed operation time	Dawn to dust	One hour in full sunlight time	One hour in full sunlight time	Dawn to dust
Sunlight condition	Full sunlight from morning 7 am. But small shadow in the late afternoon	Full sunlight from morning 8 am to afternoon 4 pm.but shadow in the morning &afternoon due to trees.	Very good sunlight condition	Poor sunlight condition. From 9.30 Am (due to the shadow of the tank) to 4PM (due to some trees)
Specific operator	none	none	none	none
Potential threat to the system	1.No. specific operator for proper maintenance & operation of the system 2.Missue by the customer	1.No. specific operator for proper maintenance &operation of the system 2. Well capacity is not sufficient to provided required water. 3.Missue by the customer	1.No. specific operator for proper maintenance& operation of the system 2. Well capacity is not sufficient to provide required water. 3. Misuse by the customer. 4. System security.	1.Security 2. No specific operator for proper maintenance& operation of the system 3. Severe misuse by the customer.

4.6 Environmental Comparisons

The environmental impacts of photovoltaic power generation are analyzed in this section. The energy used in manufacturing the PV modules and the other components of the PV system is derived from various components which has somehow effects either directly or indirectly and is therefore associated with emissions of greenhouse gases and acidic gases.

This compares with the CO_2 output from the most modern and efficient coal-fired plant of 9 million tons per gig watt-year (1991). Boiling water reactors have been estimated to emit about 75,000 tons of 2 per gigawatt-year (palz and zibetta, 1991), mainly from the fuel production steps, but this estimate did not include the energy used for decommissioning and waste treatment and storage. The materials for construction of the complete PV system other than the PV modules are steel, aluminum, copper, concrete, and electronic equipment, with which are associated the standard industrial hazards. The hazardous emissions from the various different types of solar cells are summarized in table 4.4

Table 4.4: The Hazardous Emissions from the Various Different Types of Solar Cells

Material	Production	Operation	Disposal
Silicon	Silica dust Silanes Diborane Phosphane Solvents		
Copper indium diselenide	Hydrogen selenide Cadmium oxide Cadmium dust Selenium solvents	Cadmium Selenium (in a fire)	Cadmium Selenium (if not recycled)
Cadmium telluride	Cadmium oxide Cadmium dust Tellurium Solvents	Cadmium Tellurium (in a fire)	Cadmium Tellurium (if not recycled)

Note: Though disposal materials are heavy materials but as these are recycled, so no chances of polluting the environment.

4.7 Economic and financial comparison

4.7.1 Economical Benefit

Economic analysis consists of the Comparing pumping system with the existing diesel pumping system for irrigation. In Bangladesh adaptation of irrigation techniques is reported to play a vital role in the improvement in the yield of food grain. It is roughly estimated that the number of diesel engines in Bangladesh is more than 700000 which are used for irrigation and consumed a lot of diesel fuel. Every year Bangladesh imports more than 146000 billion liters of oil from other countries, which impacts the Bangladesh economy.

Example: The fuel costs for a particular diesel generator are \$ 50 per year. And it might be assumed that diesel fuel prices will rise at 5% above inflation. Assuming a discount rate of 10% and a length of analysis of 20 years, Table 4.5 (with i= 0.05, d =0.1, and N =20) gives a cumulative discount factor Pa of 12.72. The present worth of the diesel fuel costs is therefore:

PW = \$50×12.72 = \$636

Table 4.5: Selected Values of Present worth Factors Pa for an Annually Recurring Cost

Discount rate (d)	Inflation rate (i)	Factor Pa for given number of years				
		5	**10**	**15**	**20**	**30**
0.00	0.00	5.00	10.00	15.00	20.00	30.00
	0.05	5.80	13.21	22.66	34.72	69.76
	0.10	6.72	17.53	34.95	63.00	180.94
	0.15	7.75	23.35	54.72	117.81	499.96
	0.20	8.93	31.15	86.44	224.03	1418.26
0.05	0.00	4.33	7.72	10.38	12.46	15.37
	0.05	5.00	10.00	15.00	20.00	30.00
	0.10	5.76	13.03	22.21	33.78	66.82
	0.15	6.62	17.06	33.51	59.44	164.68
	0.20	7.60	22.41	51.29	107.59	431.39
0.10	0.00	3.79	6.14	7.61	8.51	9.43
	0.05	4.36	7.81	10.55	12.72	15.80
	0.10	5.00	10.00	15.00	20.00	30.00
	0.15	5.72	12.87	21.80	32.95	64.27
	0.20	6.54	16.65	32.26	56.38	151.24
0.15	0.00	3.35	5.02	5.85	6.26	6.57
	0.05	3.84	6.27	7.82	8.80	9.81
	0.10	4.38	7.90	10.71	12.96	16.20
	0.15	5.00	10.00	15.00	20.00	30.00
	0.20	5.69	12.73	21.44	32.22	62.04

4.7.2 Financial Benefit[24].**:** Through software named RETScreen the following analysis were done for a Solar Pump Project at Dhaka to find an alternative energy source considering a baseline fuel system. Here solar energy was considered as baseline in comparison to the diesel run energy system.

Solar radiation (horizontal)=1.77 MWh/sq-m
Solar radiation (tilted surface)=2.29 MWh/sq-m
Average temperature=26.9 deg cel
Daily water requirement = 600 meter cube/d
Initial cost=32,18,870 BDT
Annual costs(credits)=66,000 BDT
Periodic costs(credits)=5,00,000 BDT
Life cycle=20 yrs
Pre- tax IRR and ROI = 9.7%
After-tax IRR and ROI = 9.7%
Simple payback= 11.5 yrs
Year –to-positive cash flow=9.8 yrs
Net Present Value,NPV= 13,94,446 BDT
Annual life cycle savings=1,11,894 BDT
Benefit-cost(B-C) ratio= 1.62
Renewable energy delivered (MWh/yr)=7.221
Net average GHG reduction(tco2/yr)=15.83

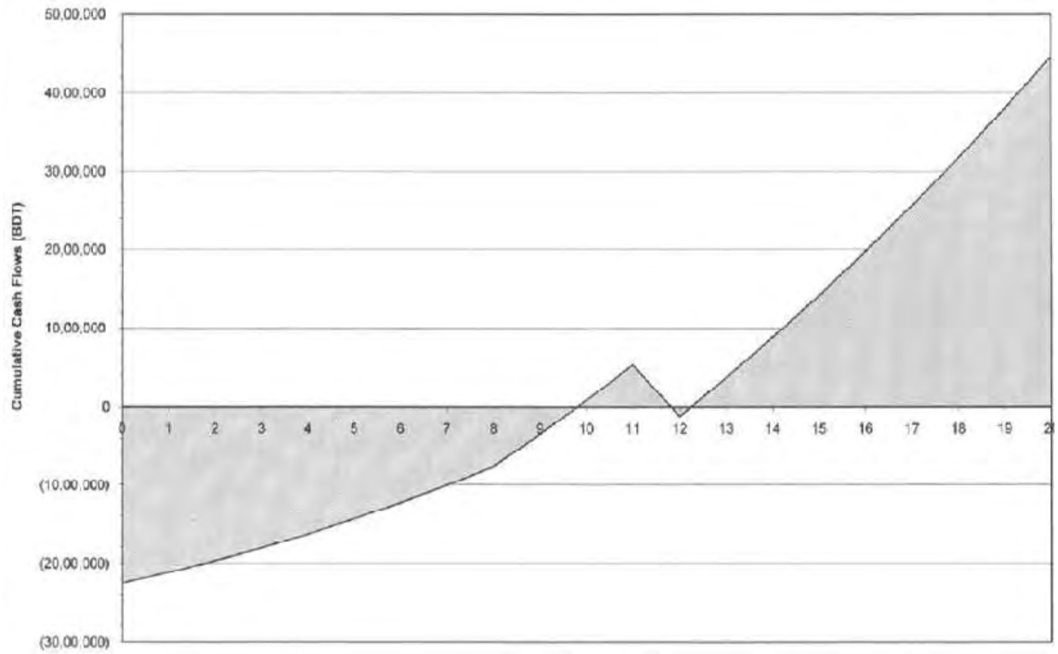


Figure 4.11 Photovoltaic Projects Cumulative Cash Flows RRE-RSF Pump Project, Dhaka

Details are given in appendix D.

4.7.3 Life cycle costing comparison : PV vs diesel generating system[18].

Period of analysis = 20 yrs

Discount rate =10%

Annualisation factor, Pa =8.51 with no inflation rate

Table 4.6 Life cycle costing comparison : PV vs diesel generating system

PV Calculation		**Diesel Calculation with 5 KVA low speed diesel engine**	
Load	2 kWh/d	Load	2 kWh/d
Battery efficiency	70%	Generator	3000$
Demand of array	2.86kWh/sq-m/d	Installation	600$
Days of battery storage	5 d	Installed capital cost	3600$
Design insulation	5.5 kwh/sq-m/d	O&M Cost	360$
Array mismatch factor	0.9	Life cycle O&M	3064.88$
Module price	4.5 $/Wp	Diesel price	0.85$/lit
Battery price	100$ kWh	Engine efficiency	25%
Array cost (lifetime 20 yrs)	2597.4 $	Diesel consumption	11 kWh/lit
Battery cost	nil	Diesel usage	0.73 lit/d
Support/wiring	866$	Diesel cost	226$
Power control	50$	Life-cycle fuel cost	1927 $
Capital cost	3513.2$	Replacement cost	
Installation	902.64$	Generator	nil
Total installation cost	4,415.84$		
O& M Cost	108.32$/yr		
Life-cycle O&M Cost	922.16 $		
Recurring cost			
Array	nil		
Battery	nil		
Support/wiring	nil		
Power control	19.28 $		
Total replacements	19.28 $		
Life cycle cost	5465.6$	Life cycle cost	8591 $
Annualised LCC	642.26$	Annualised LCC	1010 $
Unit electricity cost	0.88$/kW	Unit electricity cost	1.38 $/kW

Note: As the diesel price is most of the time increase so, it is clearly proved that unit electricity cost if considered with present worth value than it is less in PV system. Here for the irrigational purpose battery's expenditure was not considered as instantaneous generation of the electricity will continuously deliver water supply. Moreover, if we take the local products into consideration than unit electricity cost will be reduced further.

COST OF IRRIGATION

4.8 Introduction

The study was undertaken by Integrated Water Resources Management Unit (IWRMU) of Local Government Engineering Department (LGED) and centre for Integrated Water Management (CIWM), Rural Development Academy (RDA), Bogra during the boro rice growing season in 2010-2011.

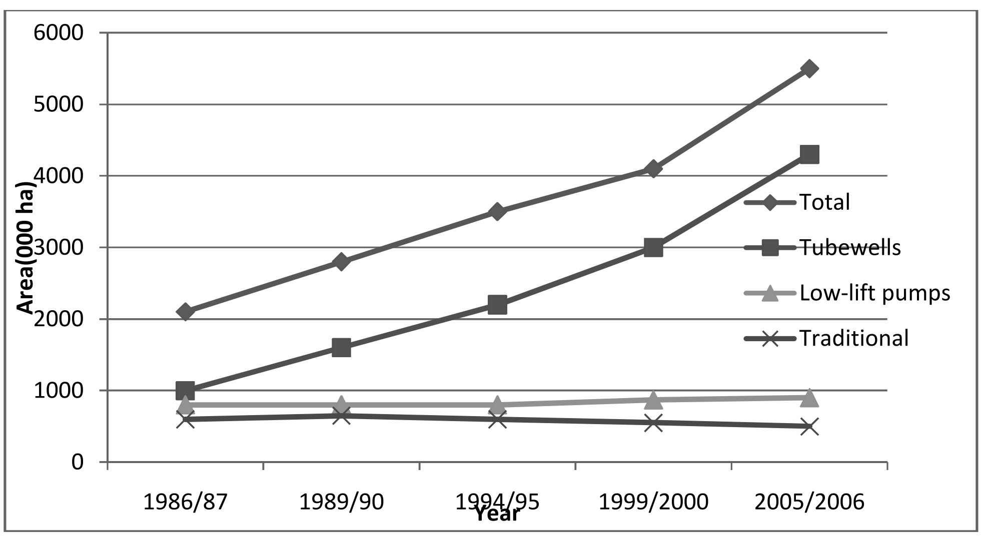
4.9 Water Resources

Water resources in the country are comprised of different forms of accumulation of water as surface water, streams, water courses, estuaries, wetlands, water bodies, aquifers and groundwater. Bangladesh has large network of rivers, streams and drainage channels. There are about 230 rivers including three major and 57 medium and small trans-boundary rivers with a length of 24,000 km and area of 9,770 sq km or about 7 percent of the country (Mukhlesuzzaman, 2003). The catchments of the major rivers, which cover about 1.7 million sq km, lie in China, Nepal, Bhutan, India, Myanmar and Bangladesh.

Annual potential recharge of groundwater is about 400 to 600 mm, which corresponds to 25 billion m^3. Most of the recharge occurs during the monsoon, when trans-boundary rivers flow and rainfall is high (Hossain, 2003). Average annual rainfall in the country is 2,320 mm of which about 80 percent occurs in the monsoon season. Precipitation varies from 1,110 mm in the west to 5,690 mm in the northeast. The country is regularly subjected to drought in early monsoon and post monsoon seasons. The internal renewable surface water resources are estimated at 105 km^3 per year. This includes 84 km^3 of surface water and about 21 km^3 of groundwater resources produced within the country, although source of the groundwater also includes the infiltration of surface water with an external origin. The total renewable water resources are therefore estimated at 1,210.6 km^3. Groundwater is the source of about 80 percent of the total irrigated area and the surface water is used to irrigate the remainder.

4.10 Irrigation Technology

Currently, STWs, LLPs and DTWs cover about 62 percent, 17 percent and 15 percent of the total irrigated area, respectively (Rahman, 2009 and BBS, 2008). Gravity and irrigation


6000
5000
4000
3000
2000
1000
0
Area(000 ha)
1986/87
1989/90
1994/95
1999/2000
2005/2006
Year
Total
Tubewells
Low-lift pumps
Traditional

4.11 Irrigated Area

Presently, cereal or food grain growing area throughout the year covers about 11.1 million ha. About 60 percent of the total cereal crop growing area is under the rain fed condition now compared to 90 percent in late 1970s. The cereal crops growing area under irrigated condition has increased to 43 percent from 7 percent during the same period. Irrigation for boro (winter) rice, wheat, potato and vegetables has increased noticeably (table 4.1). The crops, grown in the dry season, account for almost four-fifth of the total irrigated area.

Table 4.7: Changes in irrigated crop area (‘000 ha)

Rice	**1978/1979**	**2005/2006**
Aus (pre-monsoon season)	30	86
Aman (monsoon season)	160	470
Boro(winter/dry season)	713	3869

Irrigation is mainly practiced in the dry season to produce winter (Boro) rice accounting for more than two-thirds of the total irrigation area.

Combination of three factors contributed to the rapid expansion of irrigation area. Firstly, the country’s arable lands are mostly alluvial plains underline by good shallow aquifers and crisscrossed natural waterways. Secondly, accelerate pace of technological transformation made STW very attractive for the farmers that accounts nearly two-thirds of total irrigation area in the country. Thirdly, the government is rationalized irrigation development led to much needed policy reforms, institutional adjustments and program changes.

Table 4.8: Operations of Irrigation system

A. Netrokona

Description	Private			Public (Large Scale)	Public and Community
	STW	DTW	Cross-Bundh	BWDB	LGED
Irrigation source	Groundwater	Groundwater	Khal	River	River
Irrigation season	Dry	Dry	Dry	Dry	Dry
Land type	High, med high	High, Med high	Low	Low	All types
Soil type	Sandy loam	Sandy loam	Clay, sandy loam	Loam	Clay, sandy loam
Name of crop irrigated	Boro rice	Boro rice	Boro rice	Boro rice	Boro rice
Irrigated area(ha)	10	24	18	800	100
Irrigation beginning date	Early Jan	Med Jan	Early Jan	Early Dec	Early Jan
Irrigation ending date	Later April	Later April	Mid Jan	Mid mar	Late Apr
No of irrigation per crop	35-40	20-25	30-35	30-35	20-25
Method of irrigation	Earthen canal	Earthen /lined canal	LLP, Earthen	LLP , Earthen	LLP, Earthen

			canal	canal	canal
Irrigation interval(day)	2-3	3-4	3	3	3-4
Time per irrigation (hr)	3-4	3-4	3-4	5-6	3-4
Crop yield (ton/ha)	6.7	6.3	6.9	7.4	7.0
Irrigation fee(tk/ha)	2500+250 litter diesel	7500	3200+210 litre diesel	450+180 litre diesel	3700-5000+400 kg rice
Fee collection method	In advance	Post harvest	In advance	In advance	2 instalments
Action against defaulter	No supply	Pay next season	No supply	No supply	No supply
Irrigation cost(tk/ha):					
Electricity bill	-	50000	-	-	185000
Diesel procurement	-		-	-	-
Manager salary	-		-	-	20000
Operator salary	-	30000	-	-	65000
Canal development, repair	-	10000	-	-	30000
Other	-	50000	-	-	75000

B.Gopalgonj

Description	Private	Public (large-scale)		Public and Community
	STW	BWDB	BADC	LGED
Irrigation source	Ground water	Khal	Khal	Khal
Irrigation season	Dry	Dry	Dry	Dry
Land type	Medium low	Low	Medium low	Medium low
Soil type	Loam	Clay	Loam	Loam
Name of crop irrigated	Boro rice	Boro rice	Boro rice	Boro rice
Irrigated area (ha)	3	40	200	700
Irrigation beginning date	Late Dec	Late Dec	Late Dec	Late Dec
Irrigation ending date	Early May	End Apr	Early May	End Apr
No of irrigation per crop	70	40	70	40
Method f irrigation	Earthen canal	LLP, earthen canal	Floating pump, earthen canal	LLP, earthen canal
Irrigation intervals (day)	1-2	2-3	2-3	2-3
Time per irrigation (hour)	10	5	Flood Irrigation	5
Crop yield (ton/ha)	6.9	8.0	6.9	6.9
Irrigation fee (tk/ha)	¼ of the produce	10000+160 litre diesel	4500, many users fail to pay	100000+1663 litre diesel, not paid by all
Fee collection method	3 instalments	3 instalments	3 instalments	3 instalments
Action against defaulter	Community action	Community action	Difficult to take action	No supply in next season
Irrigation cost (tk/ha):				
Electricity bill	-	-	550000	-
Diesel procurement	32200	-	-	-
Manager salary	-	-	-	-
Operator salary	-	-	6000	-
Canal development, repairing	5000	-	-	-
Other	1000	-	-	-

