Economic and Environmental Viability of Solar Powered Irrigation System: A case Study of Fatah Jang

By

Samreen Niazi

Department of Environmental Economics

Pakistan Institute of Development Economics

(PIDE)

Pakistan Institute of Development Economic

CERTIFICATE

This is to certify that this thesis entitled: **"Economic and Environmental Viability of Solar Powered Irrigation System: A Case Study of Fatah Jang".** submitted by Samreen Niazi is accepted in its present form by the Department of Environmental Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree in **Master of Philosophy in Environmental Economics**.

Supervisor:

Dr. Aneel Salman
Assistant Professor
COMSATS, Islamabad.

External Examiner:

7/4/16

Dr. Khurum S. Mughal,
Assistant Professor, COMSATS,
Islamabad.

Head,
Department of Environmental Economics

Rehana Siddiqui

Dr. Rehana Saddiqui,
Head
Department of Environmental Economics
PIDE, Islamabad.

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(PIDE)

Signed by Supervisor: __________

To,

My butterflies "Haadia and Sophia"

&

Dearest "Shahzad"

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Nothing in this world is possible without the consent of ALLAH swt, He is indeed the one who grants us courage to take steps in the direction of acquiring knowledge and without HIS divine light and hope, standing by in tough times is not possible.

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Samreen Niazi

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List of Acronyms

Million tons of oil equivalence	(MTOE)
Tons of oil equivalents	(TOE)
Megawatt	(MW)
Gross domestic product	(GDP)
Green-house gases	(GHG)
World Health Organization	(WHO)
Renewable energy	(RE)
Photovoltaic	(PV)
Kilowatts per hour	(KWh)
Food and Agriculture Organization	(FAO)
Hydrocarbon Development Institute of Pakistan	(HDIP)
World Energy Outlook	(WEO)
Solar Energy Technology	(SET)
Giga Watt per hour	(GWh)

Pakistan Agricultural Research Council	(PARC)
Solar Powered Irrigation System	(SPIS)
Cost Benefit Analysis	(CBA)
Life Cycle Costing	(LCC)
Solar Powered Pumping System	(SPPS)
Diesel Powered Pumping System	(DPPS)
Renewable Energy Technology	(RET)
Net Present Value	(NPV)
Certified Emission Reductions	(CERs)
Clean Development Mechanism	(CDM)
Energy Yield Ratio	(EYR)
Simple Payback period	(SPP)
Internal rate of Return	(IRR)
Capacity factor	(CF)
Cost of energy	(COE)

Climate Change, Alternate Energy & Water Resources Institute	(CAEWRI)
Cost Benefit Ratio	(CBR)

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Abstract

Pakistan is a developing country, where majority of the population living in the rural are centrally dependent upon performance of agriculture sector. Rising population and rapid urbanization has resulted on high dependence on energy. Energy consumption in the country has increased tremendously in past two decades, with agriculture sector now being modernized and technically upgraded with improved new agro farm technologies. Pakistan has been under severe energy crisis since last decade. Annual budget deficits (as a result of circular debt), lack of political coherence and absence of vision and prioritization at state level, altogether have caused energy shortfall to persist and affect the attached segments of the economy negatively. In this scenario, agriculture sector has suffered deeply and so has common rural man for being dependent on agriculture sector for living. This vicious circle of low energy sources leading to low income growth needs to break as per to attain sustainability and growth in long run. Renewable energy, around the world is changing the energy scene. Traditional sources of energy already have caused serious threat to atmosphere, with strongly realized impacts of fossil fuel combustion on global warming. Here, renewable energy options seem to serve the purpose of fulfilling energy needs as well as being sustainable and climate friendly option in the future.

Among renewable energy options, solar energy has abundance of potential in Pakistan. Pakistan lies in the region where energy generation from Solar Photovoltaic (PV) is in the high range, 5 kw/m^2 / day. Tapping this potential to address energy crisis in Pakistan, specifically when alternate fossil fuel based energy options are either absent or incur a high operational cost, is a dire need of time.

This study analyzes potential of solar energy to be used in pumping water for irrigation purposes. A pilot case study of *water shed management and lift irrigation using solar energy* by PARC at Thatti Gujran, Fatah Jang has been taken for the analysis. The feasibility of this project, in three dimensions, (environmental, economic and social) has been calculated in this study, in comparison to a diesel. Economic tools being used for this purpose are Life cycle costs (LCC), Net present Value (NPV), Internal Rate of Return (IRR) and CBA (Cost benefit ratio).Sensitivity analysis has also been performed to analyse the impact of change in key parameters on economic indicators. Results indicate solar powered pumping system to be more viable than diesel powered pumping system. Same feasibility analysis has been attempted to be configured through simulations on RET screen , an emerging software which analyses the feasibility of projects using Renewable Energy Technologies, and similar viability of SPPS has been observed. Annual GHG reduction cost has been estimated by RET screen which indicates annual social benefit as a result of using clean energy.

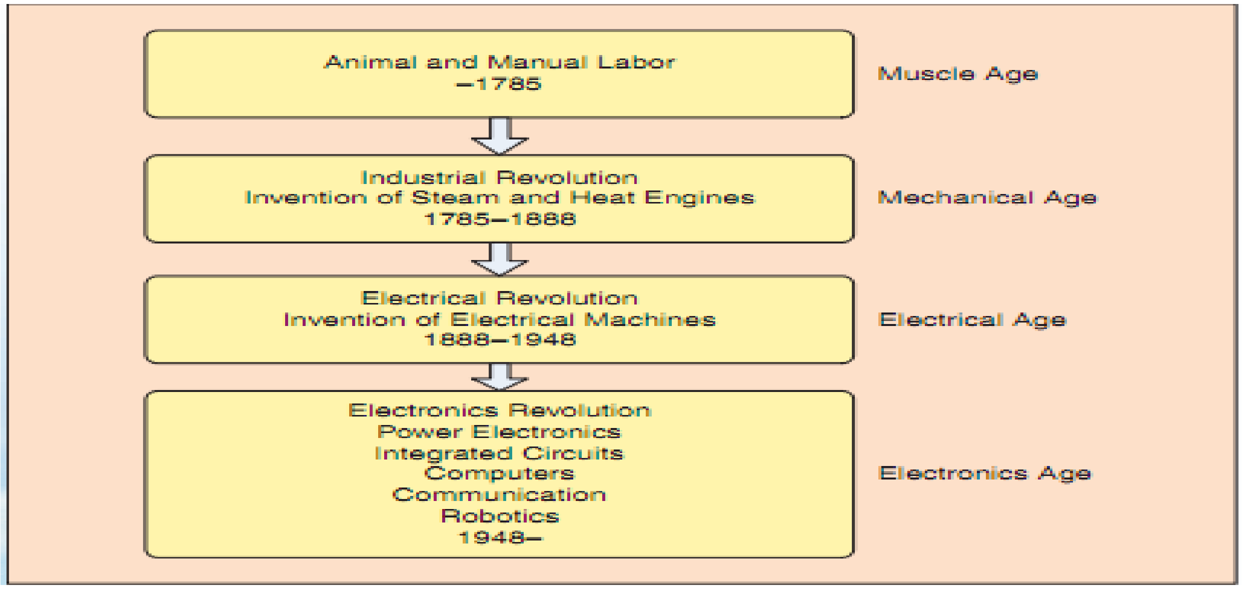
Chapter I

Introduction

“The concept of energy, is of a conserved quantity that represents the ability to do work” (Cottrell, 2009). The significant place of energy to activate life has been studied in detail since last two centuries but its participation in physical and biological transformation of Earth has existed since planet’s birth. Even scientifically acknowledged big bang theory is explained in context of energy and matter. Development in the field of energy has opened numerous gates for the transformation and progress of societies, and energy advancements have led to support insight and progress in almost every domain of life, from history to technology, economics to engineering, anthropology to ecosystems and health. Economy’s energy potentials have paved a pathway to its economic expansion (Cottrell, 2009). Talking in the perspective of economic growth, the role of energy seems central when understood through the lens of theoretical and empirical evidences. Stern in (Stern, 2011) asserts this notion through numerous literature sources, which lead to identify energy as an essential factor of production among labor and capital. Energy helps to produce further inputs in production processes. The fact that energy is a scarce resource compels its usage to be as efficient as possible.