C.Sherpur

Description	Private	Public (large-scale)	
	STW	BWDB	DAE
Irrigation source	Ground water	River	River
Irrigation season	Dry	Dry	Dry
Land type	Medium high, low	High, Medium high, low	High, Medium high, low
Soil type	Sandy Loam	Loam, Sandy Loam	Loam, Sandy Loam
Name of crop irrigated	Boro rice	Boro rice	Boro rice
Irrigated area (ha)	12	210	2800
Irrigation beginning date	Late Dec	Mid Dec	Late Dec
Irrigation ending date	Early May	Late Apr	Mid May
No of irrigation per crop	28-30	20-25	25-30
Method f irrigation	Earthen canal	LLP, earthen canal	Lined and earthen canal, LLP
Irrigation intervals (day)	2-3	3-5	3-5
Time per irrigation (hour)	2-3	2-3	2-3
Crop yield (ton/ha)	6.0	5.6	6.0
Irrigation fee (tk/ha)	10000	3500+75 litre diesel	750 (gravity), 4500+150 litre diesel
Fee collection method	2 instalments	2-3 instalments	2 instalments
Action against defaulter	Not required	Not required	Not taken
Irrigation cost (tk/ha):			
Electricity bill	35000	80000	60000
Diesel procurement	-	Procured by water users	11000
Manager salary	-	522000 (29 managers)	-
Operator salary	10000	12000 (2 operators)	90000(3 operators)
Canal development, repairing	1000	30000	-
Other	8000	15000	100000

D.Moulovibazar

Description	Private		Public	Public and Community
	STW	Traditional	BWDB	LGED
Irrigation source	Ground water	Khal	River	Stream
Irrigation season	Dry	Dry	Dry	Dry
Land type	Medium low, low	Medium low, low	Medium low, low	High, Medium high, low
Soil type	Loam	Clay, loam	Clay, Loam	Clay
Name of crop irrigated	Boro rice	Boro rice	Boro rice	Boro rice
Irrigated area (ha)	16	80	12000	200
Irrigation beginning date	Early Jan	Early Jan	End Jan	Early Jan
Irrigation ending date	Late Apr	Early Apr	Mid Apr	Mid Apr
No of irrigation per crop	15-16	‘10-12	12-13	8-9
Method of irrigation	Earthen canal	Earthen canal	Canal	Earthen canal
Irrigation intervals (day)	5-7	8-10	8-10	12-14
Time per irrigation (hour)	3-4	2-3	2	3
Crop yield (ton/ha)	4.2	4.0	4.9	4.5
Irrigation fee (tk/ha)	3000+120 litre diesel	188*	800	60**
Fee collection method	3 instalments	-	-	-

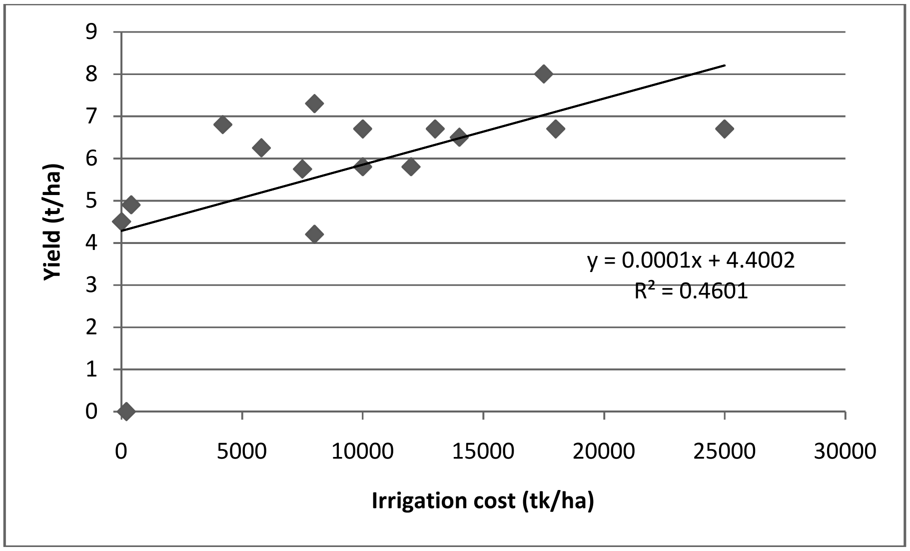
Action against defaulter	Persuasion	-	Dialogue	-
Irrigation cost(tk/ha)	-	-	NA	-
Electricity bill	-	-	-	-
Diesel procurement	-	-	-	-
Managers' salary	-	-	-	-
Operators' salary	-	-	-	-
Canal dev ,repairing	5000	5000	-	7000
Other	8000	10000 (Bundh construction)	-	5000

*Union parishad pays the expenses. **WMCA pays the expenses from O&M fund.

E.Habiganj

Description	Private		Public	Public and Community
	STW	Traditional	BWDB	LGED
Irrigation source	Ground water	River	River	Hilly stream
Irrigation season	Dry	Dry	Dry	Dry
Land type	Medium high	Medium high	Medium high	Medium high
Soil type	Clay	Clay	Clay, Sandy	Loam, clay
Name of crop irrigated	Boro rice	Boro rice	Boro rice	Boro rice
Irrigated area (ha)	25	40	80	150
Irrigation beginning date	Late Dec	Late Dec	Late Dec	Late Dec
Irrigation ending date	Early Apr	Early Apr	Early Apr	Mid Apr
No of irrigation per crop	18	18	50	40
Method of irrigation	Earthen canal	LLP, Earthen canal	LLP, Earthen canal	Gravity diversion, earthen canal
Irrigation interval(day)	6	5	3	3
Time per irrigation(hr)	18	16	15	24
Crop yield(ton/ha)	4.7	4.7	6.0	4.7
Irrigation fee(tk/ha)	15000+600 kg rice	1500+600 kg rice	6300	1500,reluctant to pay
Fee collection method	2 instalments	2 Instalment	2 instalment	No action taken yet since the operation in 2009
Action against defaulter	No supply next year	No supply next year	No supply next year	
Irrigation cost(tk/ha):		-	-	-
Electricity bill	15000	-	60000	-
Diesel procurement	-	100000	-	-
Managers' salary	-	-	20000	-
Operators' salary	-	18000	15000	-

Canal dev, repairing	30000	15000	60000	10000
Other	-	-	135000(procure ment)	-



Name of Location	Public & Community (LGED)
Netrokona	13,000 tk
Gopalgonj	20,800 Tk
Sherpur	14,700 Tk
M. Bazar	16,000 Tk
Habigonj	15,000 Tk

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Introduction

A thorough study was carried out to find the suitability of using solar power irrigation in Bangladesh considering it's inherent benefits of no emission of GHG while generating electricity but in context of Bangladesh, economical and financial aspects also play a predominant role before introduction of any new system. Through data analysis deductions have been drawn about the feasibility of solar power harnessing in Bangladesh and data are produced about the environmental effects of traditional systems.

5.2 Pump efficiency based on available solar radiation and sunshine hour

From figure 4.1, 4.2 1nd 4.3 shows that the average global solar radiation has been recorded in April is 5.5-6 KWH/m2/Day, in July it is 4-4.5 KWH/m2/Day and in December it is 4.5-5.0 KWH/m2/Day which is sufficient enough to generate electricity out of solar PV panel and represent three different seasons. It also shows that the variation is 3-7 hours from January to December basing on data from the year 2001 to 2010. From February to May the average sunshine hour value is 7 hour and in January it is 5.9 hours which is also above the irrigation daily hourly requirement for Boro rice production. It has been found during the installation of the solar energy power pump in Keranigonj for the cultivation of Boro paddy crops during mid-January to late April (3.5 months). This solar pump is designed on the assumption of peak sunshine at 5.5 hrs/day and 3 times' manual tracking.

On the other hand from working principal of the solar pump it is observed that from 7am-12 pm, at the starting of the day when solar panel starts to get charging at least one motor will start to run. From 12pm-3pm, at the middle of the day solar panel will be charged more than earlier and two motors can be run equally. From 3pm-6pm, solar panel can have its peak value at this time and can run three motors easily. Figure 4.6 shows that average sunshine hours of January are 5.9. Solar pump works fully during 12pm -3pm (3 hours) which indicates that proper sunshine hour is available for the optimum utilization of the solar pump.

5.3 Reduction in GHG emission

Table 3.4 shows that total GHG emission in Diesel (#2 oil) is 2.19 tCO2/MWh. On the other hand, in solar pump total GHG emission is 0.00 Kg/GJ. Finally it shows that solar pump can reduce annual GHG emission by 15.83 (tCO2/MWh), so total 1685 MWh of grid peak irrigation demand if replaced with solar power can save 9,95 million tons of CO2 and diesel irrigational engines if replaced can save 2.873 mil tons of CO2, In total 12.823 million tons of CO_2 .

5.4 Threats in the solar pump

There are some potential threats to installed solar powered pump in the study area. In most cases, there are no specific operator is appointed for proper maintenance & operation of the system. Well capacity is not sufficient to provide required water. Water is severely misused by the customers. All the deficiency must be eliminated from the area. Security of the system has to be ensured to make the project successful.

5.5 Effect of hazardous material

5.5.1 Total Result

According to table 6.2 It is interesting to note that the amount of cadmium contained in the CdTe modules needed to generate energy of, say, 1 GWh over their lifetime is about equal to the cadmium emitted from the smoke-stack of a typical coal-fired station whilst generating the same 1 GWh of electrical energy. So the effect of cadmium is negligible in comparison to the other cadmium generating sources.

5.5.2 Deductions

In CIS modules, the amount of cadmium used is about 0.04 gm/m^2, equivalent to 400 gm per MWp of output. This tiny amount of material is easily controlled during manufacture. The quantity of cadmium in the CdTe modules increases the potential hazards during operation and disposal compared to those with CIS cells. In operation the modules can leak cadmium into the environment only if they are broken or subject to high temperatures. Broken modules pose little hazard as the area of cadmium exposed by even a break across the entire module would be 3mm^2, and broken modules would be replaced quickly in routine maintenance. According to result if 1 GWh over their lifetime is about equal to the cadmium emitted from the smoke-stack of a typical coal-fired station whilst generating the same 1 GWh of electrical energy. Very little of the cadmium in the PV modules would be lost into the environment, so the PV plant is cleaner, even for cadmium emissions, than a coal-fired power station.

5.6 Economical and Financial Benefit

After economic analyzing, it is shown that Photovoltaic pumping system for irrigation in Bangladesh is more feasible than Diesel engine –pumping system. The Figure in fig4.8 shows that after 9.8years, the cumulative cash flow reaches the positive value of 82,416 BDT. It also shows after 20 years the total cash flow is 44, 67,123 BDT. The Figure in fig4.9 .is computed for an insulations level of 5.5 kWh/m2 day indicates that on the basis of life cycle costs, diesel will be cheaper than PV for anything above the smallest of loads (2-3 kWh/day) at the current PV system cost around $10/W. However, with the anticipated fall towards $3/W over the next 20-30 years. So according to the analysis in section 4.5 PV will become economically attractive at much greater loads. Only one season irrigation is a little bit higher than the diesel engine pumping system due to high cost of PV module and its components. For two or three seasons irrigation PV- pumping system is lower than diesel pumping system.

CHAPTER 6

CONCLUSION & RECOMMENDATION

Water pumping is an energy intensive activity and consumes a large amount of diesel and electricity. Solar pumping systems are inherently more reliable than diesel powered systems. Based on our findings through the case studies, the learning outcomes can be summarized as follows:

6.1 Conclusions

1. Solar power irrigation in though is in initial stage level but due to the gradual depletion of non-renewable energy in far future,It's uses will be increasing with courses of time. Solar power irrigation pump while in operation do not emit any GHG (while manufacturing produce some GHG which is very negligible and most of the parts are re-cycleable) which is most remarkable positive attributes to this system. Though for the entire world including Bangladesh the effect of GHGs cannot be ignored in any way but due to the economical and financial perspective of Bangladesh, side by side GHGs parameters were also given due importance and found that for short term effect if not very viable but for long term effect this method is viable well because PV life is almost 20 years. To match with the present cost of irrigation subsidy in terms of grant and micro-credit system are encouraged to make this.

2. The advantage of the solar power is non-polluting. The GHG emission of diesel is very high. The emission can be reduced by implementing solar powered pump as it emits no GHG.A small amount of hazardous materials emits from PV modules but the effect of hazardous materials are reduced substantially by recycling process.

3. Though the installation cost of solar pump is high but according to year cash flow it is beneficial in the long run. Solar pumps require a substantial up-front investment when compared to diesel pumps. At the time of purchase, how much the energy and pumping costs are going to be for the next 20 plus years has to be known. (the life of the PV power generators).In contrast, it is difficult to predict oil price after 5 years but all indications suggest that oil-derived fuels will only continue to increase in cost as global oil production slips over the top of the curve and heads downward in the face of rapidly increasing demand.

4. In the case study area of Keraniganj the time duration of boro rice cultivation is mid-January to late April; i.e. 3.5 months .The average solar radiation has been recorded in January in 1.77-2.29 kWh/m2/dr in Dhaka. From January to April average sunshine hour value was 7 hours .Above data are significantly sufficient enough to yield required irrigation for boro rice for 4 bighas of land with specifications used in the test run. As this project could sustain in adverse possible parameters so indirect way can be recommended for other crops which crop-water requirement is lesser then boro rice. Other than boro season natural rain supplements the irrigation which is an advantage for irrigations.

5. Due to the high initial investment cost of PV grid system, here should be favorable policies for this sector. These should first set a target for renewable energy production and use instruments to achieve such target.

6.2 Recommendations

1. Efforts in all regards by the government must be given to lower down the price of PV panels and necessary items.
2. More research work must be carried out in this subject because of its potentialities and necessity of food security.
3. Though in national energy policy renewable energy is mentioned but in particular to irrigation this method should be focused with due attention to ensure food security.
4. Based on the case study, we observed that in many permutation combination technique with local made parts inclusion, the cost of whole set up can be reduced to a manageable limit, which can be bearded by its stakeholders in a group basis
5. Bangladesh is abundant of solar energy which potentialities must be harassed by its citizen. This is the right juncture to gradually switch over the green, renewable energy and solar energy is one of the best options.
6. In Bangladesh farmers are usually habituated with the irrigation during night time but if introduced the solar power for irrigation pump than the mind set of the farmers needs to be addressed so that they can adjust with the proposed system during day.

References

[1] Mohammed Mozammel Haque, PHOTOVOLTAIC WATER PUMPING SYSTEM FOR IRRIGATION,4th International Conference on Mechanical Engineering, December 26-28, 2001, Dhaka, Bangladesh/pp. I 21-26.

[2]. Biddut Sorborah Karjokrom, Sech Moushum (2013), Energy Division, Ministry of Electricity, Fuel and Mineral Resource Ministry.

[3]. Summary of Daily Electricity Generation,(20 Feb 2013),Power Grid Company of Bangladesh Ltd, Energy Division, Ministry of Electricity, Fuel and Mineral Resource Ministry.

[4]. Statistical Yearbook of Bangladesh-2010, (2011), Publisher: Bureau of Statistics, Statistics Division, and Ministry of Planning

[5]. Richard T. Sheahan, (1981), Alternative Energy Sources, a Strategic Planning Guide, ISBN -13:9780894433740, Publisher: Aspen Systems

[6]. Renewable Energy Policy of Bangladesh, (6 Nov 2008), link: http://pv-expo.net/BD/Renewable_Energy_Policy.pdf, Published by: Power Division, Ministry of Power, Energy and Mineral Resource, Government of the Peoples Republic of Bangladesh.

[7]. Islam Q.R., Rahman M.& Matin M. A., Assessment of Productivity of Land in Diverse Irrigation Systems in Bangladesh, LGED Headquarters, (2011).

[8].Rahman Chowdhury, INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH, Vol.2, No.2, 2012.

[9]. CADDET renewable energy, solar pumping in India, March 2011

[10]. Desai and Rao, Application of Solar PV based Pumping for irrigation: A survey Report, Centre for Technology Alternatives for Rural Areas ,Indian Institute of Technology Bombay, Powai, Mumbai 400 076, December 2012

[11]. B.L.S. Lui,TRIAL USE OF SOLAR POWER AUTOMATIC IRRIGATION SYSTEM, November 2006.

[12]. P.SISIRA KUMARA, Adoption of Solar Powered Drip Irrigation: A Case Study of the Sustainable Agriculture Water Management Project (SAWMP) In Polonnaruwa District.

[13]. A Citizens' Guide to Energy Subsidies in Bangladesh, April 2012 Published by the International Institute for Sustainable Development.

[14]. K. M. Sadrul Islam a*, M. A. H. Mondal b and M. Ahiduzzaman, A Case Study of Grid Connected Solar PV Irrigation System in Semi-Arid Region of Bangladesh. Volume 1, No. 1 (2010) 33-38,).

[15]. S.C.Gupta & V.K.Kapor, (1994), Fundamental of Mathematical Statistics, Publisher: Sultan Chand & Sons

[16]. Richard I. Levin & David S.Rubin Statistics for Management, (7th Edition, 1998), ISBN: 0-13-606716-6, Publisher: Prentice –Hall International, Inc

[17]. Sol Wieder, (1992), an Introduction to Solar Energy for Scientist and Engineers, Publisher: Krieger Publishing Company

[18].Tomas Markvart, (April 2000, 2nd Edition), Solar Electricity. ISBN: 978-0-471-988526, Publisher: Wiley

[19]. Simon Roberts, (1991), Solar Electricity-A Practical Guide to Designing and Installing Small Photovoltaic Systems, ISBN: 0138250685, 9780138250683, Publisher: Prentice Hall, 1991

[20]. Roberta Q., International Panel on Climate Change, IPCC Guidelines for National Greenhouse Gas Inventories,Volume-2,Energy link: http://www.ipcc-nggpip.iges,or.jp/public/2006gl/vol2.html, (2006).

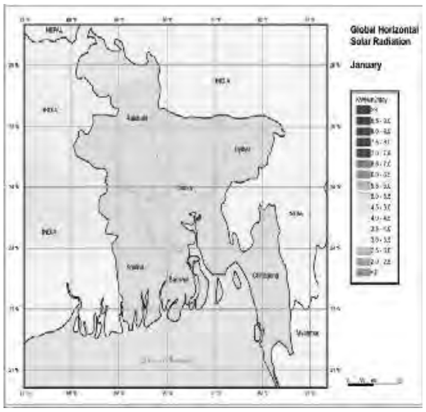
[21]. Dr M A Aziz, (1984), Water Supply Engg, Published By: Hafiz Book Centre.

[22]. Abihijit Datta, Sunita Datta& P N Pandey, (2009), Environmental Economics, Publisher:APH Publishing Corporation

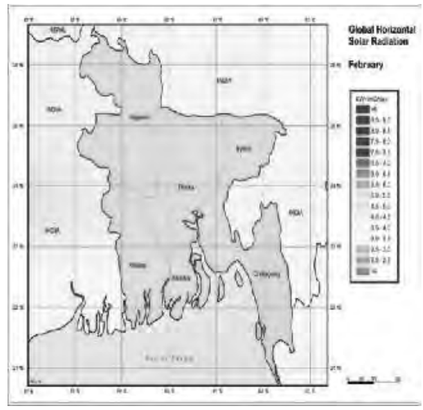
[23]. Dr.Nikhil Chandra Shil, (2011), Capital Budgeting and Investing Decision,Dept of Accounting, BUET

[24].United Nations Environment Programme & Minister Resources Canada 2000-2005,UNEP/DTIE and NRC an/CETA Verennes, Version 3.2 , http://www.retscreen.net/ang/home.php

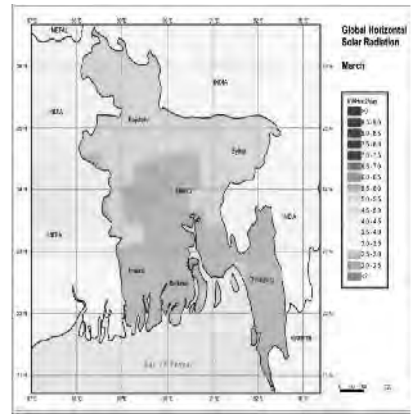
Appendix A: Global Horizontal Solar Radiation in Bangladesh (Monthly)



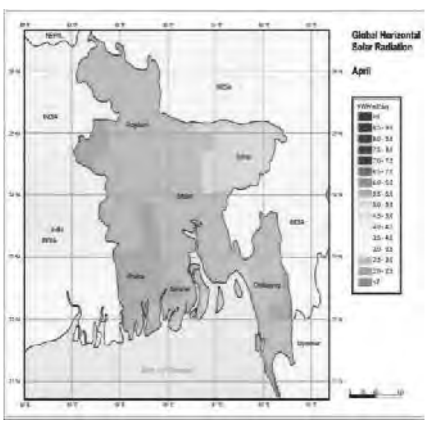
F2: Solar radiation in January



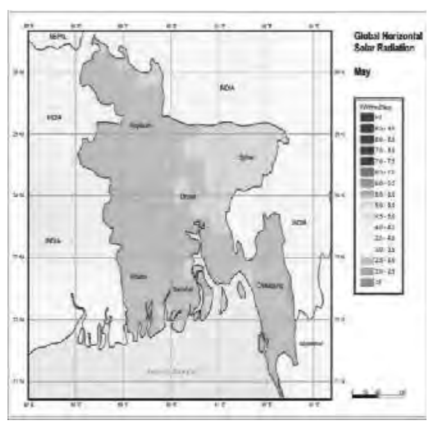
F2: Solar radiation in February



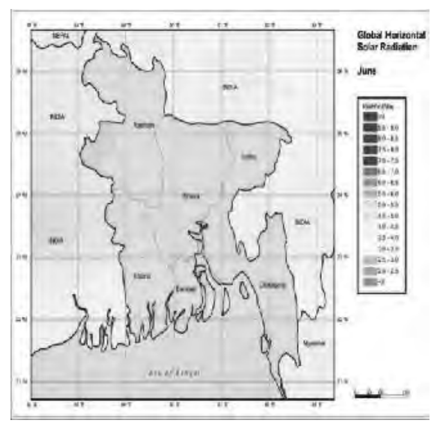
F3: Solar radiation in March



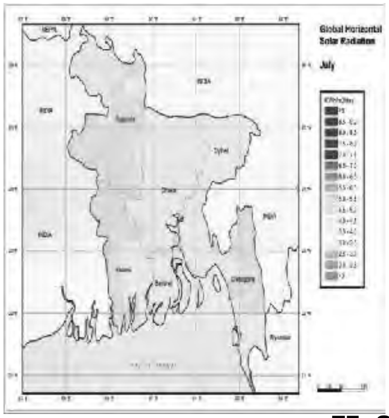
F2: Solar radiation in April

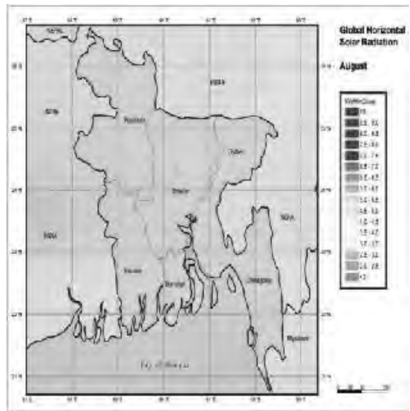


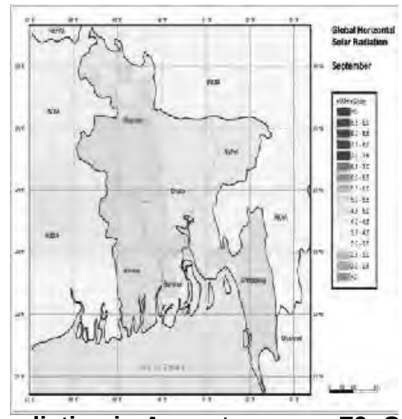
F5: Solar radiation in May



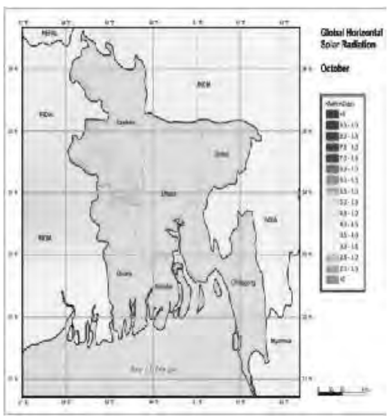
F6: Solar radiation in Jun

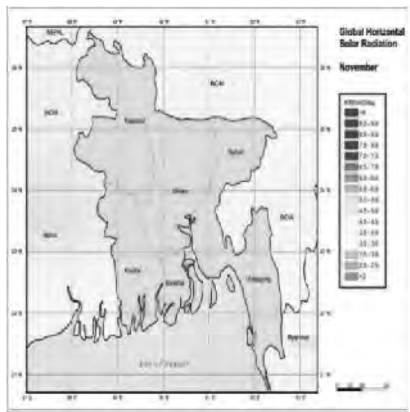


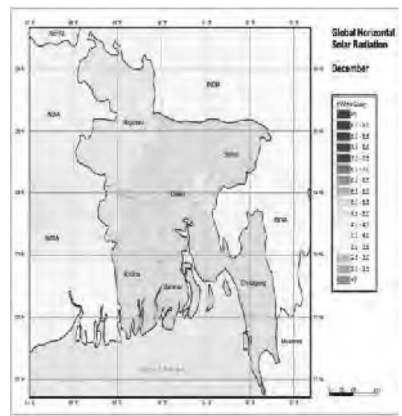




F7: Solar radiation in July **F8: Solar radiation in August** **F9: Solar radiat**







F10: Solar radiation in October **F11: Solar radiation in November** **F21: Solar radiation in December**

Appendix B: Figure of Monthly Radiation in Different locations in Bangladesh(95% confidence level), Y axis radiation data in cal/sqcm/day unit.

Conversion factor :

1 cal=1.163×0.000001 kWh

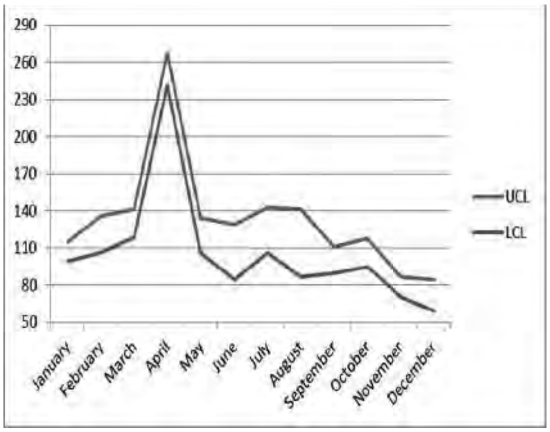


Figure 1: Solar Radiation in Comilla

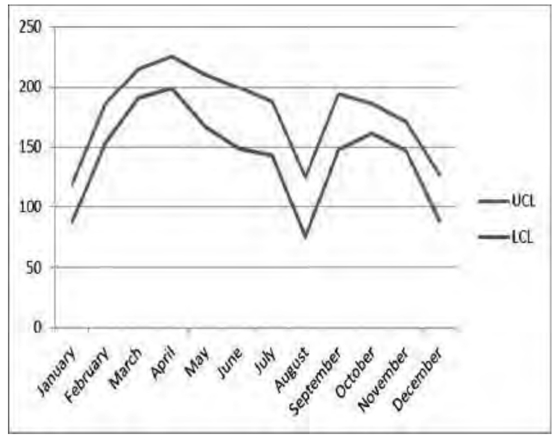


Figure 2: Solar Radiation in Bogra

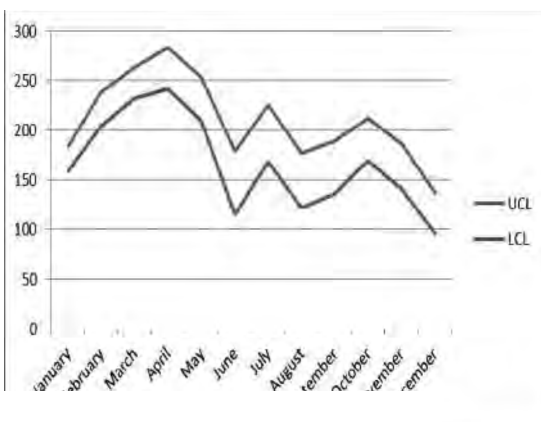


Figure 3: Solar Radiation in Dhaka

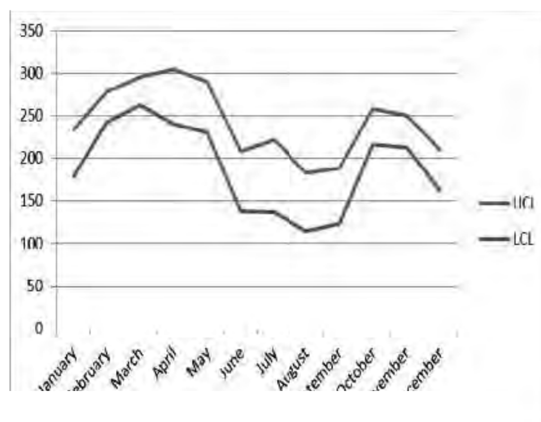


Figure 4: Solar Radiation in Barisal

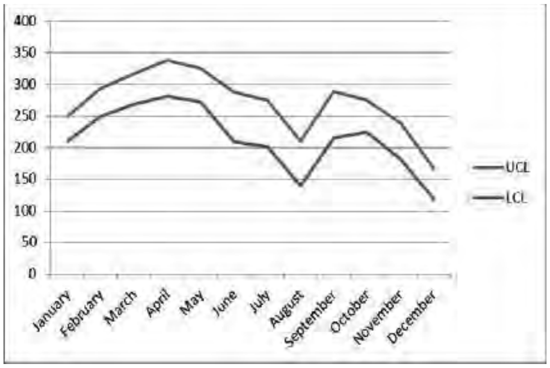


Figure 5: Solar Radiation in Khulna

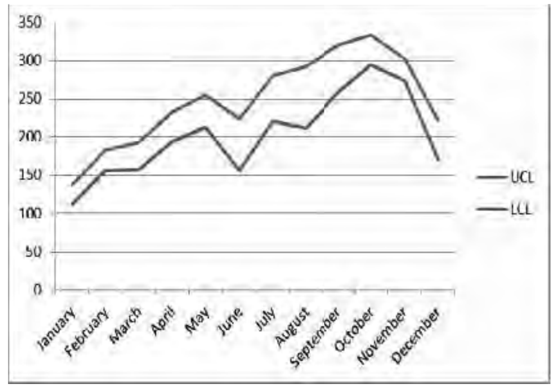


Figure 6: Solar Radiation in Joydebpur

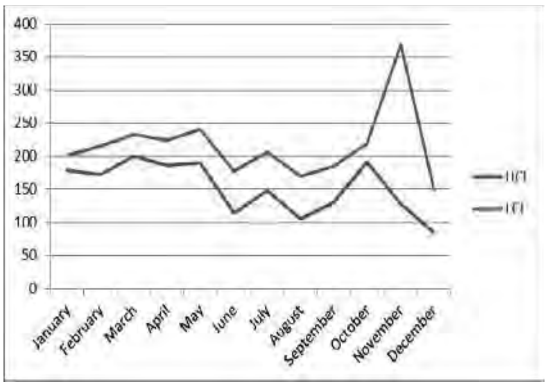


Figure 7: Solar Radiation in Mymensing

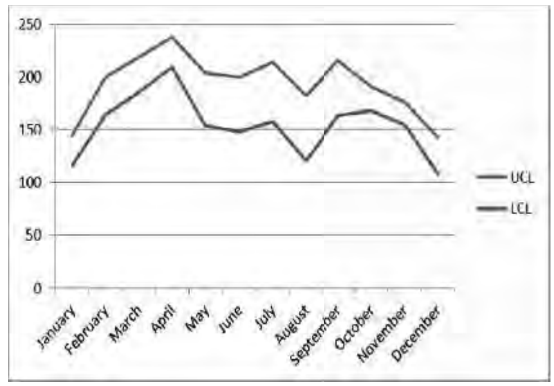


Figure 8: Solar Radiation in Mymensing

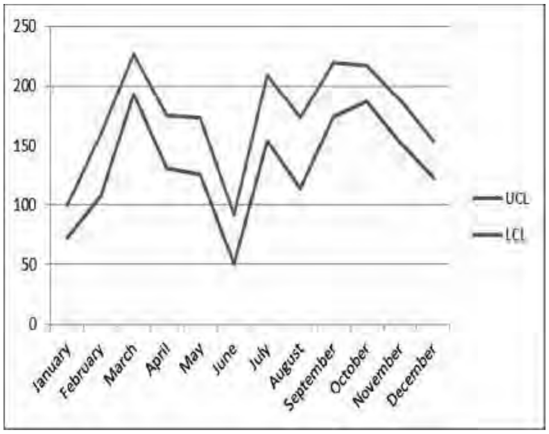


Figure 9: Solar Radiation in Srimangal

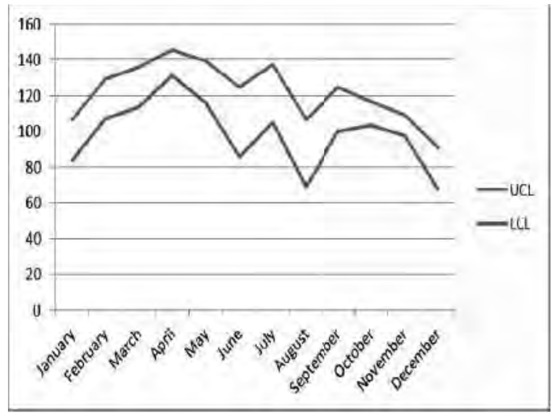
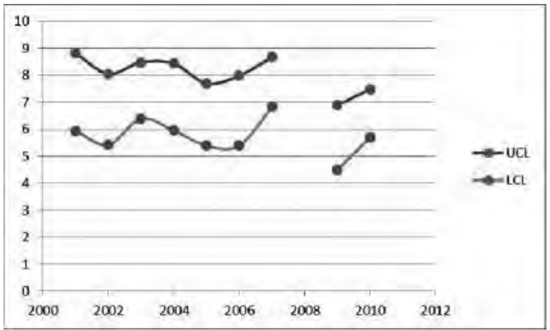