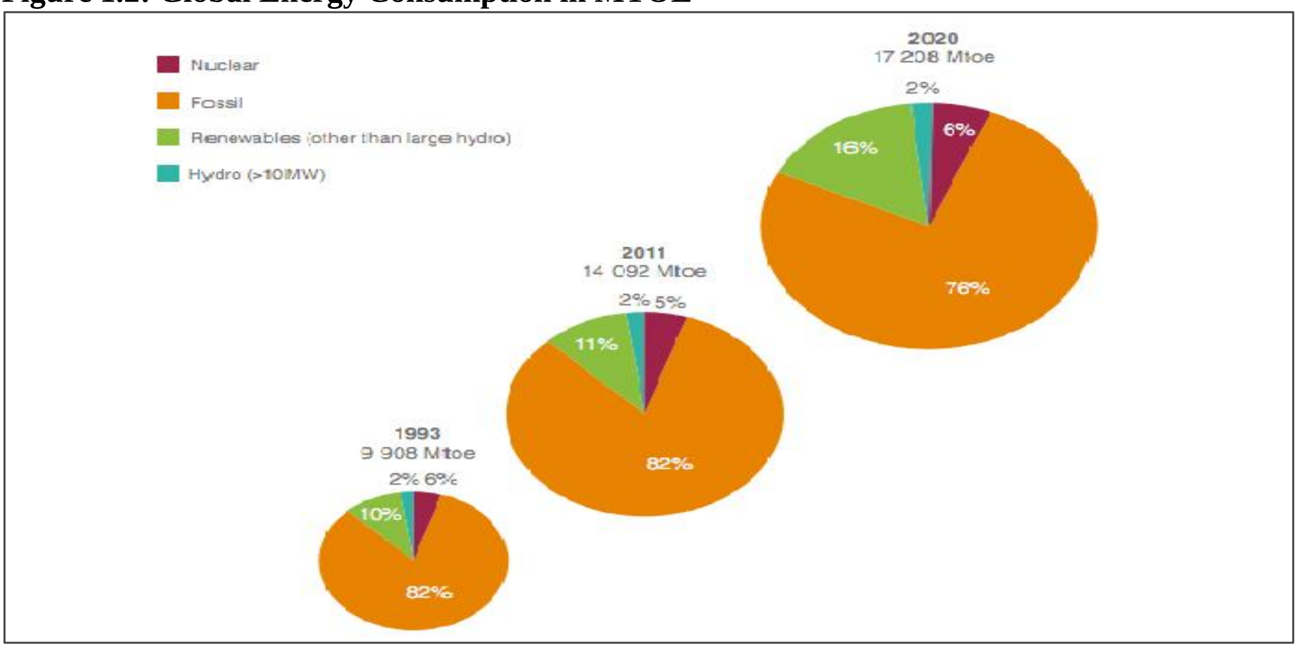
Global revolution of energy is explained in Figure 1.1. The mechanical, electrical and electronics age demonstrated energy consumption to rise exponentially to address needs of rising population. But the negative effect of fossil fuel burning was hardly paid any attention (Bose, 2010).

Figure 1.1: Evolution of Industrial Civilization



Source: (Bose, 2010)

Figure 1.2: Global Energy Consumption in MTOE



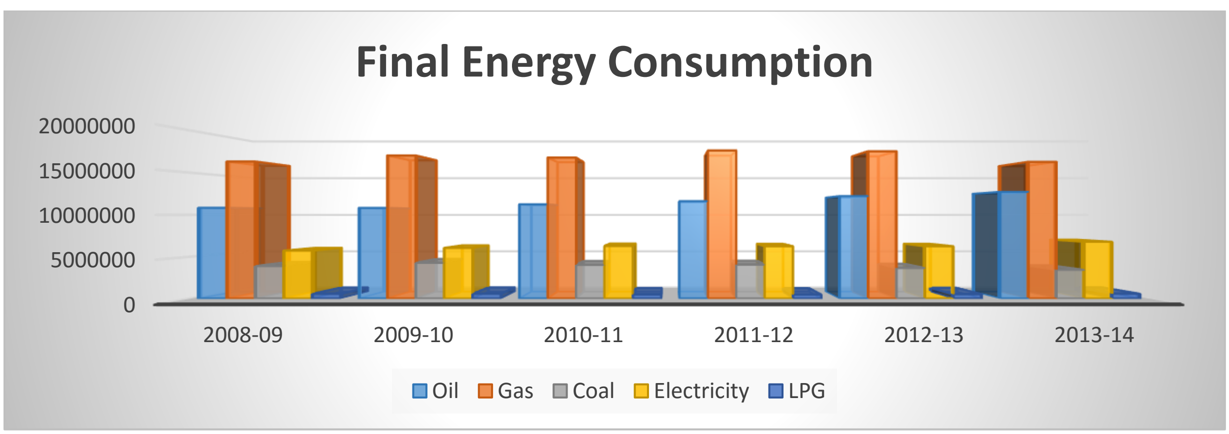
Source: (World Energy Resources, 2013)

As observed, global energy consumption has been on a constant rise, from 9908 million tons of oil equivalence (MTOE) in 1993 to approximately 15000 MTOE by 2014. Recent figures indicate that globally, 87% of total energy generated comes from fossil fuels, where the composition is 28% coal, 21% natural gas and largest ratio of 38% from oil. Nuclear plants contribute around 6% of total global energy and 7% is contributed by renewable energy resources[1] (Bose, 2010).

1.1 Current Situation of Energy in Pakistan:

Energy being a central ingredient to sustain economy's industrial, commercial and domestic activities is an imperative input in the pathway of a country's growth and development. Any disruptions halting industrial and commercial sustainability cause decline in overall economic growth as well as employment, which further disrupts social harmony adding to poverty (GOP, 2013-14). In 2014, final indigenous energy consumption was 39,819,518 tons of oil equivalents (TOE), high majority of which is acquired through burning fossil fuels where, natural gas has had the highest percentage.[2]

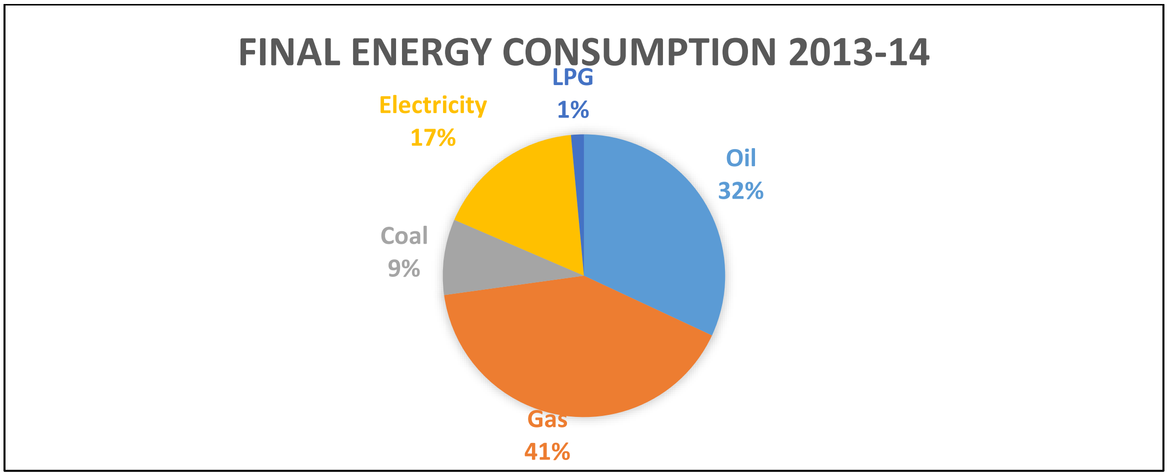
Figure 1.3. Final Energy Consumption by Source. . Unit: TOE.