Figure 10: Solar Radiation in Rangpur

Appendix C: Sunshine hours in different areas of Bangladesh



Figures 1: Sun Shine Hour of Bogra- May

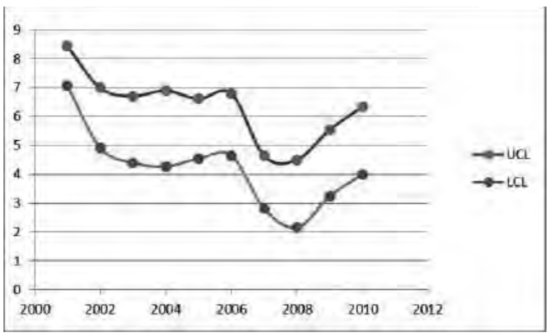


Figure 1: Sun Shine Hour in Jan- Bogra

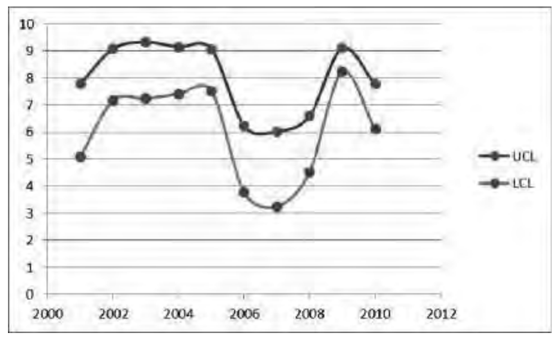


Figure 2: Sun Shine Hour in Feb- Bogra

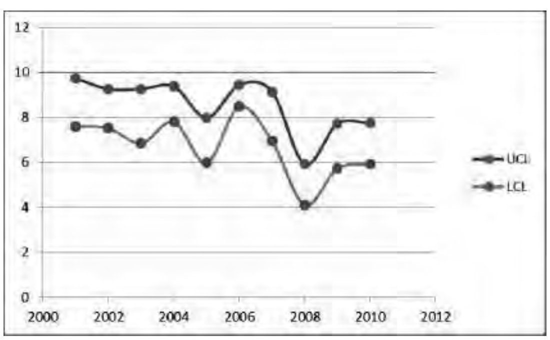


Figure 3: Sun Shine Hour in Mar-Bogra

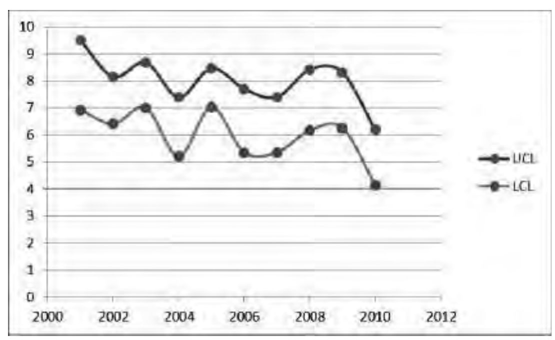


Figure 4: Sun Shine Hour in Apr-Bogra

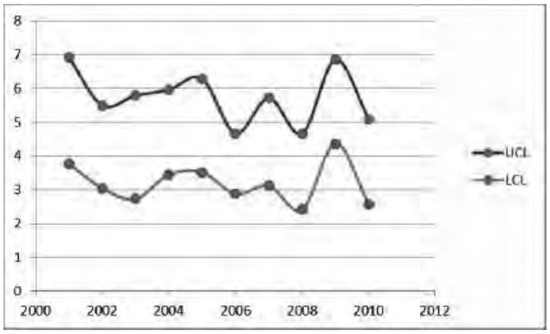


Figure 5: Sun Shine Hour in June-Bogra

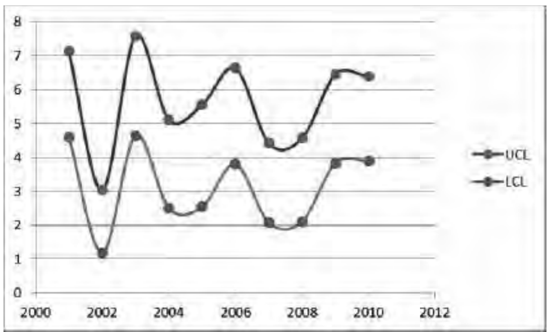


Figure 7: Sun Shine Hour in July-Bogra

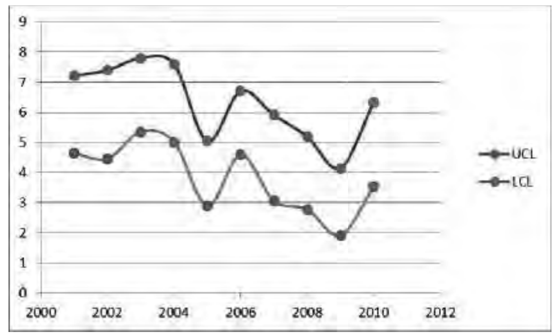


Figure 8: Sun Shine Hour in Aug-Bogra

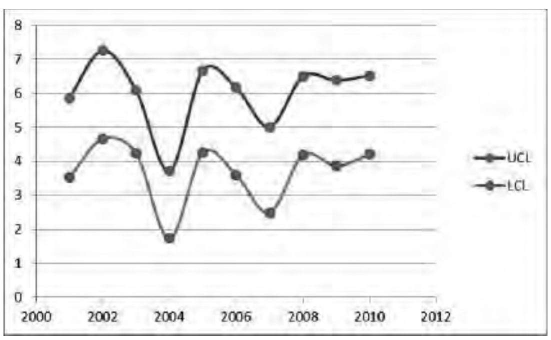


Figure 9: Sun Shine Hour in Sep-Bogra

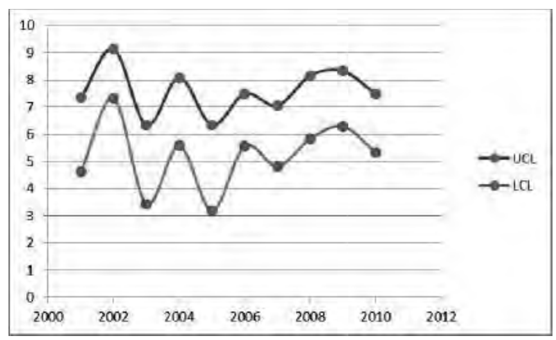


Figure 10: Sun Shine Hour in Oct-Bogra

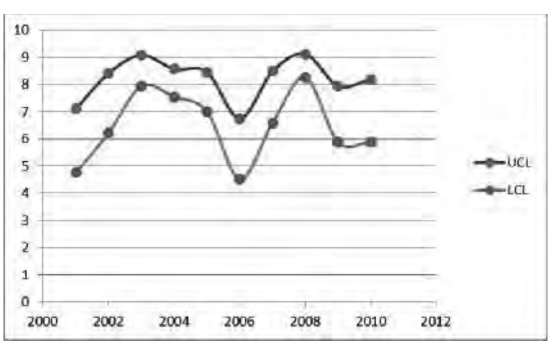


Figure 11: Sun Shine Hour in Nov-Bogra

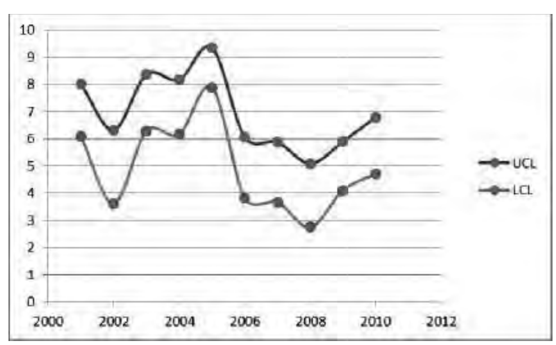


Figure 12: Sun Shine Hour in Dec-Bogra

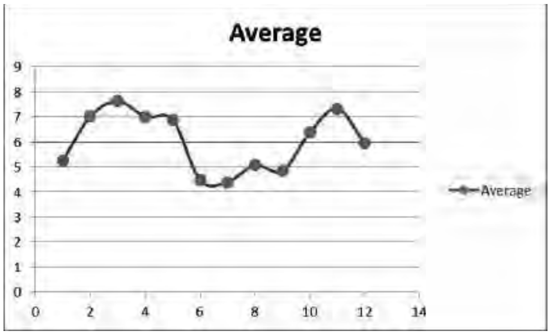


Figure 13: Average Sun Shine Hour in Bogra

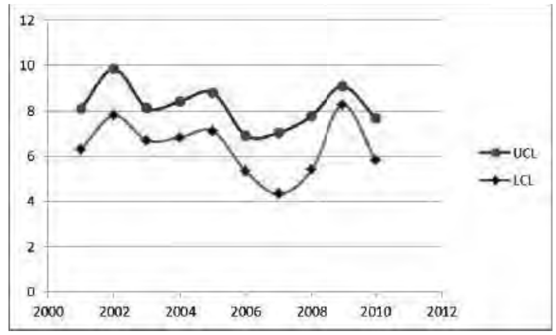


Figure 14: Sun Shine Hour in Feb- Dhaka

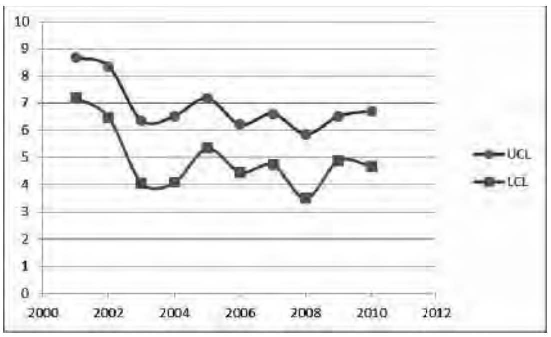


Figure 14-26: Sun Shine Hour of Dhaka-Jan

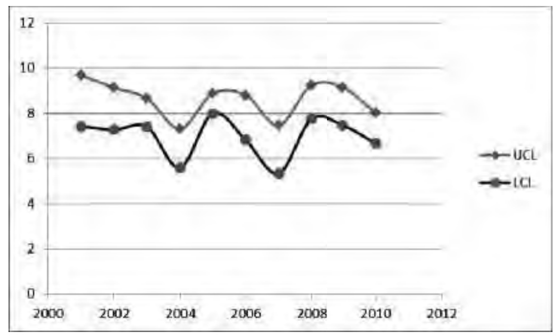


Figure 14: Sun Shine Hour in Apr- Dhaka

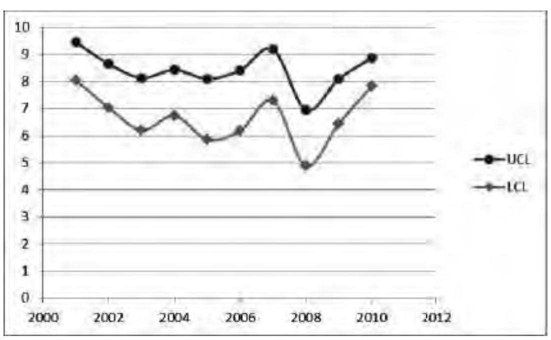


Figure 16: Sun Shine Hour in March Dhaka

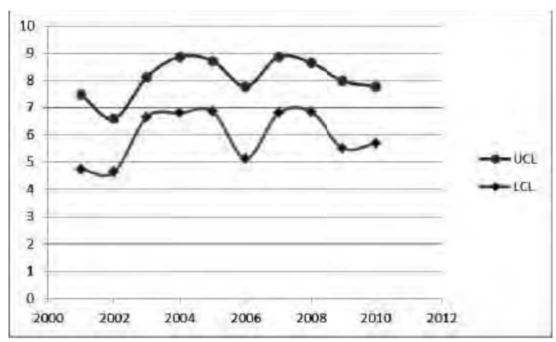


Figure 18: Sun Shine Hour in May Dhaka

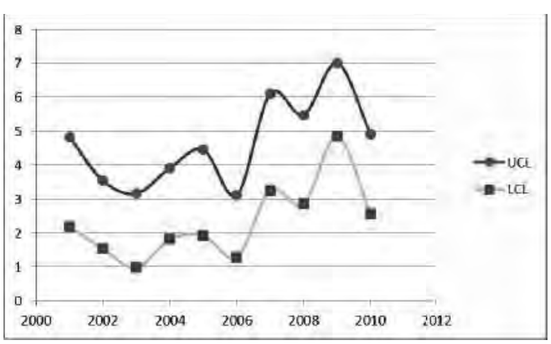


Figure 19: Sun Shine Hour in June Dhaka

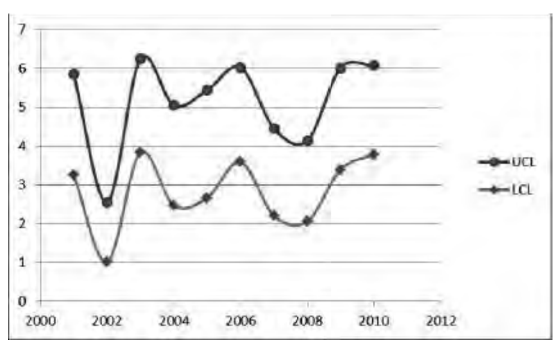


Figure 20: Sun Shine Hour in July Dhaka

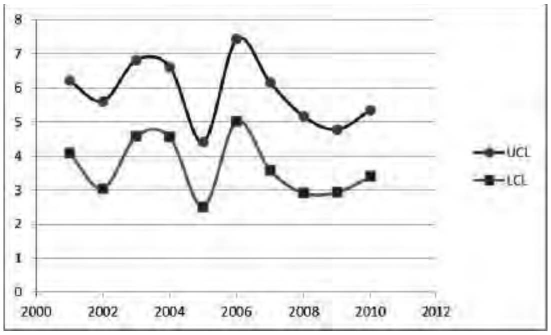


Figure 21: Sun Shine Hour in Aug- Dhaka

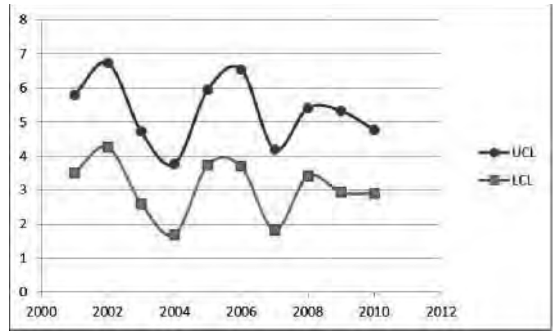


Figure 22: Sun Shine Hour in Sep- Dhaka

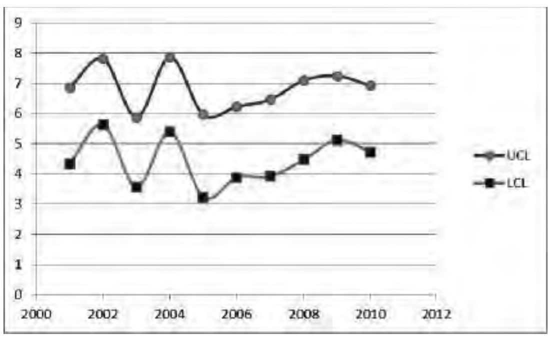


Figure 23: Sun Shine Hour in Oct- Dhaka

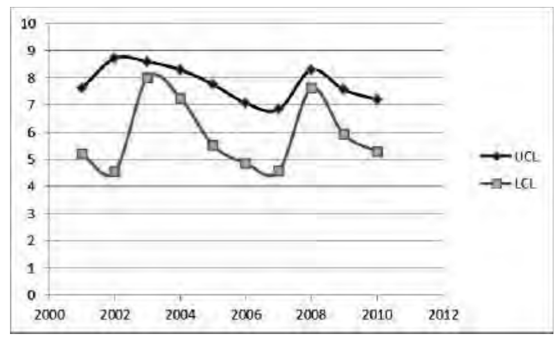


Figure 24: Sun Shine Hour in Nov- Dhaka

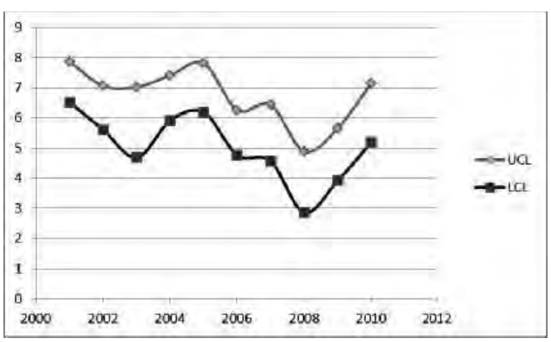


Figure 25: Sun Shine Hour in Dec- Dhaka

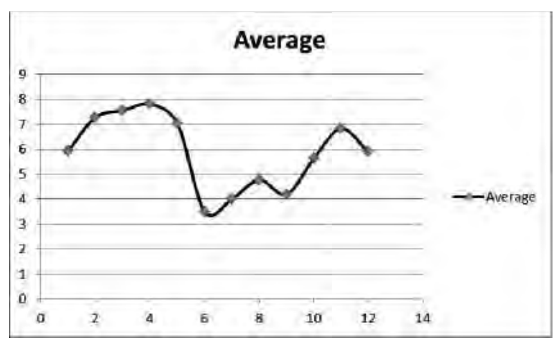


Figure 26: Average Sun Shine Hour in Dhaka

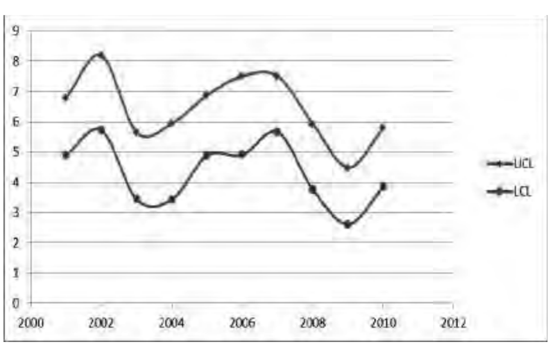


Figure 27: Sun Shine Hour in Jan- Dinajpur

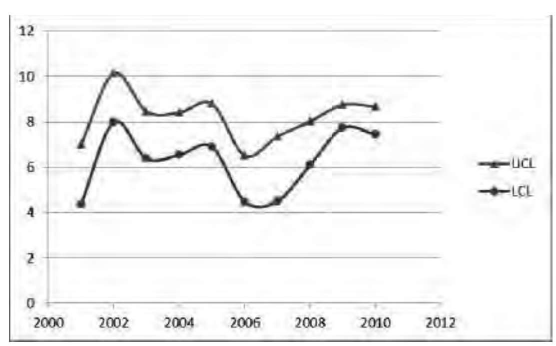


Figure 30: Sun Shine Hour in Feb- Dinajpur

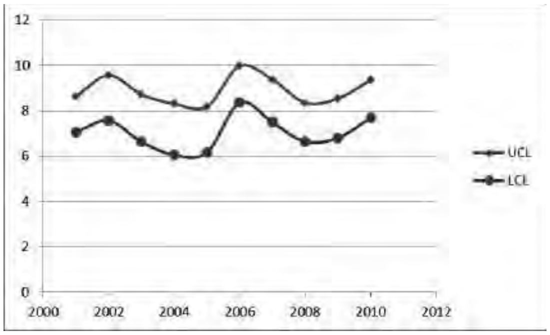


Figure 29: Sun Shine Hour in Mar-Dinajpur

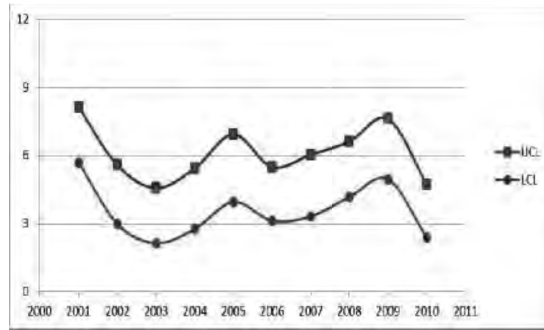


Figure 28: Sun Shine Hour in Jun-Dinajpur