Source: Pakistan Energy Yearbook 2013-14

[1] Renewable energy sources such as Biofuel, Nuclear , Wind and Solar energy
[2] HDIP Pakistan Energy Yearbook 2014

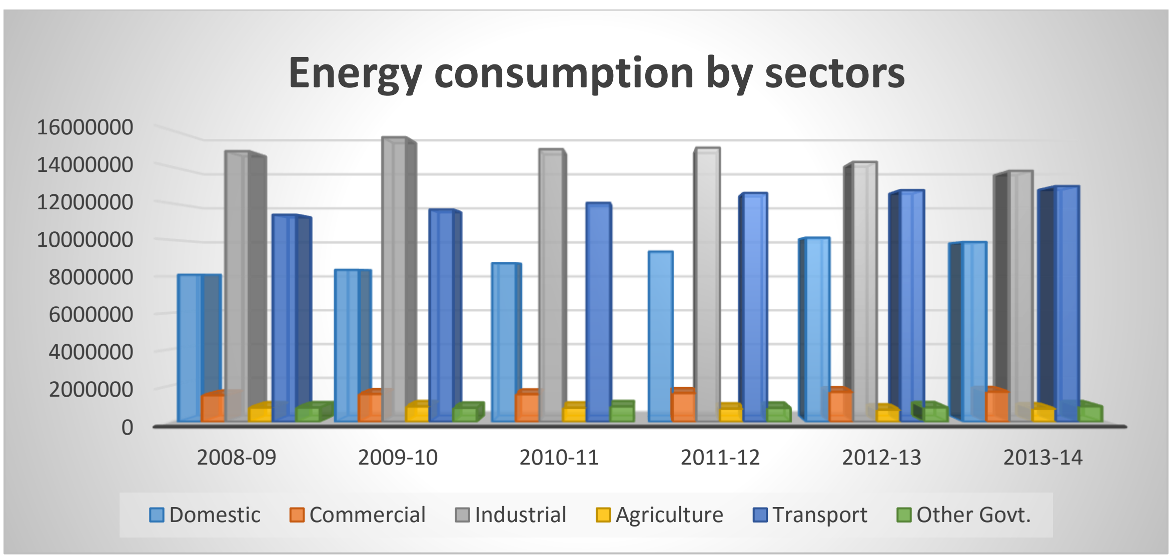
Figure 1.4: Final Energy Consumption 2014



Source: Pakistan Energy Yearbook 2013

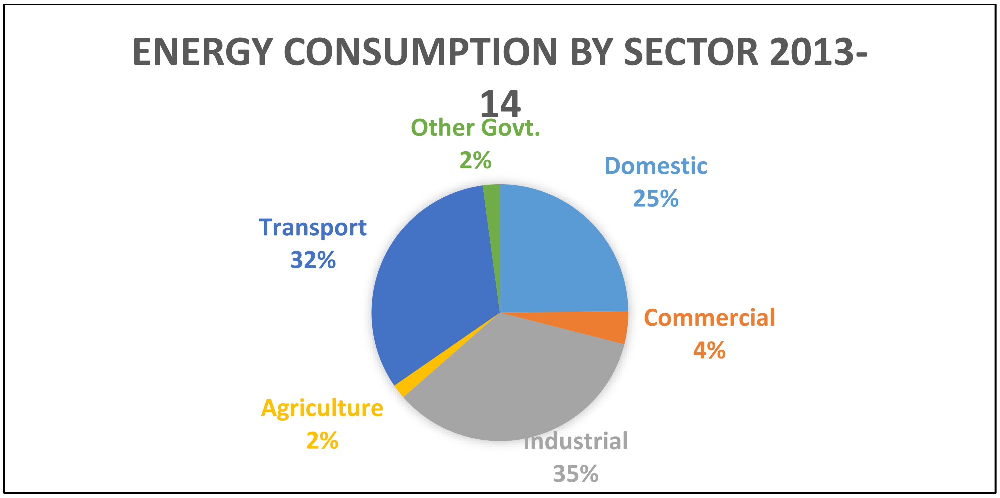
Figure 1.3 and figure 1.4 demonstrate the energy mix scenario in 2013-14 in Pakistan. A closer look at the sectoral consumption of energy is shown in Figure 1.5 and Figure 1.6.

Figure 1.5: Sectoral Consumption of Energy in 2013-14 in TOE



Source: Pakistan Energy Yearbook 2013-14

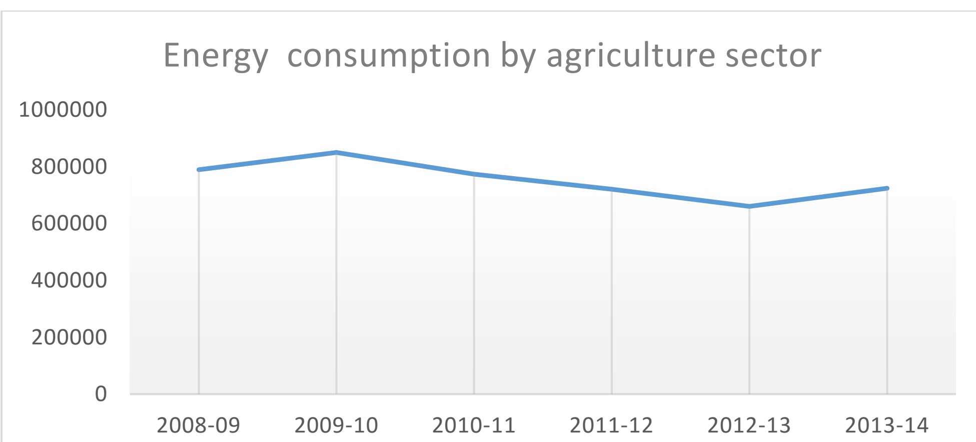
Figure 1.6 : Energy Consumption by Sectors



Source: Pakistan Energy Yearbook 2013-14

Figure 1.5 and 1.6 clearly indicate that the major sectors of energy consumption in are industry, transport and domestic use. Over the years, agriculture is seen as the least energy consuming sector which has been on a continuous decline in the recent years as depicted in Figure 1.7.

Figure 1.7: Energy (Electricity plus oil) Consumption by Agriculture sector over the years in Pakistan.



Source: Pakistan Energy Yearbook 2013-14

1.2 Energy and Agriculture

According to FAO (n.d.) agriculture in itself could be seen as an energy conversion process, the conversion of solar energy to energy for humans and animals (FAO n.d.). As compared to primitive agriculture, modern agriculture needs energy as input at various stages of production and in a larger amount for numerous purposes (Ibid).

Agriculture has been exercised in developing countries while largely relying on animal and human energy. Deficient mechanical and electrical energy for agriculture has therefore slowed down the possible potential gains in the sector production. The benefits of technology based modern agriculture have not being recognized as yet. Demand of energy in agriculture sector has direct as well as indirect needs*;* from irrigation to water storage and management, cultivation to harvesting, post cultivation to food storage and transport, availability of sufficient and economical energy sources is crucial. Apart from direct use, indirect use of energy in agriculture may include *sequestered energy in fertilizers, herbicides, pesticides, and insecticides.* Industrialized nations have reaped lager benefits from advancements in energy sources in agriculture than developing countries (Ibid).

Pakistan, being an agrarian economy, depends heavily on the agriculture sector for employment, contribution to gross domestic product (GDP), sustaining livelihoods, provision of raw inputs to industries and earning foreign exchange. Up to 67.5% of Pakistan's population is based in rural areas and are directly or indirectly involved in agricultural activities (Safdar 2013). While 52% of employment in Pakistan is provided by the agriculture sector. Agriculture in Pakistan contributes

21% to the GDP, with almost 45% of exports are based on materials from this primary sector (Ibid).[3].

Deficiency in power generation and Energy demand in agriculture sector, has affected agricultural output and growth negatively. To fulfill the energy gap, Government of Pakistan has imported oil worth of 1 billion USD, which has further drained the economy and budget through circular debt. (Ahmed and Zeshan 2014)[4]

1.3 Energy Deficiency in Pakistan

Rising population and escalating demand for energy consumption indicate that energy crisis will be one of the central problems in coming years. Like many other developing countries, Pakistan is undergoing energy deficiency which results in load-shedding in both urban and rural areas. Hiking oil prices in mid 2000s have been the major reason for this under-utilization, which has disrupted electricity generation from thermal power plants. (Farooq and Kumar, 2013).

Currently, a deficit of 4500-5000 MW (average) in demand and supply of electricity is being observed, which is a threat to economic growth. The demand in electricity is forecasted to be 5-6 % in the coming decade, which now signifies the indispensable incorporation of new resources of energy generation, adding to presently installed capacity. (Sher et.al, 2015)

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[3]Safdar, A. 2013, 'Challenges faced by Pakistan's Agriculture Sector', Agribusiness, Rawalpindi, http://www.agribusiness.com.pk/challenges-faced-by-pakistans-agriculture-sector/ viewed 22 June 2015

[4] (Ahmed and Zeshan 2014)

1.4 Renewable Energy: Need of time to address energy deficiencies

Identifying the impacts of inefficient power plants, Khan and Latif (2010) analyze the need to import petroleum products for fulfilling the domestic energy needs, thus burdening the economy with circular debt. Government of Pakistan has announced power generation plans, which while expecting peak demand of electricity to rise to 474 GW by 2050, reveal 65% of its enhanced plant capacity to be thermal based electricity. This would implicitly mean increased usage of fossil fuels hence contributing to (Green-house gases) GHG emissions and global warming (HDIP 2013; Farooq 2014). Khan and Latif (2014) recognize that the future of environmental quality is decided by the nature of energy used today, furthermore, swift increase in agricultural production requires higher and efficient energy sources (Van Campen et al. 2000).

The situation of energy in Pakistan has become alarming because of its heavy reliance on hydel power generation to provide energy. Presently, main hydel power plants in operation are Tarbela, Mangla, and Ghazi Brotha, producing electricity which is however insufficient for the rising population's needs. In given circumstances, it is imperative to emphasize on renewable energy sources. Solar energy is an economical and widely used energy option being used in modern world today (Adnan.et.al, 2012).

1.5 Environmental Implications of Energy Choice

Fossil fuels, which have been dominating the energy provision scenario of the world till date (80%) are depleting, thus indicating towards need for discoveries of alternate energy sources, further the environmental impacts associated with the use of fossil fuels have been releasing horrendous consequences in the form of GHG emissions causing global warming. As World Health Organization (WHO) reports, 160,000 people die each year from the side effects of climatic changes and the number could double by 2020. In order to meet the energy needs of rising population without inflicting a permanent loss to environment, use of renewable energy resources is indispensable. (Hrayshat, 2009)

1.6 Solar Energy: Photovoltaic (PV)

'Earth receives about 100,000 TW of solar power at its surface. Enough energy every hour to supply humanity's energy needs for a year, theoretically, the world's primary needs could be served by less than a tenth of the area of the Sahara' (Shiermeier et.al, 2008, p.821)

It is the technology that produces Direct Current (DC) of electricity which can be measured in Watts (W) or Kilowatts (KW) from semiconductors when they are lightened up by photons. (Bhutto et.al, 2012).

'A PV power generation system is rated in peak Kilowatts, which is an amount of electrical power that a system is expected to, deliver when the sun is directly overhead on a clear day' (Ibid, pp -2763)

Energy generation from solar PV installation alters with variation in solar irradiation present[1]. From a geographical point of view, solar irradiation is maximum at tropical region and is more evenly distributed than wind. Solar PV systems can well forecast seasonal and daily patterns in power generation (WEO, 2013). Environmental benefits of using solar energy technology (SET) have been discussed in various studies.

"SETs present tremendous environmental benefits when compared to the conventional energy sources. In addition to not exhausting natural resources their main advantage is, in most cases, total absence of almost any air emissions or waste products. In other words, SE can be considered as an almost absolute clean and safe energy source" (Tsoutsos et al. 2005)

Hrayshat (2009) also asserts that solar PV systems generate electricity with little maintenance (with) no direct pollution or depletion of resources. *'Photovoltaic energy conversion is one the best ways to harvest the solar energy'* (Gopal et al. 2013).

1.7 Global trends and development in Solar PV energy

Solar energy based photovoltaic (PV) systems support sustainable development by generating clean energy thus making a contribution in climate protection. Being an alternate energy, PV systems help to reduce the use of diesel and fossil fuels for electricity generation, thus mitigating CO^2 emissions (Chaurey & Kandpal, 2010).

Globally, over the last decade, energy generation from solar PV has increased by 50% per year, and was accounted around 100 terawatt per hour (TWH) in 2012 (WEO 2013). A visible and exponential progress has been observed in PV technology in the last two decades .Presently, PV is counted among the most essential technology in times to come. Maximum installed PV technology is grid connected (GC), whereas the off-grid capacity is only 2% of entire global PV capacity. However, there is a rising trend of capacity building in off-gird PV systems, specifically in developing countries (Harijan et.al, 2015). Maximum installed capacity in 2013, installed solar capacity expanded by 43% and counts for 15% of the entire growth of power generation capacity worldwide (Chaurey & Kandpal, 2010).

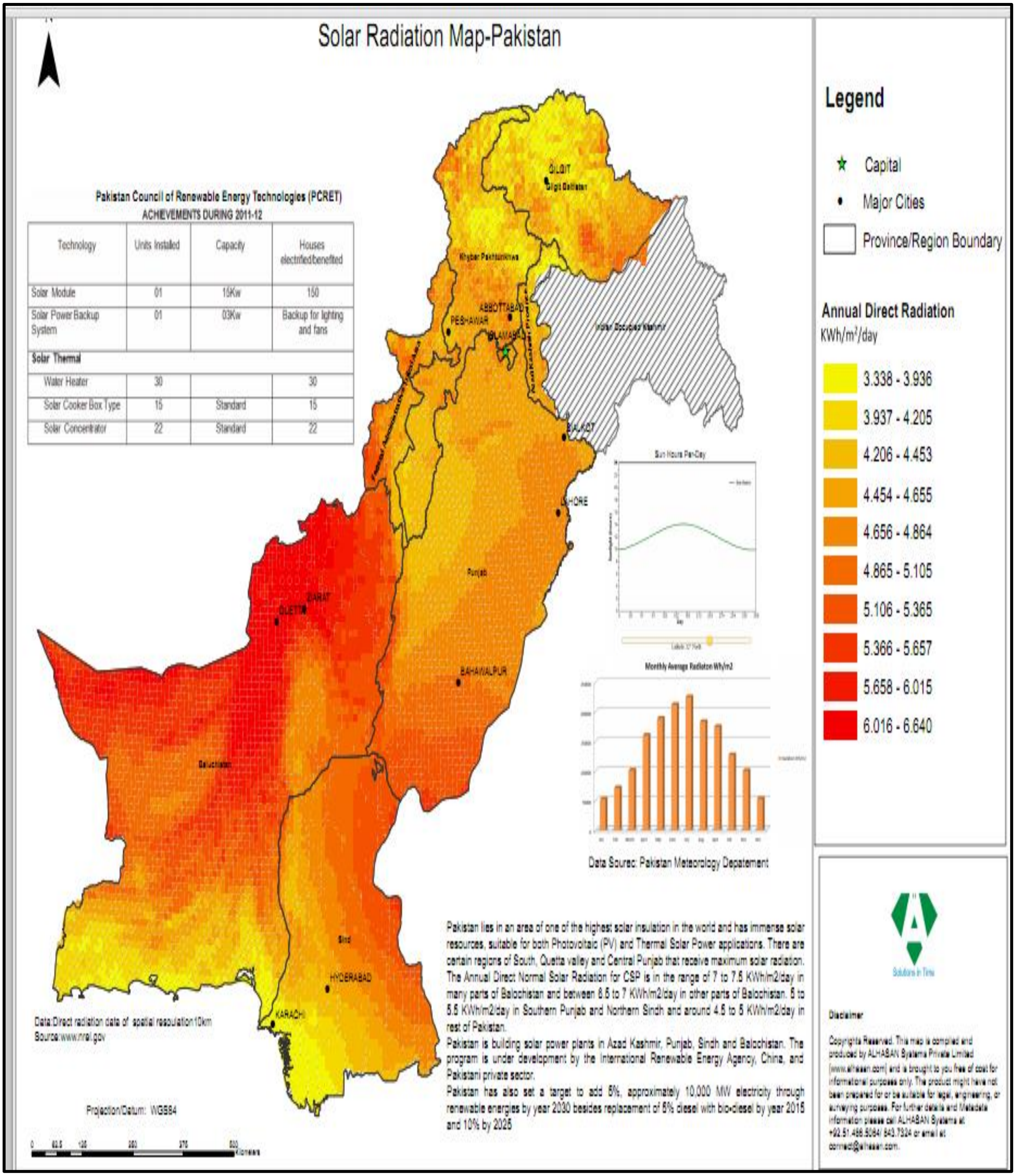
1.8 Solar PV potential in Pakistan

Pakistan is situated between latitudes 24^o and 37^o north and longitudes 62^o and 75^o east with an area of 796096 km square. The solar radiation incident is in the range of 5-7/KWh/m^2 day over 95% of the total area with persistence factor of over 85%. (Farooq & Kumar, 2013).