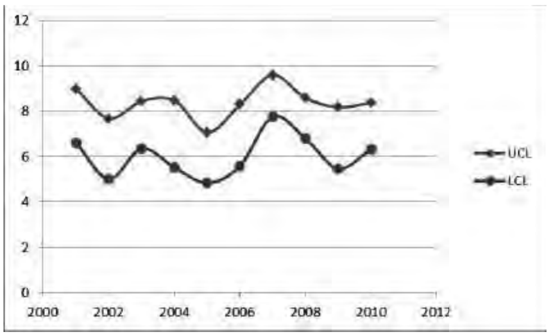


Figure 31: Sun Shine Hour in May-Dinajpur

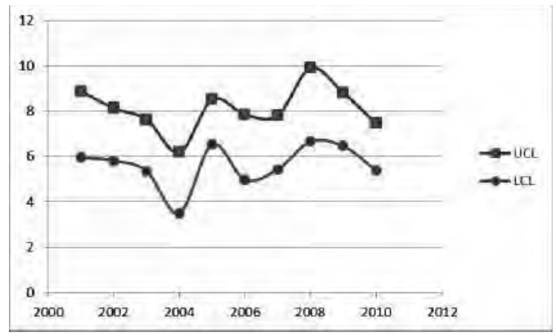


Figure 32: Sun Shine Hour in Apr-Dinajpur

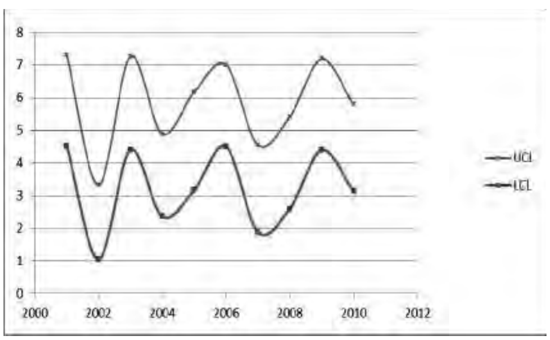


Figure 33: Sun Shine Hour in July-Dinajpur

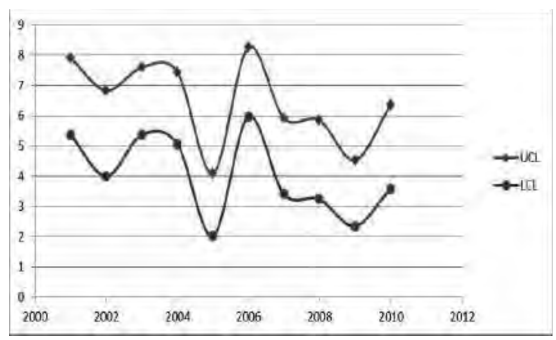


Figure 34: Sun Shine Hour in Aug-Dinajpur

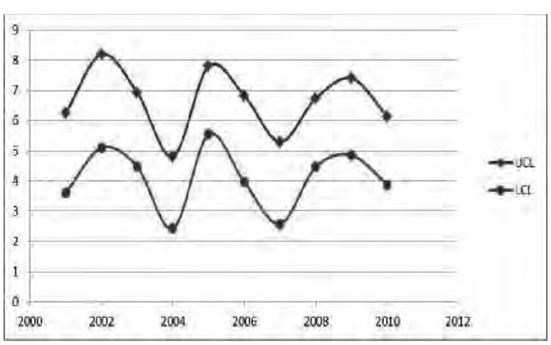


Figure 35: Sun Shine Hour in Sep-Dinajpur

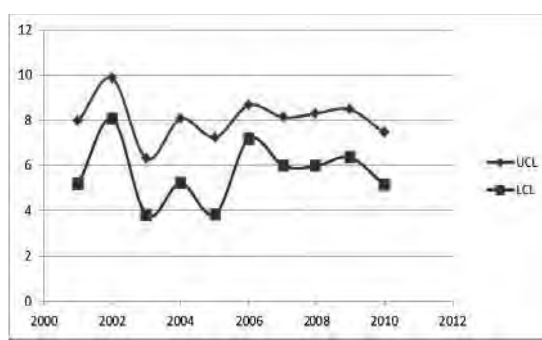


Figure 36: Sun Shine Hour in Oct-Dinajpur

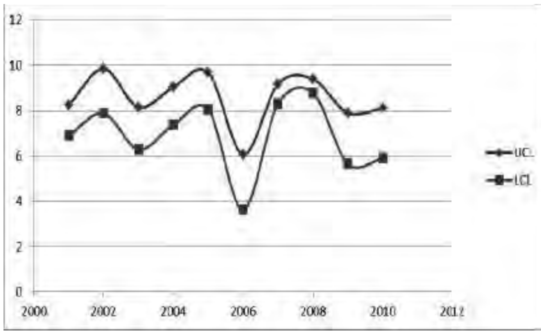


Figure 37: Sun Shine Hour in Nov-Dinajpur

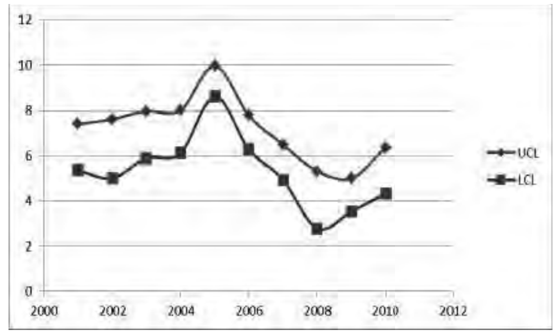


Figure 38: Sun Shine Hour in Dec-Dinajpur

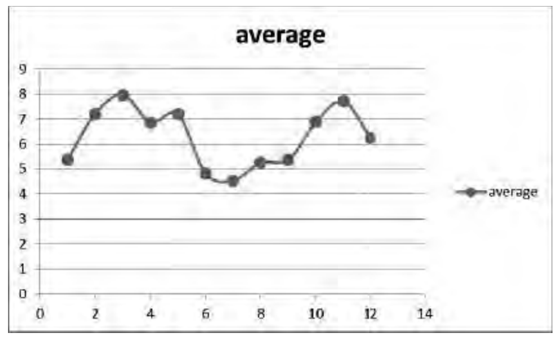


Figure 39: Average Sun Shine Hour in Dinajpur

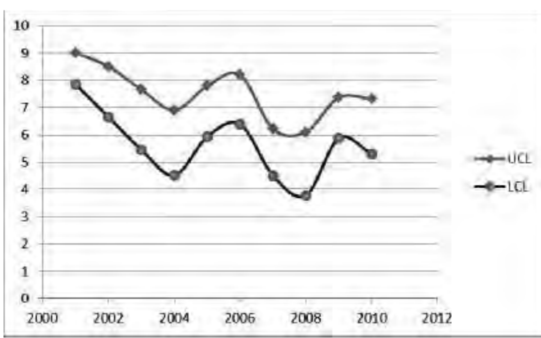


Figure 40: Sun Shine Hour in Jan-Faridpur

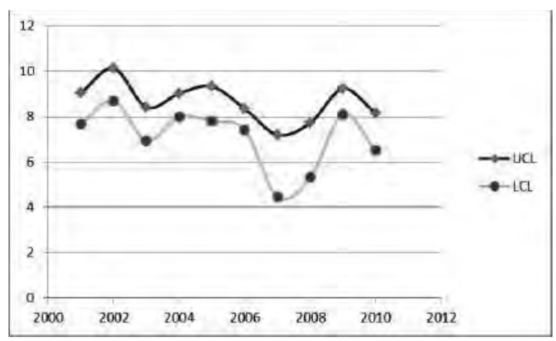


Figure 41: Sun Shine Hour in Feb-Faridpur

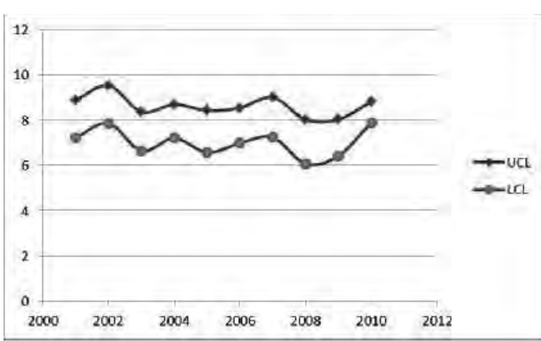


Figure 42: Sun Shine Hour in Mar-Faridpur

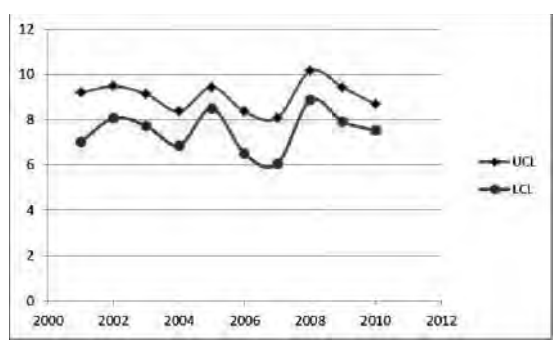


Figure 43: Sun Shine Hour in Apr-Faridpur

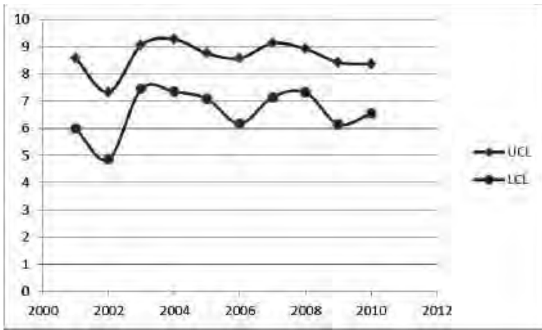


Figure 44: Sun Shine Hour in May-Faridpur

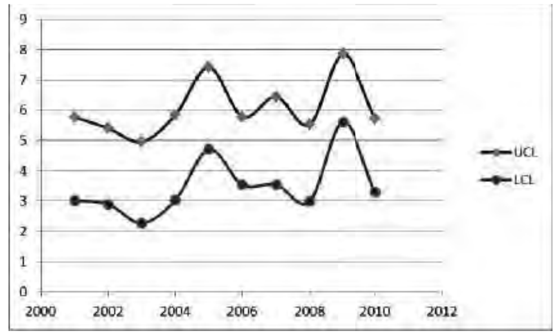


Figure 45: Sun Shine Hour in June-Faridpur

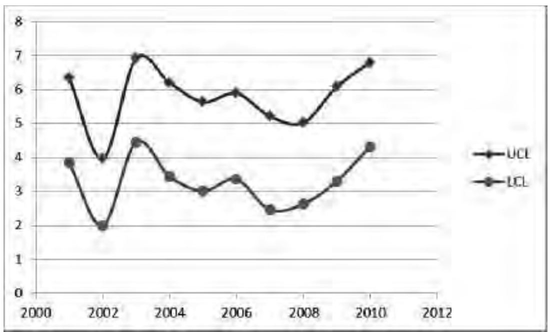


Figure 46: Sun Shine Hour in July-Faridpur

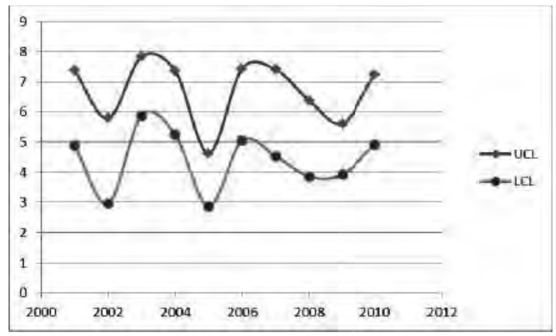


Figure 47: Sun Shine Hour in Aug-Faridpur

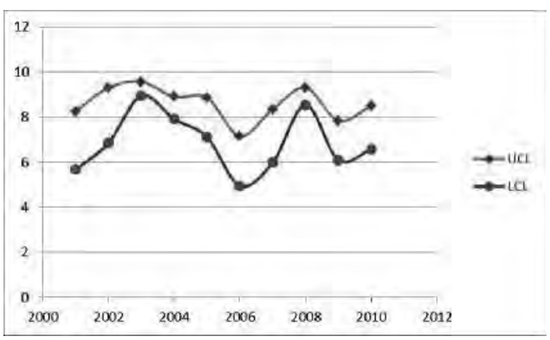


Figure 50: Sun Shine Hour in Nov-Faridpur

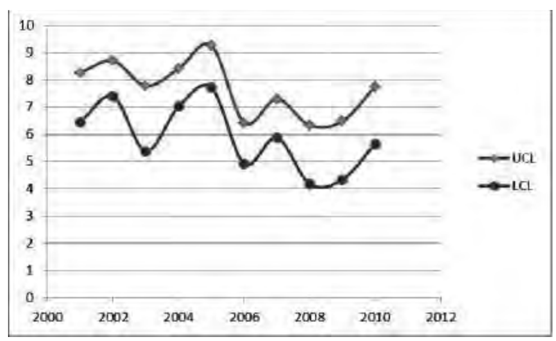


Figure 51: Sun Shine Hour in Dec-Faridpur

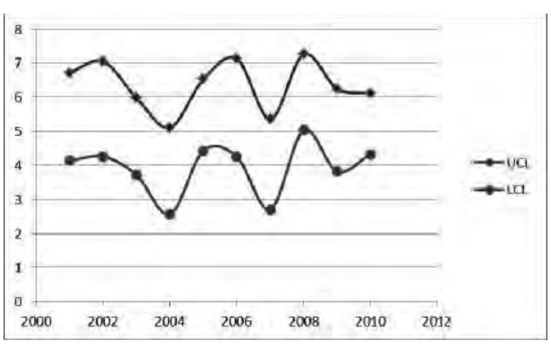


Figure 48: Sun Shine Hour in Sep-Faridpur

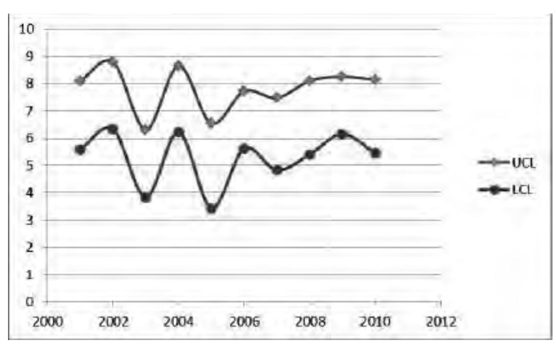


Figure 49: Sun Shine Hour in Oct-Faridpur

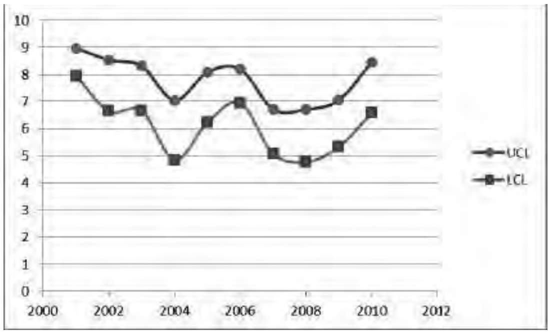


Figure 53: Sun Shine Hour in Jan-Khulna

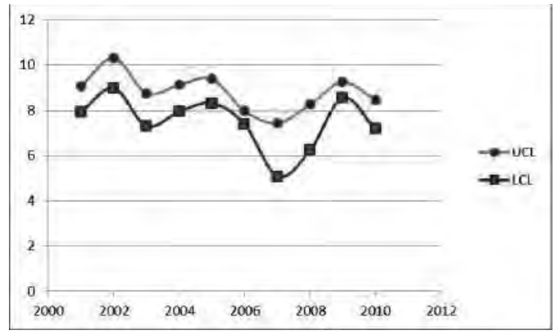


Figure 54: Sun Shine Hour in Feb-Khulna

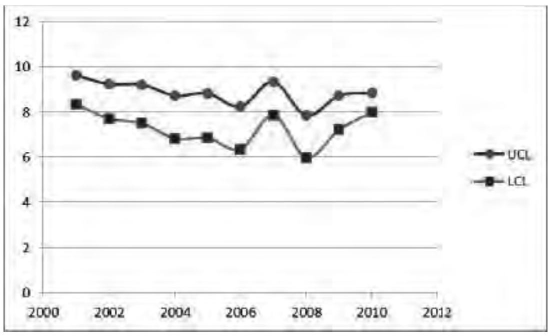


Figure 55: Sun Shine Hour in Mar-Khulna

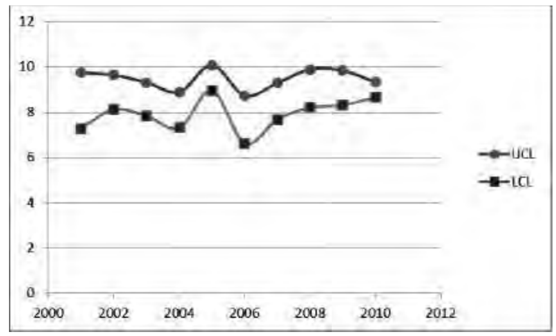


Figure 56: Sun Shine Hour in Apr-Khulna

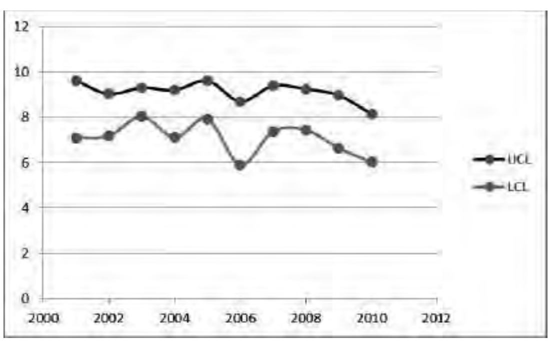


Figure 57: Sun Shine Hour in May-Khulna

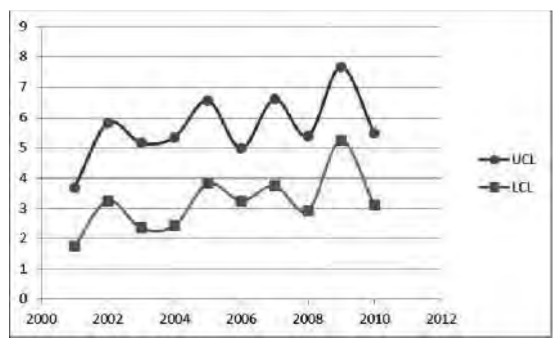


Figure 58: Sun Shine Hour in June-Khulna

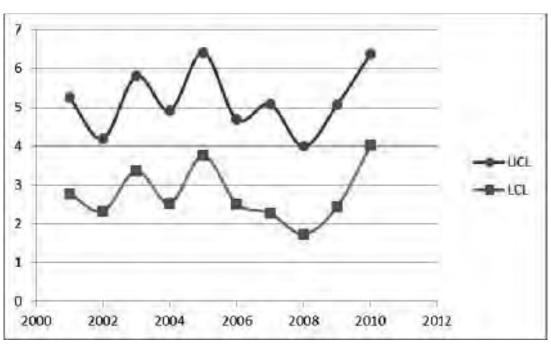


Figure 59: Sun Shine Hour in July-Khulna

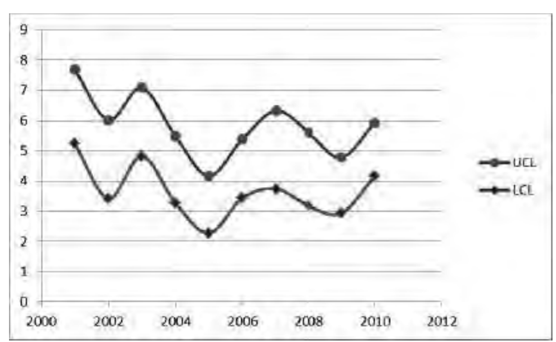


Figure 60: Sun Shine Hour in Aug-Khulna

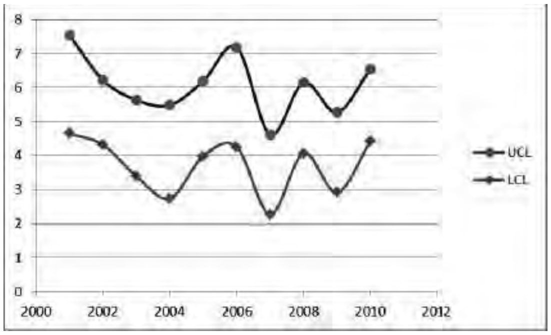


Figure 61: Sun Shine Hour in Sep-Khulna

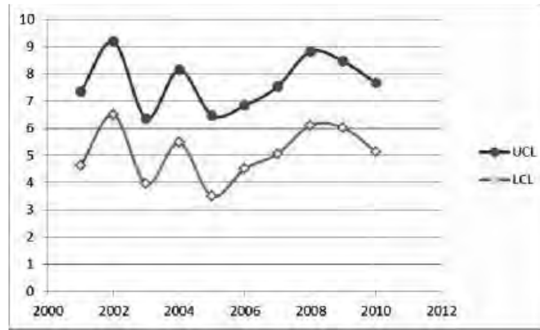


Figure 62: Sun Shine Hour in Oc-Khulna

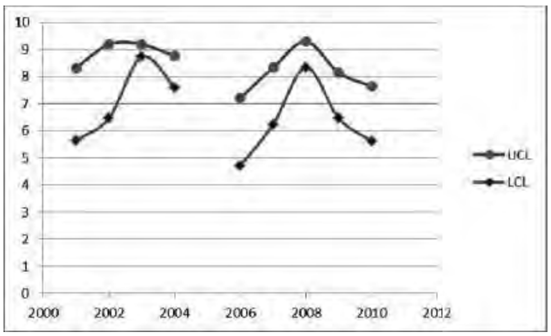


Figure 63: Sun Shine Hour in Nov-Khulna

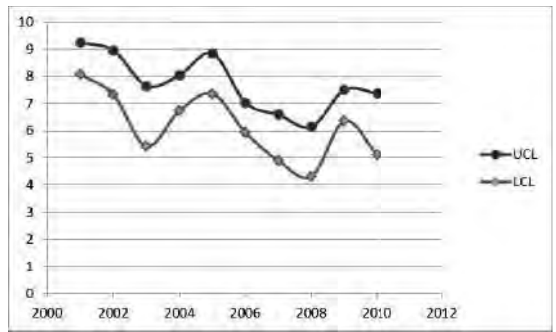


Figure 64: Sun Shine Hour in Dec-Khulna

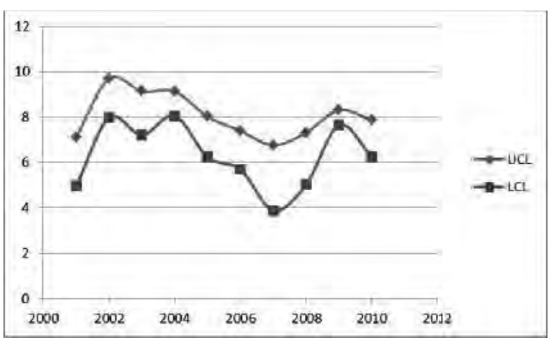


Figure 67: Sun Shine Hour in Feb-Msing

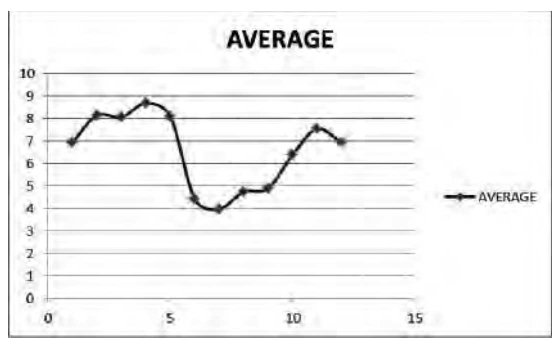


Figure 65: Average Sun Shine Hour in Khulna

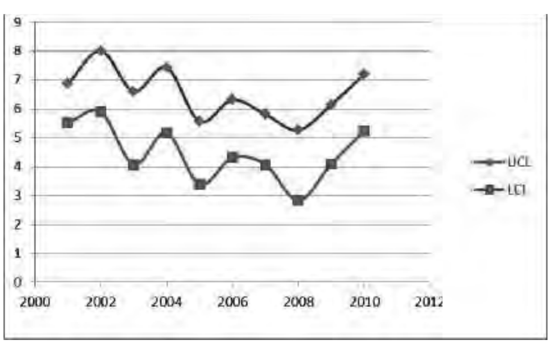


Figure 67: Sun Shine Hour in Jan-Msing

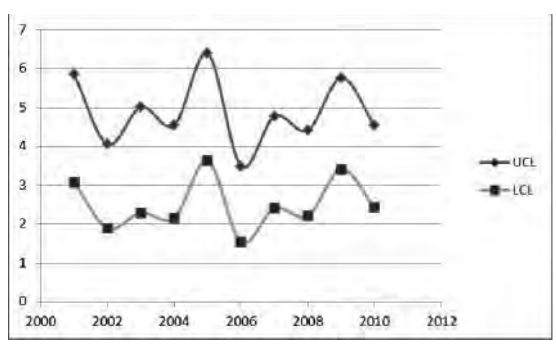


Figure 68: Sun Shine Hour in Jun-Msing

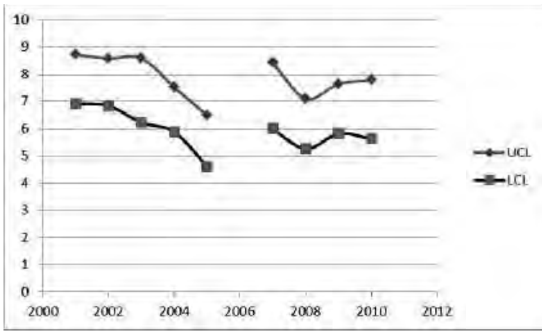


Figure 66: Sun Shine Hour in Mar-Msing

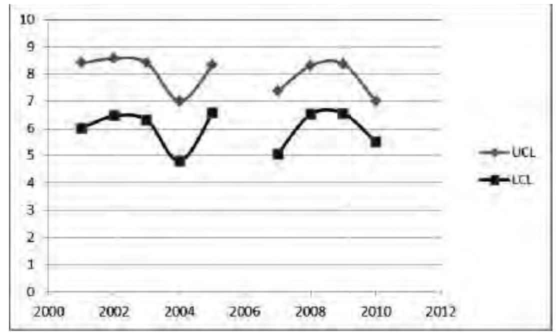


Figure 69: Sun Shine Hour in Apr-Msing

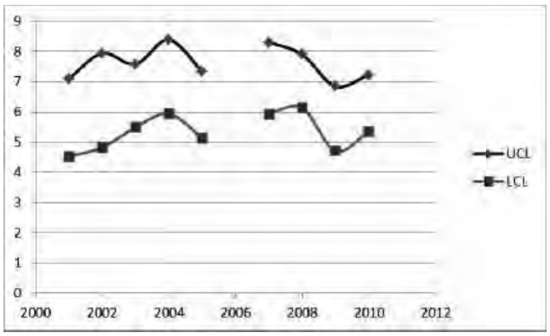


Figure 70: Sun Shine Hour in May-Msing

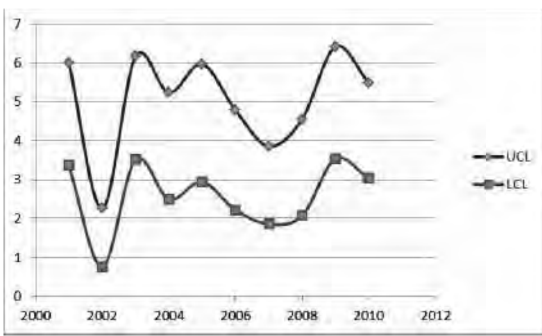


Figure 72: Sun Shine Hour in July-Msing

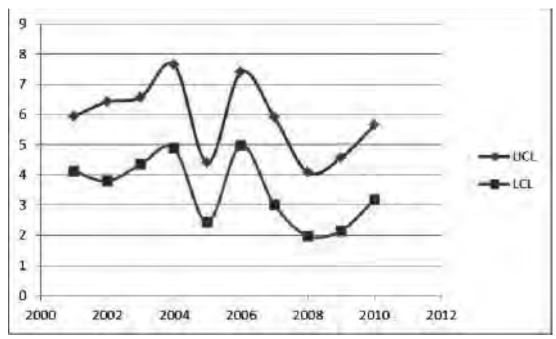


Figure 73: Sun Shine Hour in Aug-Msing

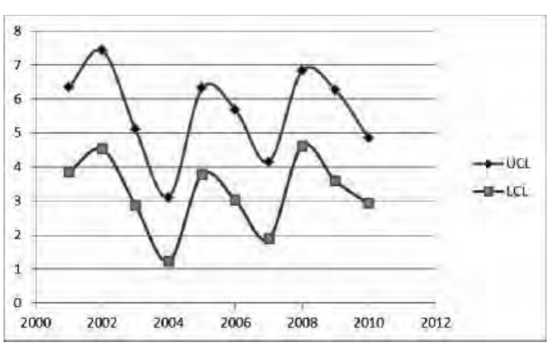


Figure 74: Sun Shine Hour in Sep-Msing

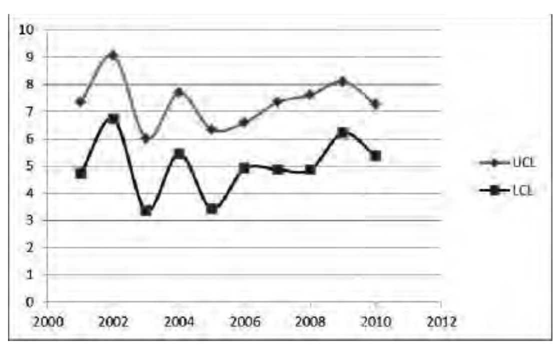


Figure 75: Sun Shine Hour in Oct-Msing

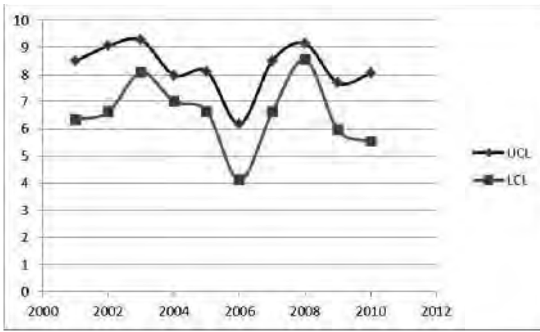


Figure 76: Sun Shine Hour in Nov-Msing

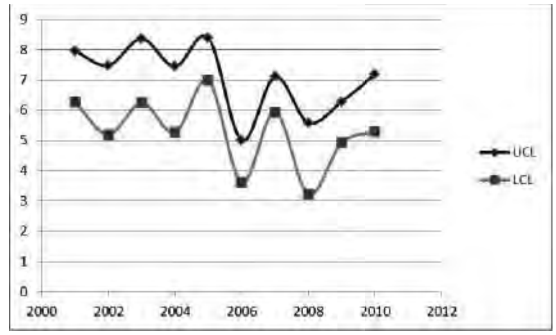


Figure 77: Sun Shine Hour in Dec-Msing

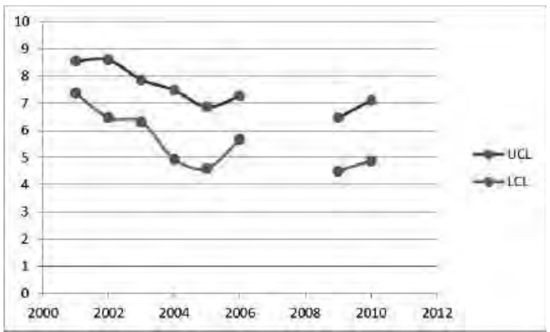


Figure 79-91: Sun Shine Hour ofJan-Rajshahi

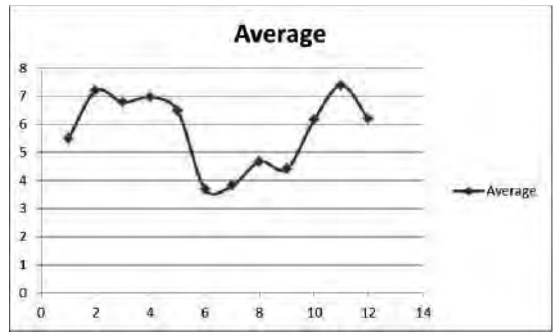


Figure 78: Average Sun Shine Hour in Mymensingh

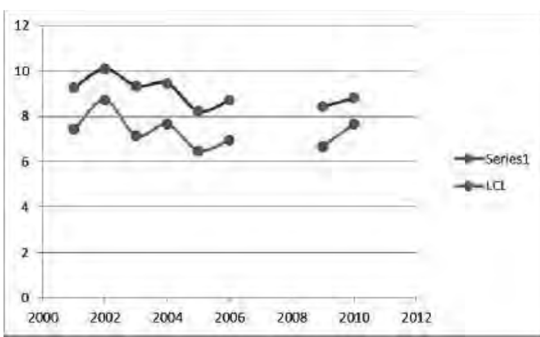


Figure 81: Sun Shine Hour in Mar-Rajshahi

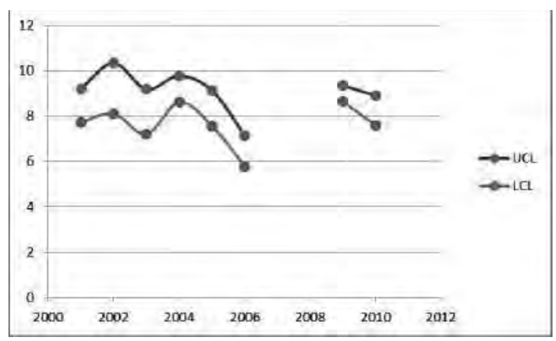


Figure 80: Sun Shine Hour in Feb-Rajshahi

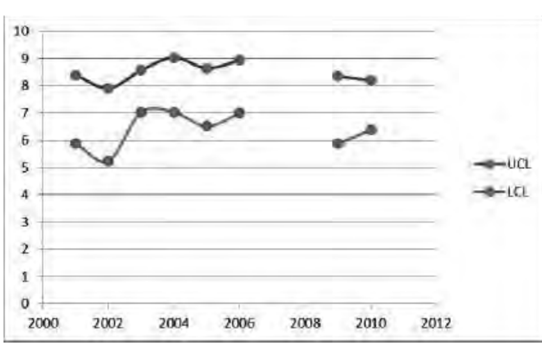


Figure 83: Sun Shine Hour in May Rajshahi

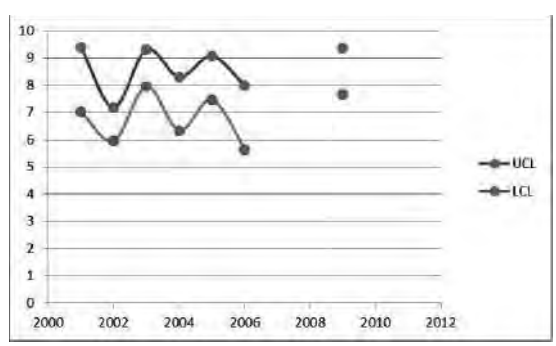


Figure 82: Sun Shine Hour in Apr-Rajshahi

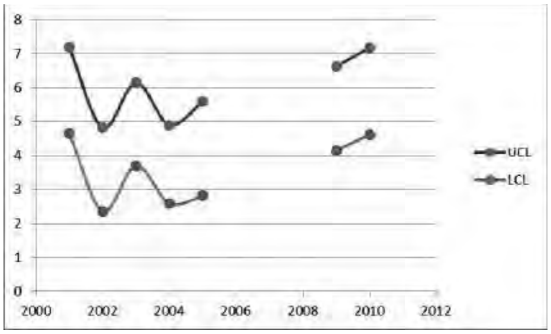


Figure 85: Sun Shine Hour in July- Rajshahi

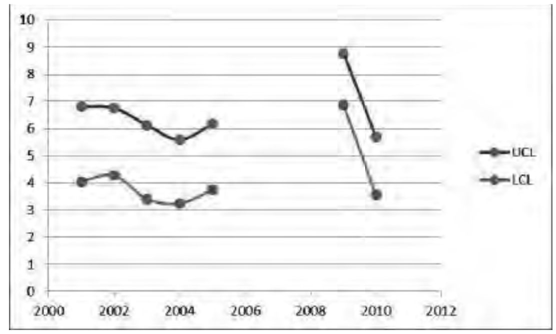


Figure 84: Sun Shine Hour in June - Rajshahi

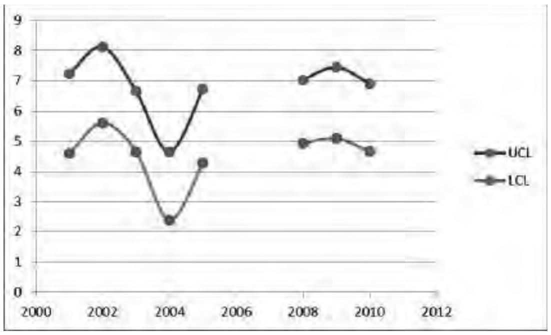


Figure 87: Sun Shine Hour in Sep- Rajshahi

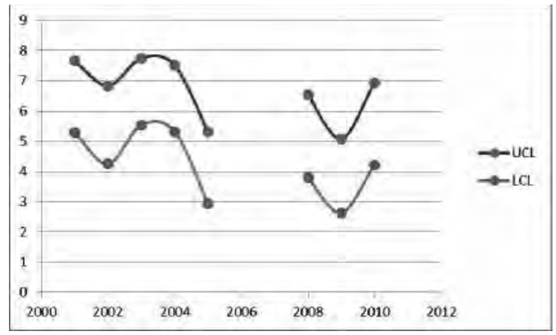


Figure 86: Sun Shine Hour in Aug- Rajshahi

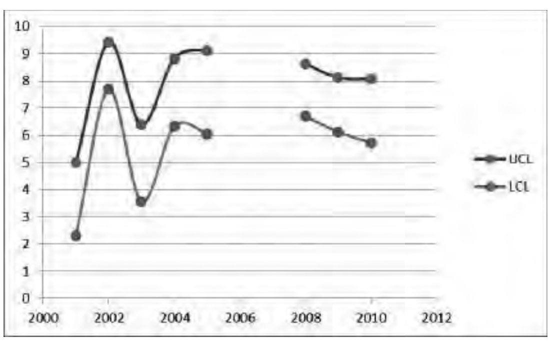


Figure 88: Sun Shine Hour in Oct- Rajshahi

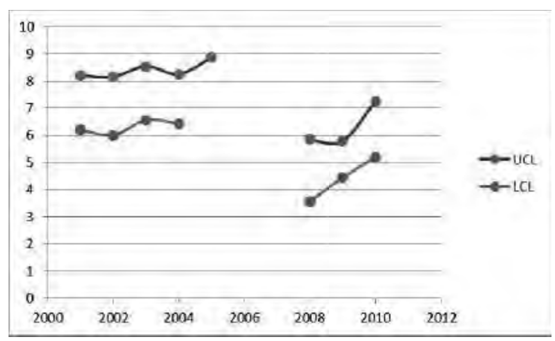


Figure 90: Sun Shine Hour in December

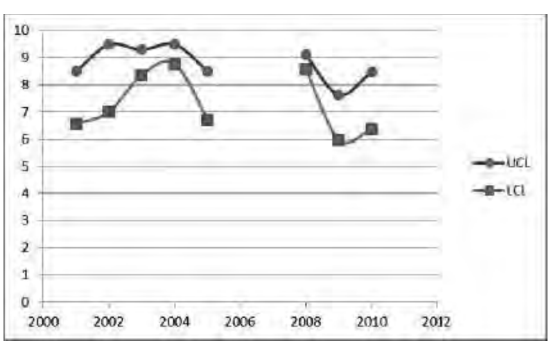


Figure 89: Sun Shine Hour in Nov- Rajshahi

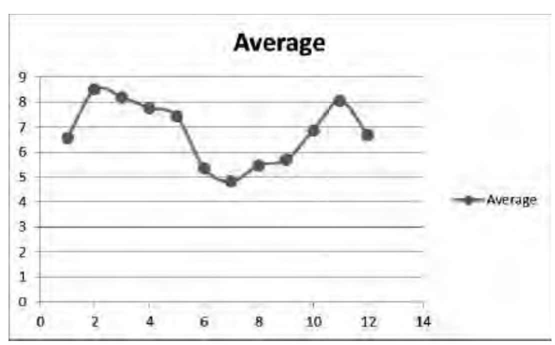


Figure 91: Average Sun Shine Hour in Rajshahi