"Pakistan is a high insolation country. It receives about 1KW of solar energy for square meter of its landmass for 6-7 hours on the average per day. The number of sunshine hours amount almost to 3000-3300 per year. The weather is most favorable for the utilization of solar energy". (Ulfat et.al, 2012, pp.1496)

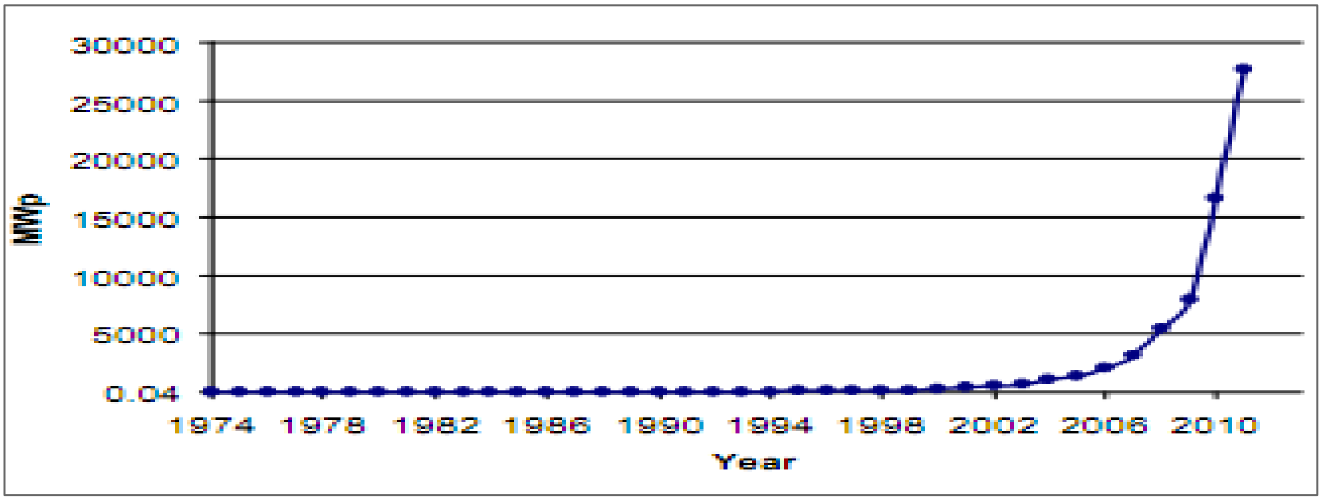
As depicted in figure 1.8, the western coast border areas in Pakistan i.e. Sindh, Cholistan desert of Punjab and Balochistan are heavily endowed with high solar radiation, and thus, can be exploited for building large solar PV plants. Sunshine hours in these areas lie between 2300-2700 hours. Three out of four provinces of Pakistan, Balochistan, Sindh and Punjab receive more than 5 kwh/m^2 /day throughout the year. As a huge expanse of Balochistan province is remote and un electrified , the immense solar radiation in this area, makes solar irradiation in this area, makes solar PV an ideal energy option for this place .Social development and projects and infrastructural growth can thus reach these less developed portions of the country. Similarly, the villages in the desert of Sindh and Punjab can also be benefitted and can contribute to community growth (Sher et.al, 2015)

Figure 1.8: Solar Radiation Map in Pakistan



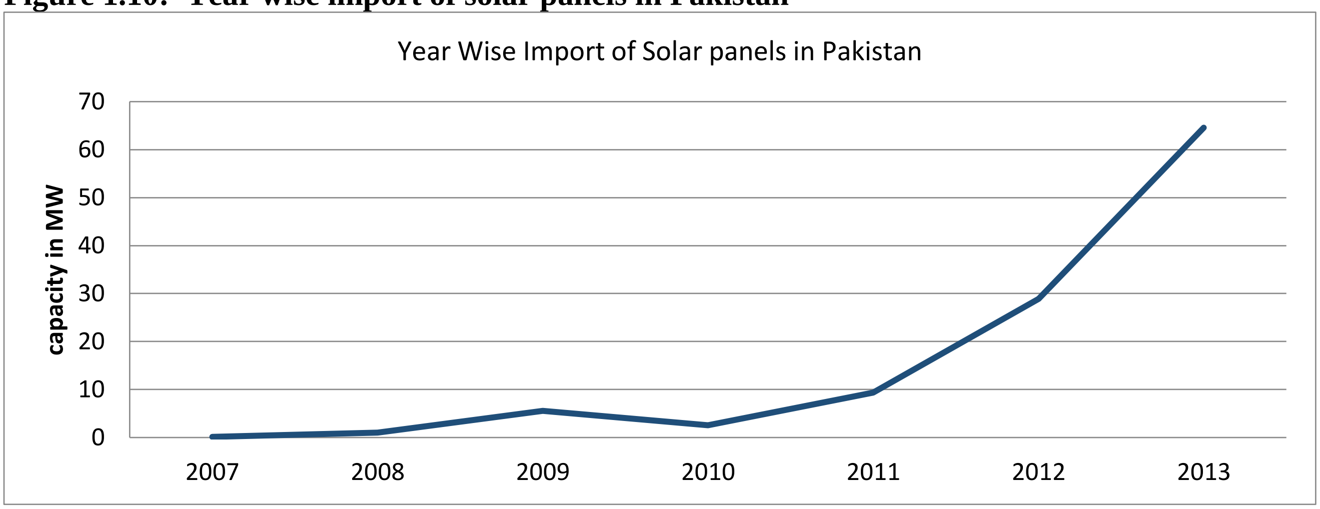
Source: http://www.alhasan.com/sites/default/files/12-6.pdf

Figure 1.9: World Annual installation of PV 1974-2010.



Source: Khalid & Junaidi, (2013)

Figure 1.10: Year wise import of solar panels in Pakistan



Source: Pakistan Energy Year Book 2013

As figures 1.9 and 1.10 depict, use of solar energy has been rising since the last decade, understanding its economic viability in comparison to traditional energy use e.g. diesel, electricity and some other renewable energies i.e. wind, biogas becomes crucial to attain most efficient option for energy generation. Numerous studies worldwide have studied the feasibility of solar energy.

1.9 Solar Potential and the Case study of Fatah Jang

Given high potential of Solar energy in Pakistan and recognizing energy deficiency in agriculture sector, which affects the chain of consequences inside the economy, it is therefore imperative to find solutions in renewable energy to address country's current energy deficiency.

The case study taken up by this research is an example of renewable energy use in agriculture. (Pakistan Agricultural Research Council) PARC initiated a pilot project (2012) of vegetation and crop harvesting at Thatti Gujran, District Fateh Jang, Punjab, where only solar energy has been utilised for irrigation purpose in the farm area of 20 hectare (ha). A watershed in the form of a mini dam (10 feet deep) has been the water resource for this specific area (PARC 2013) Water pumping for irrigation has been executed by using solar energy, instead of diesel operated generators. This study, aims at the economic viability of solar powered irrigation in comparison to diesel powered irrigation system. Details of the project are discussed in next chapters to give a complete overview of the study.

Research problem

As energy crisis soars in Pakistan, resulting in handicapped industrial sector and disturbance in all other sectors including agriculture, it is about time to consider naturally endowed alternate renewable energy sources, like solar energy, to pave a sustainable pathway to development. However, the affordability and economic viability of solar energy as compared to traditional fuels, remain questionable. Keeping this perspective in mind, this study aims to conduct an economic feasibility analysis of a solar powered pumping system for irrigation in order to analyze its cost effectiveness in comparison to diesel, using economic and environmental indicators.

Research Question

- Is use of solar power in pumping for irrigation a more economically viable option than diesel based pumping system?

Objectives of the Study

- To analyze the feasibility of solar powered pumping system for irrigation in comparison to diesel based pumping system through Cost Benefit Analysis (CBA) and Life Cycle Costing Method. (LCC).
- To analyze the influence of different economic factors i.e. discount rate, inflation, time period, on the feasibility of the project through Sensitivity Analysis.
- Performing avoided GHG emission analysis, to assess the benefit of using solar PV system as Clean Energy instead of diesel based pumping system.

Significance of the Study

Deficiency of energy in Pakistan and environmental implication of conventional energy generation has led to an indispensable need of renewable energies' contribution at a larger scale. Above mentioned analysis stresses upon the need to understand and find the most cost effective method for pumping water for irrigation, among numerous choices of energy generation. This study aims to find out the economic viability of solar pumping system in comparison to diesel based pumping system, for the pilot project under the program "Watershed Rehabilitation and Irrigation Improvement in Pakistan" by PARC, in Thatti Gujran, Fateh Jang, Potohar District, Punjab.

Pakistan has yet to tap its potential in solar PV energy, as well as in depth feasibility analysis of the renewable energy projects. This study can prove to be a milestone as a reference in this regard and pave a pathway for further research in this direction.

Organization of the study

This study has been organized as follows, the first chapter has built the context of the study with the introduction of the topic. The second chapter of literature review discusses different studies in literature regarding energy deficiency, significance of renewable energy, use of solar PV energy worldwide and specifically feasibility analysis of PV related projects. Details of research methods and data have been analyzed in third chapter. Fourth chapter is composed of all the results and their interpretation. Final and fifth chapter concludes the study and suggests policy recommendations to improve the current energy situation and promote use of solar PV energy as an alternative.

CHAPTER II

LITERATURE REVIEW

The discussion from chapter I has highlighted the notion that it is essential and about time to understand and tap the potential of alternative energy sources[5]. Renewable energy options are progressively rising in proportion to be a significant part of global energy mix, tapping the share of 13% in global primary energy use in 2011, to the projected share of 18% by 2035 (WEO 2013). Major sources of renewable energy worldwide are wind energy, solar (photovoltaic (PV) and thermal), hydropower, biomass, geo thermal, nuclear fission, ocean tidal wave energy (Schiermeier et al. 2008) However, the potential to utilize a renewable energy source depends upon many factors. As Boyle (2004) describes 'The potential of renewable energy (RE) is the energy which can be provided by the specific source annually. However, the potential depends upon geographical, technical, and economic limitations.