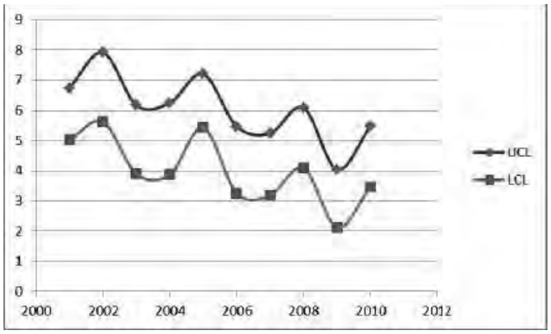


Figure 92: Sun Shine Hour in Jan-Saidpur

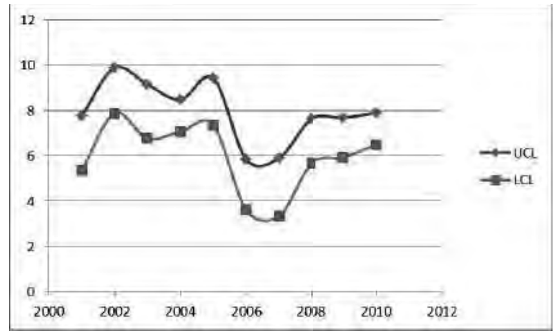


Figure 93: Sun Shine Hour in Feb-Saidpur

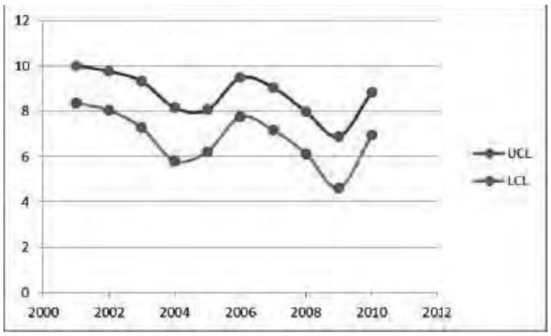


Figure 94: Sun Shine Hour in Mar-Saidpur

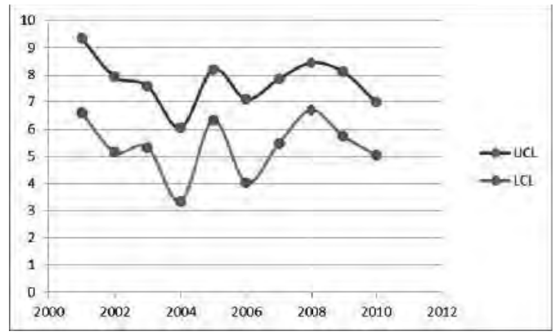


Figure 95: Sun Shine Hour in Apr-Saidpur

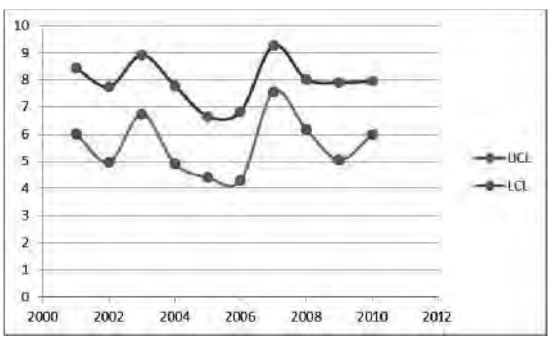


Figure 96: Sun Shine Hour in May-Saidpur

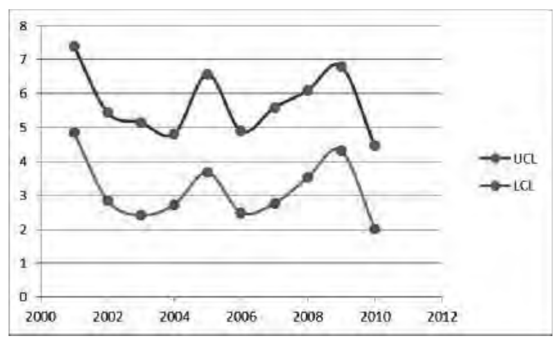


Figure 97: Sun Shine Hour in June-Saidpur

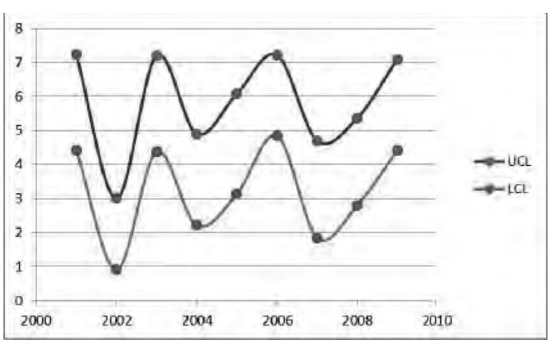


Figure 98: Sun Shine Hour in July-Saidpur

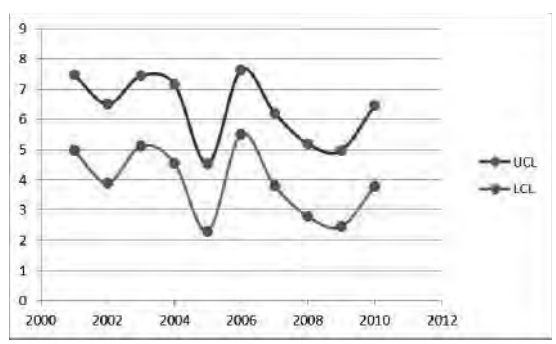


Figure 99: Sun Shine Hour in Aug-Saidpur

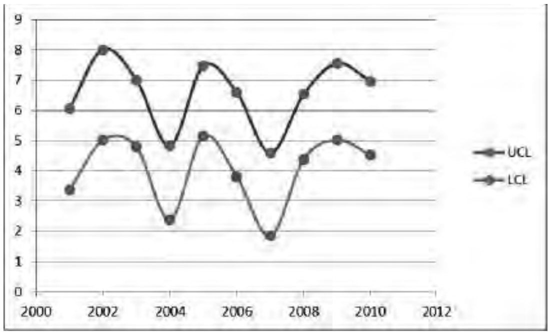


Figure 100: Sun Shine Hour in Sep-Saidpur

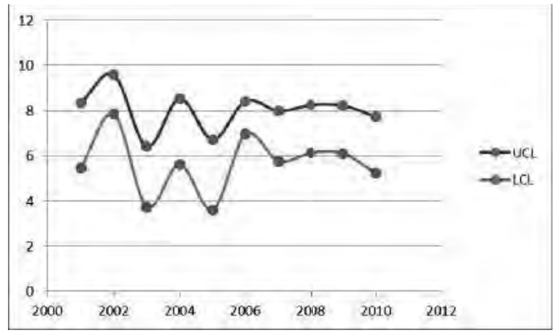


Figure 101: Sun Shine Hour in Oct-Saidpur

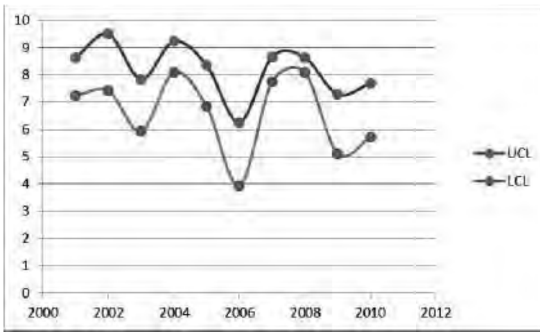


Figure 102: Sun Shine Hour in Nov-Saidpur

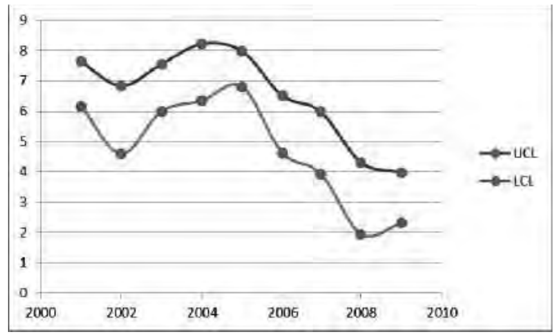


Figure 103: Sun Shine Hour in Dec-Saidpur

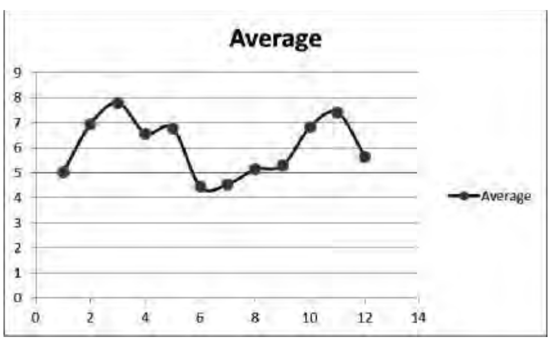


Figure 104: Average Sun Shine Hour in Saidpur

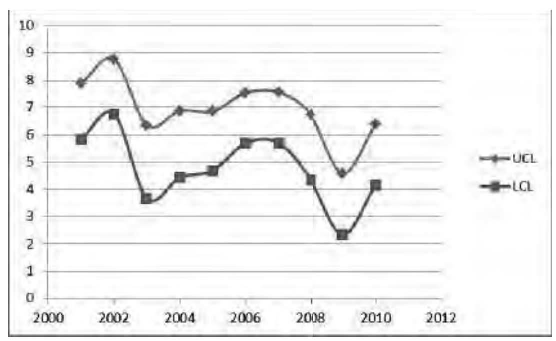


Figure 104: Sun Shine Hour in Jan-Tangail

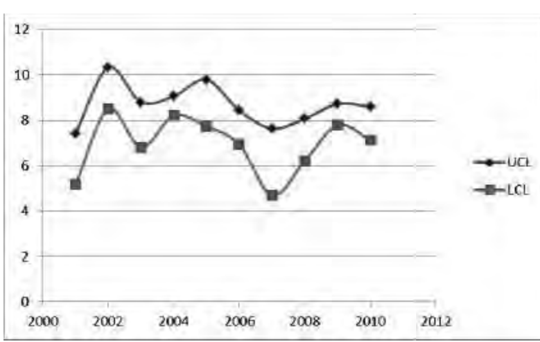


Figure 105: Sun Shine Hour in Feb-Tangail

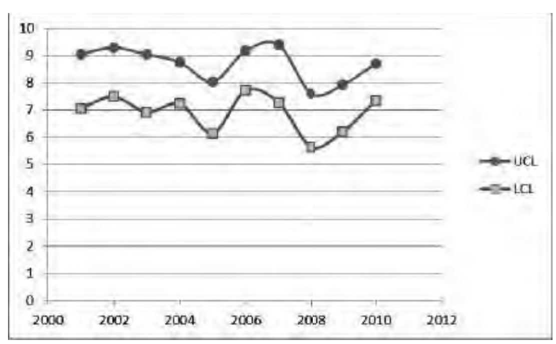


Figure 106: Sun Shine Hour in Mar-Tangail

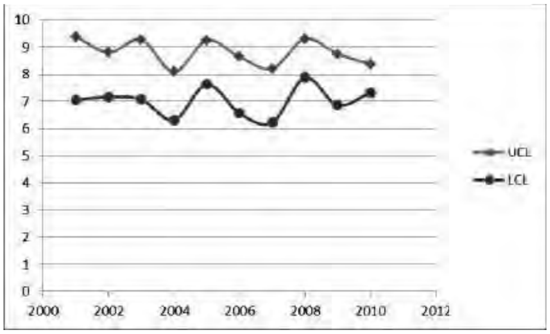


Figure 107: Sun Shine Hour in Apr-Tangail

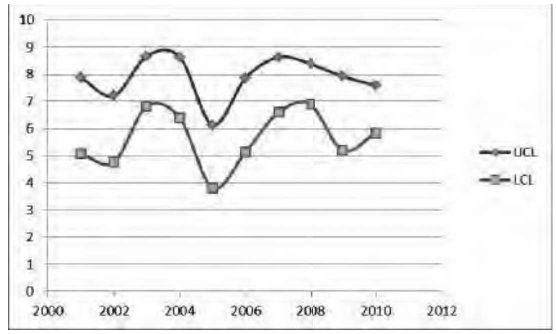


Figure 108: Sun Shine Hour in May-Tangail

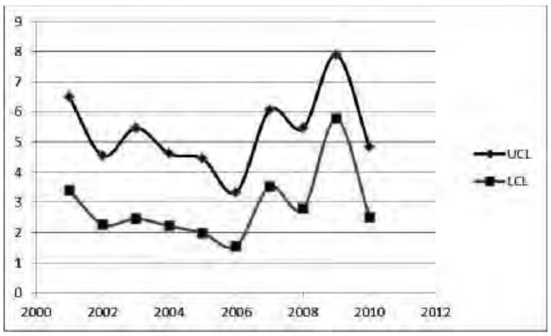


Figure 109: Sun Shine Hour in June-Tangail

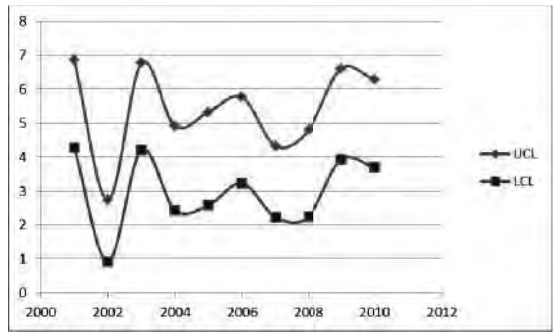


Figure 110: Sun Shine Hour in July-Tangail

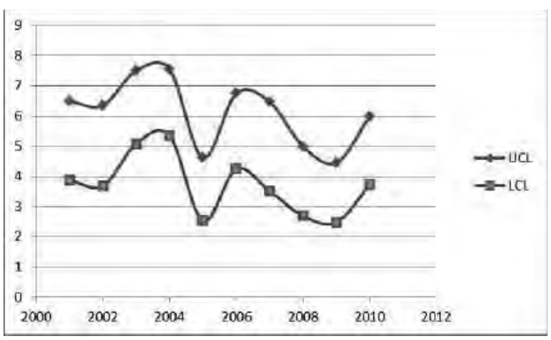


Figure 111: Sun Shine Hour in Aug-Tangail

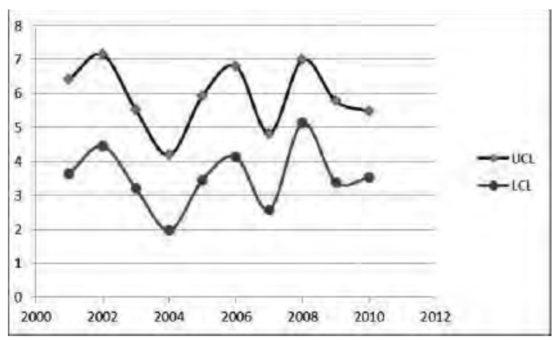


Figure 112: Sun Shine Hour in Sep-Tangail

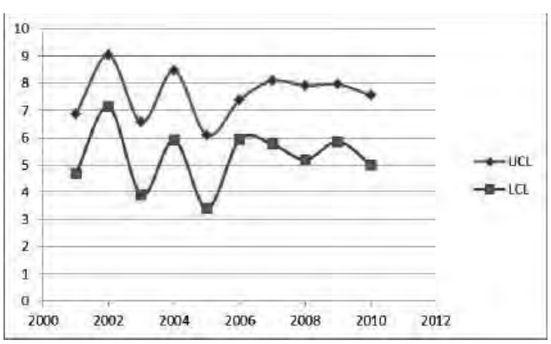


Figure 113: Sun Shine Hour in Oct-Tangail

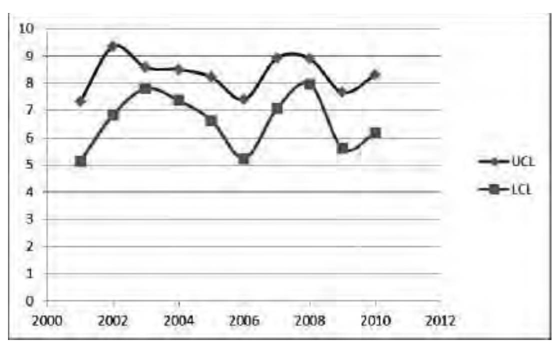


Figure 114: Sun Shine Hour in Nov-Tangail

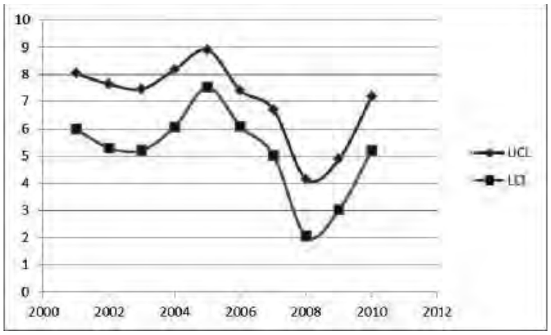


Figure 115: Sun Shine Hour in Dec-Tangail

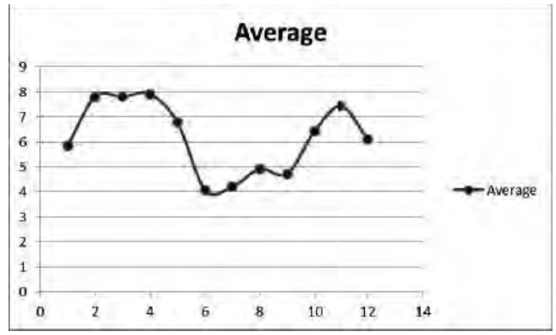


Figure 116: Average Sun Shine Hour in Tangail

RETScreen® Solar Resource and System Load Calculation - Photovoltaic Project

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Dhaka	*See Weather Database*
Latitude of project location	°N	23.0	-90.0 to 90.0
PV array tracking mode	-	One-axis	
Slope of tracking axis	°	23.0	0.0 to 90.0
Azimuth of tracking axis	°	0.0	0.0 to 180.0

Monthly Inputs

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/d)	Monthly solar fraction (%)
January	1.00	3.97	20.1	5.92	100%
February	1.00	4.89	23.0	7.27	100%
March	1.00	5.53	27.6	7.48	100%
April	1.00	6.22	30.2	7.76	100%
May	1.00	6.42	30.7	7.71	100%
June	1.00	4.92	30.3	5.34	100%
July	1.00	4.64	29.2	5.03	100%
August	1.00	4.47	29.1	4.96	100%
September	1.00	4.64	29.1	5.68	100%
October	1.00	4.53	28.2	6.26	100%
November	1.00	4.28	24.9	6.19	100%
December	1.00	3.83	20.8	5.88	100%

		Annual	Season of use
Solar radiation (horizontal)	MWh/m²	1.77	1.77
Solar radiation (tilted surface)	MWh/m²	2.29	2.29
Average temperature	°C	26.9	26.9

Load Characteristics		Estimate	Notes/Range
Application type	-	Water pumping	
Use detailed load calculator?	yes/no	Yes	

Description	Water pumping application	Unit	# of units	Water use per unit		Daily water required (m^3/d)
Farm house	Domestic	Person	0.0	L/d/person	0.0	0.00
Cows	Livestock	Head	0.0	L/d/head	0.0	0.00
Corn field	Irrigation	ha	12.0	$m^3/d/ha$	50.0	600.00

Daily water requirement	m^3/d	600.00		
Suction head	m	0.0		
Drawdown	m	2.0		
Discharge head	m	8.0		
Pressure head	m	1.0		
Friction losses	%	10%		5% to 10%
Total head	m	12.1		
		Daily	*Annual*	
Equivalent energy demand	kWh	19.78	7,220.98	

Return to Energy Model sheet

Type of analysis: Pre-feasibility | Currency: Bangladesh | Cost references: None

itial Costs (Credits)	Unit	Quantity		Unit Cost		Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study									
Other - Feasibility study	Cost	1	BDT	20,000	BDT	20,000		-	-
Sub-total :					BDT	20,000	0.6%		
Development									
Other - Development	Cost	1	BDT	20,000	BDT	20,000		-	-
Sub-total :					BDT	20,000	0.6%		
Engineering									
Other - Engineering	Cost	1	BDT	20,000	BDT	20,000		-	-
Sub-total :					BDT	20,000	0.6%		
Energy Equipment									
PV module(s)	kWp	8.40	BDT	1,10,000	BDT	9,24,000		-	-
Transportation	project	1	BDT	20,000	BDT	20,000		-	-
Other - Energy equipment	Cost	0	BDT	-	BDT	-		-	-
Credit - Energy equipment	Credit	0	BDT	-	BDT	-		-	-
Sub-total :					BDT	9,44,000	29.3%		
Balance of Equipment									
Module support structure	m^2	56.0	BDT	15,000	BDT	8,40,000		-	-
Inverter	kW AC	10.0	BDT	50,000	BDT	5,00,000		-	-
Water pump	project	1	BDT	4,50,000	BDT	4,50,000		-	-
Pipes/reservoir	project	1	BDT	1,00,000	BDT	1,00,000		-	-
Other electrical equipment	kWp	8.40	BDT	10,000	BDT	84,000		-	-
System installation	kWp	8.40	BDT	8,000	BDT	67,200		-	-
Transportation	project	1	BDT	20,000	BDT	20,000		-	-
Other - Balance of equipment	Cost	0	BDT	-	BDT	-		-	-
Credit - Balance of equipment	Credit	0	BDT	-	BDT	-		-	-
Sub-total :					BDT	20,61,200	64.0%		
Miscellaneous									
Training	p-h	6	BDT	65	BDT	390		-	-
Contingencies	%	5%	BDT	30,65,590	BDT	1,53,280		-	-
Sub-total :					BDT	1,53,670	4.8%		
Initial Costs - Total					BDT	32,18,870	100.0%		

Annual Costs (Credits)	Unit	Quantity		Unit Cost		Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M									
Property taxes/Insurance	project	0	BDT	-	BDT	-		-	-
O&M labour	p-h	1	BDT	60,000	BDT	60,000		-	-
Other - O&M	Cost	0	BDT	-	BDT	-		-	-
Credit - O&M	Credit	0	BDT	-	BDT	-		-	-
Contingencies	%	10%	BDT	60,000	BDT	6,000		-	-
Sub-total :					BDT	66,000	100.0%		
Annual Costs - Total					BDT	66,000	100.0%		

Periodic Costs (Credits)		Period		Unit Cost		Amount		Interval Range	Unit Cost Range
Inverter Repair/Replacement	Cost	12 yr	BDT	5,00,000	BDT	5,00,000		-	-
			BDT	-	BDT	-		-	-
			BDT	-	BDT	-		-	-
End of project life		-	BDT	-	BDT	-			

Go to GHG Analysis sheet

GHG analysis sheet? Yes

Type of analysis: Standard

Background Information

Project Information

Project name: RRE-RSF PUMP PROJECT

Project location: DHAKA

Global Warming Potential of GHG

1 tonne CH_4 = 21 tonnes CO_2 (IPCC 1996)

1 tonne N_2O = 310 tonnes CO_2 (IPCC 1996)

Base Case Electricity System (Baseline)

Fuel type	Fuel mix (%)	CO_2 emission (kg/GJ)	CH_4 emission (kg/GJ)	N_2O emission (kg/GJ)	Fuel conversion efficiency (%)	GHG emission (t_{CO2}/MWh)
Diesel (#2 oil)	100.0%	74.1	0.0020	0.0020	12.3%	2.192

Proposed Case Electricity System (Photovoltaic Project)

Fuel type	Fuel mix (%)	CO_2 emission (kg/GJ)	CH_4 emission (kg/GJ)	N_2O emission (kg/GJ)	Fuel conversion efficiency (%)	GHG emission (t_{CO2}/MWh)
Electricity system						
Solar	100.0%	0.0	0.0000	0.0000	75.0%	0.000

GHG Emission Reduction Summary

	Base case GHG emission factor (t_{CO2}/MWh)	Proposed case GHG emission factor (t_{CO2}/MWh)	End-use annual energy delivered (MWh)	Annual GHG emission reduction (t_{CO2})
Electricity system	2.192	0.000	7.221	15.83
			Net GHG emission reduction t_{CO2}/yr	15.83

Complete Financial Summary sheet

Annual Energy Balance

Project name		RRE-RSF PUMP PROJECT			
Project location		DHAKA	Nominal PV array power	kWp	8.40
			Equivalent pumping energy demand	MWh	7.2
Renewable energy delivered	MWh	7.221	Net GHG reduction	t_{CO2}/yr	15.83
Firm RE capacity	kW	-	Net GHG emission reduction - 20 yrs	t_{CO2}	316.64
Application type		Water pumping	Type of fuel displaced		Diesel (#2 oil)

Financial Parameters

Avoided cost of energy	BDT/L	63.000	Debt ratio	%	30.0%
RE production credit	BDT/kWh	-	Debt interest rate	%	6.0%
			Debt term	yr	8
GHG emission reduction credit	BDT/t_{CO2}	-	Income tax analysis?	yes/no	No
Energy cost escalation rate	%	5.0%			
Inflation	%	7.0%			
Discount rate	%	5.0%			
Project life	yr	20			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.6%	BDT	20,000	O&M	BDT	66,000
Development	0.6%	BDT	20,000	Fuel	BDT	-
Engineering	0.6%	BDT	20,000	Debt payments - 08 yrs	BDT	1,55,506
Energy equipment	29.3%	BDT	9,44,000	**Annual Costs and Debt - Total**	**BDT**	**2,21,506**
Balance of equipment	64.0%	BDT	20,61,200			
Miscellaneous	4.8%	BDT	1,53,670	**Annual Savings or Income**		
Initial Costs - Total	**100.0%**	**BDT**	**32,18,870**	Energy savings/income	BDT	3,44,925
Incentives/Grants		BDT	40			
				Annual Savings - Total	**BDT**	**3,44,925**
Periodic Costs (Credits)						
Inverter Repair/Replacement		BDT	5,00,000	Schedule yr # 12		
		BDT	-			
		BDT	-			
End of project life -		BDT	-			

Financial Feasibility

			Calculate energy production cost?	yes/no	Yes
Pre-tax IRR and ROI	%	9.7%	Energy production cost	BDT/L	50.27
After-tax IRR and ROI	%	9.7%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	11.5			
Year-to-positive cash flow	yr	9.8	Project equity	BDT	22,53,209
Net Present Value - NPV	BDT	13,94,446	Project debt	BDT	9,65,661
Annual Life Cycle Savings	BDT	1,11,894	Debt payments	BDT/yr	1,55,506
Benefit-Cost (B-C) ratio	-	1.62	Debt service coverage	-	1.67

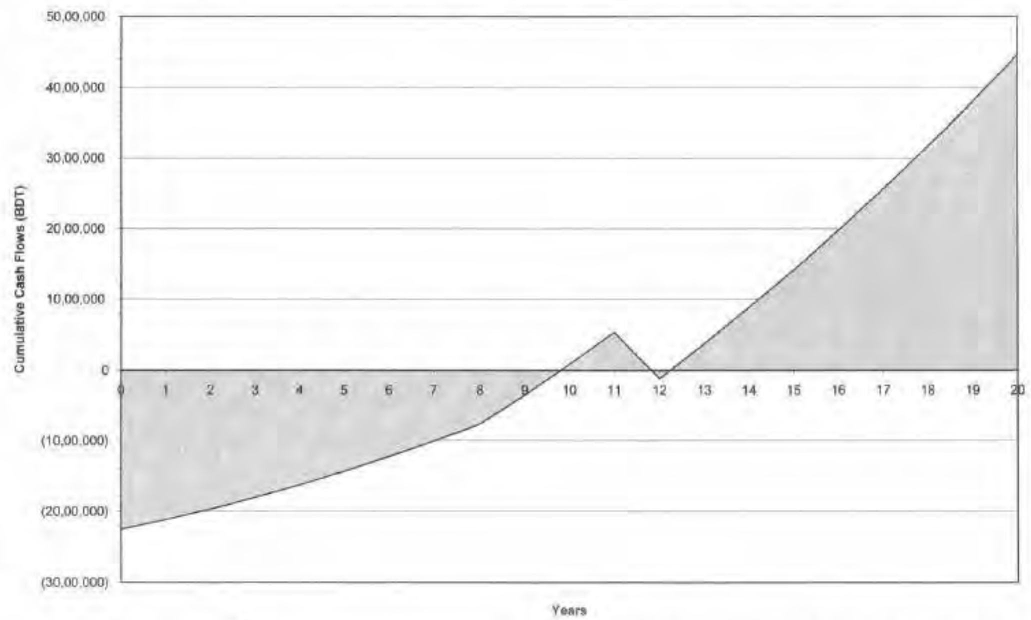
Yearly Cash Flows

Year #	Pre-tax BDT	After-tax BDT	Cumulative BDT
0	(22,53,169)	(22,53,169)	(22,53,169)
1	1,36,045	1,36,045	(21,17,124)
2	1,49,210	1,49,210	(19,67,913)
3	1,62,935	1,62,935	(18,04,978)
4	1,77,240	1,77,240	(16,27,738)
5	1,92,147	1,92,147	(14,35,592)
6	2,07,678	2,07,678	(12,27,913)
7	2,23,856	2,23,856	(10,04,057)
8	2,40,705	2,40,705	(7,63,352)
9	4,13,754	4,13,754	(3,49,598)
10	4,32,014	4,32,014	82,416
11	4,51,019	4,51,019	5,33,435
12	(6,56,306)	(6,56,306)	(1,21,870)
13	4,91,358	4,91,358	3,69,488
14	5,12,745	5,12,745	8,82,232
15	5,34,978	5,34,978	14,17,211
16	5,58,085	5,58,085	19,75,296
17	5,82,093	5,82,093	25,57,388
18	6,07,028	6,07,028	31,64,416
19	6,32,917	6,32,917	37,97,333
20	6,59,790	6,59,790	44,57,123

Cumulative Cash Flows Graph

Photovoltaic Project Cumulative Cash Flows
RRE-RSF PUMP PROJECT, DHAKA

Renewable energy delivered (MWh/yr): 7.221 | Total Initial Costs: BDT 32,18,870 | Net average GHG reduction (t_{CO_2}/yr): 15.83



IRR and ROI: 9.7% | Year-to-positive cash flow: 9.8 yr | Net Present Value: BDT 13,94,446

Use sensitivity analysis sheet?	Yes	Perform analysis on	After-tax IRR and ROI
Perform risk analysis too?	Yes	Sensitivity range	20%
Project name	RRE-RSF PUMP PROJECT	Threshold	15.0 %
Project location	DHAKA		

Sensitivity Analysis for After-tax IRR and ROI

Initial costs (BDT)		Avoided cost of energy (BDT/L) 50.4000 -20%	56.7000 -10%	**63.0000** 0%	69.3000 10%	75.6000 20%
25,75,096	-20%	8.0%	10.6%	13.3%	15.7%	18.0%
28,96,983	-10%	6.4%	9.0%	11.4%	13.6%	15.7%
32,18,870	0%	5.1%	7.5%	9.7%	11.8%	13.8%
35,40,756	10%	3.9%	6.2%	8.4%	10.3%	12.2%
38,62,643	20%	2.9%	5.2%	7.2%	9.1%	10.8%

Annual costs (BDT)		Avoided cost of energy (BDT/L) 50.4000 -20%	56.7000 -10%	**63.0000** 0%	69.3000 10%	75.6000 20%
52,800	-20%	6.2%	8.5%	10.7%	12.7%	14.6%
59,400	-10%	5.7%	8.0%	10.2%	12.3%	14.2%
66,000	0%	5.1%	7.5%	9.7%	11.8%	13.8%
72,600	10%	4.4%	7.0%	9.2%	11.4%	11.4%
79,200	20%	3.8%	6.4%	8.7%	10.9%	12.9%

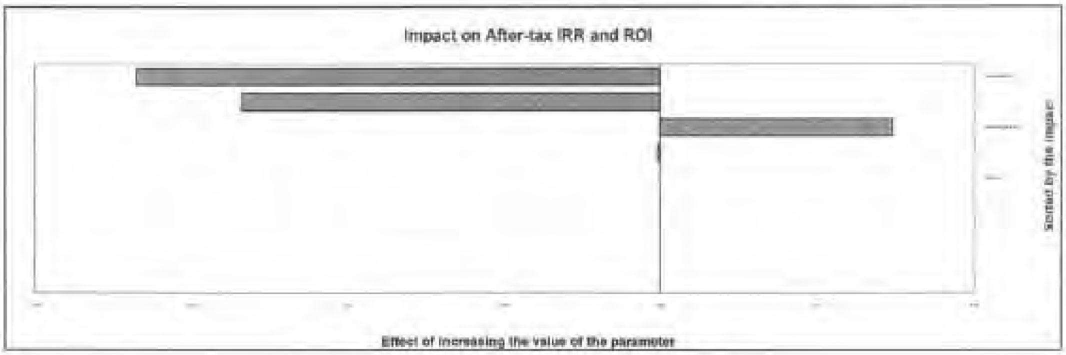
Debt interest rate (%)		Debt ratio (%) 24.0% -20%	27.0% -10%	**30.0%** 0%	33.0% 10%	36.0% 20%
4.8%	-20%	9.8%	9.8%	9.9%	10.0%	10.1%
5.4%	-10%	9.7%	9.8%	9.8%	9.9%	10.0%
6.0%	0%	9.0%	9.7%	9.7%	9.8%	9.9%
6.6%	10%	9.6%	9.0%	9.6%	9.7%	9.7%
7.2%	20%	9.5%	9.5%	9.5%	9.6%	9.6%

Debt interest rate (%)		Debt term (yr) 6.4 -20%	7.2 -10%	**8.0** 0%	8.8 10%	9.6 20%
4.8%	-20%	10.0%	9.9%	9.9%	10.2%	10.2%
5.4%	-10%	9.9%	9.8%	9.8%	10.1%	10.1%
6.0%	0%	9.8%	9.8%	9.7%	10.0%	10.0%
6.6%	10%	9.8%	9.7%	9.6%	9.9%	9.9%
7.2%	20%	9.7%	9.6%	9.5%	9.8%	9.8%

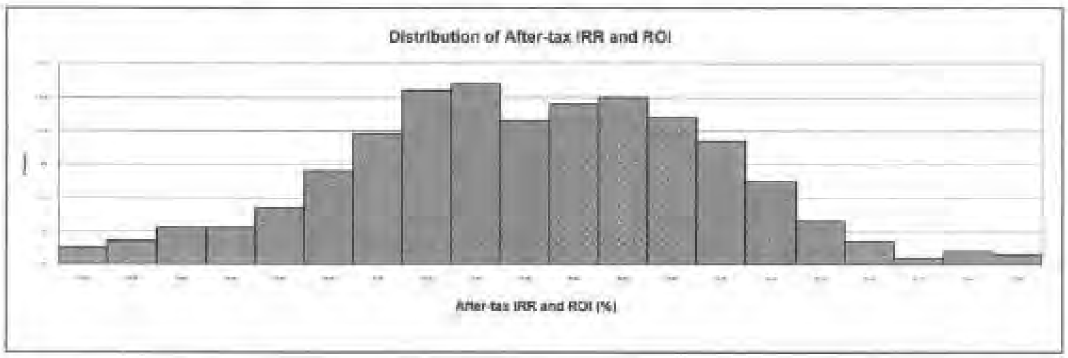
Risk Analysis for After-tax IRR and ROI

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Avoided cost of energy	BDT/L	63.0000	5%	59.8500	66.1500
Initial costs	BDT	32,18,870	5%	30,57,926	33,79,813
Annual costs	BDT	66,000	5%	62,700	69,300
Debt ratio	%	30.0%	0%	30.0%	30.0%
Debt interest rate	%	6.0%	30%	4.2%	7.8%
Debt term	yr	8	0%	8	8

Click here to Calculate Risk Analysis



Median	%	33.3%
Level of risk	%	10%
Minimum within level of confidence	%	30.8%
Maximum within level of confidence	%	35.4%



5.0%	Minimum	Median	Maximum	5.0%
	30.8%	33.3% (Level of confidence = 90%)	35.4%	