2.1 Energy and economic growth

Multiple studies have been published regarding the energy and economic growth nexus. In context of Pakistan, Chaudhry et al., (2012) studied the role of energy consumption in economic growth, and have empirically indicated the significant participation of energy in the process of Pakistan's economic development. Previously, Siddiqui (2004) demonstrated the energy to be a significant determinant of economic growth, and further apprehended a shortfall in energy to be crucial enough to halt economic growth.

[5] (Khan &Latif 2010) (Farooq,2014) (Khalil &Zaidi 2014) (Sheikh, 2009) (Awan &Khan 2014)

Many studies have highlighted the gap in energy consumption and provision and have assessed numerous factors to be the cause of this deficiency. Khalil & Zaidi, (2014) have analysed the difference in energy generation and energy demand has increased from 2645 megawatt (MW) in 2007 to 6151MW in 2011. Farooq and Kumar (2013) have assessed that Pakistan's lagging capacity to fulfill energy demands can be attributed to under-utilization of power generating units. Further, Khalil& Zaidi (2014) have indicated that the old and worn out infrastructure, excess load on transmission lines in power distributing companies are also among the reason for inefficient energy utilization. (Sheikh, 2009) have also recognized absence of vigilant planning and implementation of country's energy policy to be the cause of current energy crisis.

As Figure 1.6 indicated the rising rate of solar panel installation, the hike in solar energy for multiple purposes is an easy observation worldwide. Numerous studies, around the globe have assessed the potential of solar energy particularly for irrigation purposes, in comparison to diesel, electricity and other renewable energy resources.

Economic feasibility of PV system has been observed to be varying at different places in last 10-15 years for various reasons. Many studies have compared renewable energy sources like wind and biomass with PV system for energy generation (Bouzidi, 2011). Diesel and grid connected electricity are few of the non-renewable options of energy generation for pumping water[6]. While other studies have analyzed selection of the most suitable place in their respective countries for a potential PV pumping system to address the specific energy requirement of e.g. 5MW, 10MW. [7]

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[6] (khan et.al 2014, Bhuyian et.al, 2000)
[7] (Khalid & Junaidi, 2013; Mirzahosseini & Taheri, 2012)

2.2 Empirical analysis of Solar PV feasibility

For comparative analysis of different pumping methods, life cycle costing is a commonly used methodology Khan et al. (2014)investigated the feasibility of Solar Powered Water Pumping Systems (SPPS) and diesel powered pumping Systems (DPPS) for 27 crops in Bangladesh. Two pumps of same horsepower 5 (hp) were selected for comparison. The study compared the present value of total cost of irrigation from each pumping system for the period of ten years, and identified the SPPS to be more cost effective for 10 of these crops as compared to DPPS. In another study for Bangladesh, Bhuiyan et al. (2000) evaluated the economic feasibility of a Photovoltaic (PV) system for remote and rural electrification. The study presented a comparative view of generating energy for a family from PV system, with diesel generators, petrol generators and grid electricity (with distribution line being 1 km away from the villages).

Method of life cycle costing has been used to assess the per unit cost in kWh for all energy generation sources for a period of 20 years, and it has been found that PV system is most feasible option in rural and remote areas of Bangladesh where grid electricity is not available. Regarding rural electrification, Oparaku (2003) also performed the cost comparative analysis of PV systems against diesel/gasoline generators and electricity grid extension option for a period of 20 years using life cycle cost method for Nigeria. With given module of PV system, price of diesel fuel and distance (1.8 km) to grid utility, PV system was not found economically feasible, however, this feasibility was assessed to be found sensitive to fuel pricing, change in PV module and rising distance to the grid provision through sensitivity analysis.

Bouzidi et al. (2009) assessed the potential for PV system for pumping ground water in Algeria in comparison to diesel pumping system using life cycle cost analysis for the period of 20 years and concluded the PV system to be economically unfeasible for the Algerian fuel abundant economy basically attributing to high cost of investment in PV system. However, the sensitivity analysis demonstrated beyond escalation rate of 25% in diesel price, PV system is economically feasible for ground water pumping.

Bouzidi (2011) also assessed the SPPS economic viability for Algerian Sahara regions in comparison to wind turbine based pumping systems. Life cycle costs of two systems for a period of 20 years has been analyzed and results of cost per cubic meter of water demonstrated wind turbine system to be more feasible economically than SPPS despite having lower observed potential of wind energy. Reasons were attributed to common robbery and damage cases of equipment causing fear along the border areas and the higher initial cost of PV installation systems.

Similarly, Mahmud and Nather (2003) evaluated economic viability of SPPS in comparison to DPPS in remote areas of Egypt[8] for irrigation purposes. Using life cycle cost analysis, for three different time periods[9] indicated SPPS to be more economically viable than DPPS. Sensitivity analysis demonstrated water cost to be more sensitive to the pricing of PV cells than the different time periods considered.

In a case study from Saudi Arabia, Kelley et al. (2010) analyzed economic feasibility of PV pumps for irrigation purpose at different locations through same methodology and found SPPS to be more feasible than diesel and electric pumps. Similar results have been obtained by (Gao et al., 2013) for Qinghai-Tibet plateau in china, where irrigation of grassland was found more cost effective through SPPS than DPPS. Results were drawn comparing unit cost of water from both

[8] As Egypt being a rich country in solar irradiance, SPPS and DPPS comparison seems need of time.(Mahmoud & El Nather,2003)

[9] 20 , 25 and 30 years

pumping systems. Observed economic ratio of input and output (income growth of herders) was 1:2.9 and payback period of 8 years also depicted excellent economic feasibility of PV systems.

In India, Kolhe et. al., (2002) assessed PV systems to be an economical option for low energy demand up to 15KWh (Kilowatt/hour) by deducing their respective LCCs. Sensitivity analysis showed the decline in cost of PV systems and rise in diesel price makes PV systems feasible at higher energy demand level.

However, in a financial comparison to other Renewable Energy Technologies (RETs) [10]for water pumping in India replacing diesel or electric pumps, (Purohit, 2007) has evaluated PV pumping system to be economically unviable.[11] Study used Net Present Value (NPV) of RETs, unit cost of water and unit cost of useful energy delivered as indicators for economic evaluation.

(Purohit & Michaelowa, 2008) have further highlighted the importance of SPPS as a potential Clean Development Mechanism (CDM) source to earn substantial Certified Emission Reductions (CER) units. The study projected annual CER volumes to reach 0.25-0.75 million by 2020, however, strong subsidies would still be required to utilize maximum potential of SPPS.

Apart from Life cycle costs analysis, another indicator Energy Yield Ratio (EYR) has been introduced to quantify the ratio of input and output energy. (Richards & Watt, 2007) has discussed EYR as “how many times energy invested is returned or paid back by the system in its entire life time”. Indicated value if found to be *greater than unity* shows system generates more energy over its life time than was needed to produce it. The study aims to nullify the conventionally used

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[10] Windmill pump, biogas pumps and producer gas-driven pumps

[11] (Purohit & Kandpal, 2005) also observed infeasibility of SPPS in comparison to diesel and electricity based pumps.

indicator of Energy Payback Time (EPT)[12] for PV systems claiming it to be misleading and obsolete, and keeping the myth intact that PV systems do not pay back the energy used to create it.

2.3 Using RET screen for feasibility analysis of renewable energy

Numerous recent studies have used RET screen International Photovoltaic project Model worldwide to quantify energy production through RETs. RET screen is a Clean Energy Project Analysis software which enables to calculate energy production analysis, financial analysis and GHG emission analysis[13] (Mirzahosseini & Taheri, 2012) .

RET screen software has been used in many studies to check the viability of PV as an electricity generating source. (Mirzahosseini & Taheri, 2012) have assessed environmental and economic feasibility of solar power plants by RET screen in Iran according to the multiple scenarios of electricity tariffs. Simple Payback period, Internal rate of Return (IRR) were analyzed. Simulation results indicated that electricity price raised to 17.5cents/kWh and Carbon credit of $30 for 1 ton of CO^2 reduced could result in payback time of 6 years and IRR of 21.9%. The study suggested financial support to the PV system to keep it feasible and clean energy generation promoted.

(Hrayshat, 2009) also assessed viability of PV systems for electricity generation source in Jordan for a proposed 5 MW plant using RET screen. Using financial indicators of IRR, SPP, NPV, Benefit cost (B-C) ratio, annual life cycle saving (ALCS), cost of energy avoided (COE)the study analyzed potential of PV at 24 locations in Jordan and found Tafila and Karak to be most

[12] EPT is the ratio of energy generated from a PV system over its life time than was required to fabricate it
[13] This software evaluates the details of available energy resource, all costs of the project, avoided cost of energy, environmental characteristics of displaced energy and environmental credits (subsidies/taxes) if any provided.

suitable sites for energy generation with highest B-C ratio, NPV, IRR, ALCS & avoided GHG emissions and minimum SPP and COE.

Same analysis for Pakistan has been made by (Khalid & Junaidi, 2013) for Pakistan where the feasibility of PV system for proposed plant of 10 MW was assessed by comparing monthly average daily global solar radiation data of eight Pakistani cities . The study declared Quetta as most suitable for solar PV power plants among them. RET Screen simulation of the power plant indicated that about 23.206 GWh of electricity generation is possible with one tracking axis method from the proposed power plant and electricity could be generated at a rate of $0.157/kWh. Results further indicated PV generated electricity would be 30.8% more expensive in comparison to grid supplied electricity. Emission analysis showed avoided CO^2 to be 17,938 tons/year. Considering only the economic factors, the proposed plant was not rendered feasible, however sensitivity analysis demonstrated a break even with grid supplied electricity at a reduced cost of PV plant from $50 m to $35 m.

(El-Shimy, 2009) has also investigated potential of 10 MW of PV plant in Egypt using RET screen simulation. Study included energy production analysis, financial analysis and GHG emission analysis. Keeping these indicators in focus, Wahat Kharga site could give highest profitability, energy produced and most GHG emissions avoided. Financial indicators included NPV, IRR, equity payback, COE, B-C ratio. The study suggested positive potential of PV plant for all considered sites in Egypt.

Similarly, (Harder & Gibson, 2011) have evaluated the costs and benefits of large scale PV plant (10 MW) in Abu Dhabi, UAE through RET screen simulation, and have found out it infeasible while only considering financial costs in accounting. However adding the economic benefits of over 10,000 tons of GHG emissions annually could bring the NPV to $47m and render it feasible. Same investigation has been made by (Al-Badi, Albadi, Al-Lawati, & Malik, 2011) who found economic perspective of PV electricity in Oman (25 selected sites) for a 5 MW plant. COE and capacity factor (CF) have been calculated to find Marmul to have the highest energy produced, and lowest COE. PV energy at Marmul is found to be competitive without adding environmental costs to the accounting equation.

CHAPTER III

DATA AND RESEARCH METHODOLOGY

3.1 Background of the study

Figure 3.1: Map of Potohar region

Source: historypak.com/Potohar-plateau

Figure 3.2: Map of Thatti Gujran, district Fatah Jang

Source: www. Maps/google.com

Potohar plateau is located in the north of Punjab and west of Azad Kashmir i.e. north-eastern parts of Pakistan, on a spread of 2.2 million hectare (mha). Attock, Jhelum, Chakwal and Rawalpindi Districts constitute the Potohar Plateau. River Jhelum and River Indus cross this plateau. A number of mountain ranges including Salt Range and Kala Chitta Range are also a part of it. Agriculture in this region is dependent on natural rainfall, including fine fertile soil, this area is rich in natural resources. The occupations of the people in the rural and urban areas of the Potohar Plateau differ. However, the livelihood source of majority of people is linked with farming and agriculture directly or indirectly. Also, keeping dairy farms and livestock is common. (http://historypak.com/potohar-plateau/)

The uneven expanse of Potohar region produces large quantity of excess water specifically in short span of monsoons. Keeping food security through efficient conservation of rainwater in perspective, federal as well as provincial government of Punjab have constructed over 1200 mini water reservoirs in the overall Potohar region. This step was taken to minimize agricultural uncertainties and improvement of rural livelihood. More than 300 conventional fuel based lift irrigation schemes have been launched to subsidize agriculture production in the area. However, efficient farming and proper capacity utilization of the areas around these mini dams has not been attained. Main reason of this inefficiency utilization of the watershed has been lack of energy required to accomplish lift irrigation in the uneven tracts of Potohar. (PARC, 2013)

3.2 Solar powered pumping system at Fatah Jang, improving Water shed Management

To address this problem in order to attain maximum possible benefits from the fertile land, PARC took the challenge in 2012, where a pilot project was developed and successfully implemented to irrigate 20 hectare agricultural land at Thatti Gujran, Fateh Jang, performing lift irrigation from a 20ft deep water reservoir through a solar based pumping system of irrigation. The traditional pumping system was based on diesel for irrigation.

At this farm, a high efficiency irrigation model has been established, which shows a combination of developed orchards, successful demonstrations of tunnel farming, seasonal vegetation, cereal cultivation, agro-forestry and aquaculture made possible through irrigation; entirely based on Solar Powered Irrigation System (SPIS). Before the introduction of the Solar Based Pumping System, the reservoir water was being utilized in income generation through aquaculture. (Ibid) The replacement of solar energy PV pumping system for lift irrigation is one its kind in this area. The replacement of energy provision from a diesel powered system to a solar based pumping technique requires a basic economic viability analysis.

Chapter II has elaborated many methodologies to evaluate the economic viability of the projects of energy generation utilizing solar PV energy in comparison to other renewable technologies or fossil fuel driven diesel. This chapter, now, discusses the methods of research to be used in this study. Table 1 analyzes the most common methodologies used for assessing economic feasibility and its advantages/ disadvantages stated.

Figure 3.3: Watershed at Thatti Gujran, Fatah Jang.

Figure 3.4: Pre-Project Situation of the farmland at Thatti Gujran, Fateh Jang.

Figure 3.5: Aquaculture at Watershed in Thatti Gujran, Fateh Jang

Figure 3.6: Sparse Cropping in the pre-project situation

Figure 3.7: Each PV Modules 2oo Watts.

Figure 3.8: Total System Capacity 48oo Watts

Figure 3.9: 6.7 LPS discharge

Figure 3.10: Filter Design

Figure 3.11: 5 hp submersible Pump

Figure 3.12: Practical display of solar insolation measurement by Program leader, Muhammad Saleem Malik (Program leader & Training moderator) at training workshop at Thatti Gujran, Fatah Jang field station.

Figure 3.13: Female Training Workshop of HEIS and SPPS at ThattiGujran, Fateh Jang

Figure 3.14: Attending Female Training Workshop for High Efficiency Irrigation System and Solar Powered Pumping System at Thatti Gujran, Fatah Jang Field Station

Table 3.1: Studies and their research methodologies

Studies	**Research Methodology**	**Strengths**	**Weaknesses**
(Hammad,1995) (Mahmoud & El Nather, 2003) (Bouzidi, 2011; Bouzidi, Haddadi, & Belmokhtar, 2009) (Bhuiyan, Asgar, Mazumder, & Hussain, 2000) (Khan, Sarkar, Hossain, Ahmed, & Pathik, 2014) (Gao et al., 2013) (Kelley, Gilbertson, Sheikh, Eppinger, & Dubowsky, 2010) (Kolhe, Kolhe, & Joshi, 2002) (Odeh, Yohanis, & Norton, 2006)	Life cycle costing (LCC) :	It has a holistic life cycle approach It has a familiar unit i.e. money Controls the information flow by simplifying Multi-characteristic alternatives.[14]	It over-simplifies environmental Problems into a monetary dimension. it neglects entities without owner, for example as the environment relies on many estimated variables due to the complex nature of variables[15]
(Richards & Watt, 2007)	Energy yield ratio : "how many times the energy invested is returned or paid back	Elegant and simple as EYR >1 indicates sustainability of the energy source	

[14] [16] (Gluch & Baumann,2004)

	by the system in its entire life"	(Richards and watt,2007)	
(Mirzahosseini & Taheri, 2012)	Simple Payback period (SPP) :	It is easily understood / it favors expenditures that produce huge cash flows in early years.[16]	It ignores the time value of money/ not feasible to be used in studies to compare [18] different economic lives/ ignores cash flows that incur after PP is calculated[17]
(Gao.et al, 2013)	Economic benefit : income growth of the farmers, pasture regeneration[18] Monetary worth of saved fuel[19]		
(Odeh et al., 2006) (Puro hit & Kandpal, 2005)	NPV	It considers all cash flows during all periods of investment life / entails time value of money (Linn,2010)	It delivers result for the true capital cost/ can be misleading when different life spans are considered (Linn,2010)

[16] [18](Linn,2010)

[18] (Gao et.al, 2013)
[19] (Purohit&Kandpal,2005)

(Odeh et al., 2006)	Annuity Cost per annuity		
(Purohit&Kandpal,2005)	IRR	It is easy to understand/ considers true value of money (Linn, 2010)	Can misdirect results when there is not a large initial cash flowing (Linn,2010)
(Odeh et al., 2006) (Harder & Gibson,2011) (Bouzidi.et.al,2009) (Purohit & Kandpal,2005) (Kolhe et al.,2002) (Oparaku,2003)	Sensitivity Analysis		

3.3 Economic Analysis and Indicators

After discussing multiple economic viability methods as discussed in chapter II, Life Cycle Costing method (LCC), unit cost method, NPV, IRR, net GHG reduction cost and CBR have been selected to be estimated for this feasibility analysis. Major reason for choosing these indicators is that they have been the most widely used indicators to analyse economic viability in considered literature. Additionally, assessing all these indicators collectively can help have a broader picture of the environmental and economic viability of the SPPS.

Following is the detail of economic indicators which can be used for calculating feasibility and have been used by various studies in the literature

3.3.1 Life cycle costing (LCC): An assessment to choose among the traditional diesel based pumping system and solar PV pumping system for irrigation is to be made depending upon the economic indicators chosen for analysis. Life cycle costing (LCC) has been a widely used methodology for evaluating economic feasibility of any project where same output can be approached by different methods .This method allows different systems to be compared at an equal level, bringing all future costs incurring at different intervals in a system's life time, to one single comparable unit known as LCC. Life Cycle Costing approach becomes more significant in case of RET projects where investors might get intimidated by the *high initial cost* and conventional options like diesel economical in short run[20]. As table 3.1 indicates, numerous studies have utilized LCC for feasibility analysis, deducing per unit cost of water drawn from both possible options for pumping for comparison.

3.3.1.1 Components of Life cycle costing (LCC)

The lifecycle cost breakdown in case of both pumping systems is stated as below;

- Capital cost
- Operating cost; and
- Maintenance and replacement cost

a) Capital Cost: These costs are also called initial costs and they are incurred at the initial stage of the project. These costs include costs of the equipment, accessories, installation, transportation of the setup material to the site, and manpower involved (EmCON, 2006).

[20] (EmCON, 2006)

b) Operating Cost:_ These costs are majorly applicable to a diesel based pumping system where the operational costs include costs of fuel to run the pumping system; and transportation cost of fuel to the site (Ibid).

c) Maintenance and Replacement Cost:_ These are applicable to both the pumping systems. These include costs inspection and maintenance by skilled personnel, service, minor and major repairs and overhauls. The replacement costs in case of PV pumping system include costs of pump, motor and controller in 5-10 years. Whereas, diesel pumping system needs minor, major services and overhauls at regular intervals in a year. Services such as de-carbonization, adjustments, oil change, and filter replacements are categorized as major services. (Ibid)

3.3.2 Cost –benefit Analysis: Quantifying Benefits for Analysis

"Cost–benefit analysis (CBA) is an economic technique applied to public decision-making that attempts to quantify and compare the economic advantages (benefits) and disadvantages (costs) associated with a particular project or policy for society as a whole". Torritia & Ikpeb (2014 p.1) From the installation of PV pumps replacing DP at Thatti Gujran site, Fateh Jang, following benefits have been observed and will be quantified for study.

- Income generated from the farm and crops at project site;
- Income growth in fish farming of the considered water reservoir;
- Intangible benefits of up skilling sessions for solar integration and irrigation techniques for farmers/professionals held at the site. (This can be done by collecting the statistics of attendants and participators at the workshops that have been held at the site for the up skilling sessions and multiplying it by the cost each would incur if these sessions would have been attended commercially)

- Recreational aspect of the site can be calculated by calculating its recreational value through questionnaires; (though not yet a commercially identified recreational spot, however its scenic beauty can be quantified to attain its recreational value through Travel Cost Method)
- Reduction in GHG emissions by opting for a clean energy pumping method, the reduced GHGS emissions can be calculated by RET screen software.

3.3.3 Sensitivity Analysis

This analysis allows to calculate the impact of different economic factors on the feasibility of a given project. The possible changes in the data can alter the economic indicators for efficiency and change the viability of the project (Hanley & Spash, 1993).

3.4 Feasibility Analysis through RET screen software

"*The RET Screen International Photovoltaic Project Model is used world-wide to evaluate the energy production, lifecycle costs and greenhouse gas emissions reduction for three basic PV applications: on-grid; off-grid; and water pumping*" Mirzahosseini & Taheri (2012). RET Screen Clean Energy Project Analysis software is capable of performing energy production analysis, financial analysis, and GHG emission analysis. The software accounts for details including energy resource available at project site, performance of the equipment, initial project costs, base case (energy generated from using traditional fossil fuels) carbon credits, periodic project costs, avoided cost of energy, taxes on equipment and income (or savings) . Central advantage of using the RET Screen software is that it makes the project assessment process easier for project financers and decision making entities. The financial analysis worksheet, contains financial parameters input items such as discount rate, debt ratio, inflation rate and it evaluates financial viability output items (e.g. IRR, simple payback, NPV, etc.)(Ibid).

3.5 Other Economic Indicators used in RET screen simulations[21]

1) (Internal Rate of Return) IRR: Internal Rate of return represents time adjusted return on investment and is calculated by finding the discount rate that causes NPV to be zero.
2) (Simple payback period) SPP: it indicates the amount of time that it takes the project to recover its initial cost, from its generated outflow cash.
3) (Net Present Value) NPV: this is the net discounted value of all future cash flows.it is the difference between the present value of all cash inflows and present value of all cash outflows.
4) Benefit Cost ratio (B/C ratio): it is the ratio of the present value of net benefits to costs of the present value of costs of the project.
5) GHG emission Mitigation: it is the most important indicator in terms of environmental economic analysis. It calculates the possible greenhouse gasses emissions (water vapors, CO_2. methane CH_4 , nitrous oxide NO_2, ozone O_3, and many halo carbons) being avoided by opting for a clean energy over a conventional pumping system.

[21] (Hrayshat, 2009)

CHAPTER IV

RESULTS AND INTERPRETATIONS

As methodology for the analysis of this study has been mentioned in the previous chapter, this chapter shall now encompass the details of the results which are deduced using the methodology previously suggested.

The main objective of the study is to find the environmental and economic viability of solar pumping system in comparison to diesel pumping system. The pumping system was designed to irrigate the 20 ha farm land area near a watershed at Thatti Gujran, Fatah Jang district. High Efficiency Irrigation System (HEIS) was used at project site for efficient energy utilization. Solar panels of 4.8 Kilowatts (KW) have been installed at the farm to provide energy for irrigation of the entire area which includes different crops and orchids.

This study therefore aims to find out the economic feasibility of running a solar pumping system instead of diesel pumping system. As chapter IV suggests, different economic indicators, as suggested by the literature for this purpose, are calculated and discussed henceforth in this chapter.

4.1 Data for the Case Study

This project had been taken up by Climate Change, Alternate Energy and Water Resources Institute (CAEWRI), NARC to demonstrate efficient utilization of rain fed watersheds for irrigation as schemed out by GOP in 2012. Data for all the relevant variables of all-inclusive costs and benefits in the project has been provided by officials of CAEWRI, NARC.

4.2 Components of Solar Powered Irrigation System (SPIS)[22] :

A standard SPIS computes of these central components to supply water to the agricultural area.

- **Photovoltaic Modules**: Photovoltaic (PV) modules are available of few types, with mono-crystalline and poly-crystalline being commonly used. Mono-crystalline type has been used in this particular project. These modules or panels, collect radiations from sun and change them into energy for use through photovoltaic effect.
- **Pump Controller**: This is a very essential component, as it regulates the energy obtained from photovoltaic modules to meet up the requirements of pumping.
- **Pumping Unit**: This unit contains motor and pump set. The motor receives photovoltaic current through pump controller and drives pump for lift irrigation of water from the water shed. The pump utilized in this scenario is submersible and is used by providing direct current for this purpose (DC).

As optimal design of photovoltaic and diesel generator water pumping were selected and matched for a certain level of water pumped, the detail economic analysis of the both the pumping system is given below:

The purpose of this study is to make a cost comparative analysis for two options possible for irrigation of this particular site in the district of Fatah Jang, and deduce which is most viable. Since the area is mentioned to be off-grid, the selection of energy to perform lift irrigation could have

[22] (as described in *Technology Reporter, PARC (2013))*

only two choices, diesel based generators or an alternative sustainable source of energy. The input parameters considered for the economic assessment are:

- Assessed costs of various components of both the systems to be operational.
- The discount rate
- Salvage value of all systems (Solar , diesel, HEIS)
- Costs of maintenance and operation and replacement costs of these units
- The analysis period is assumed to be 20 years at a discount rate of 6.5%

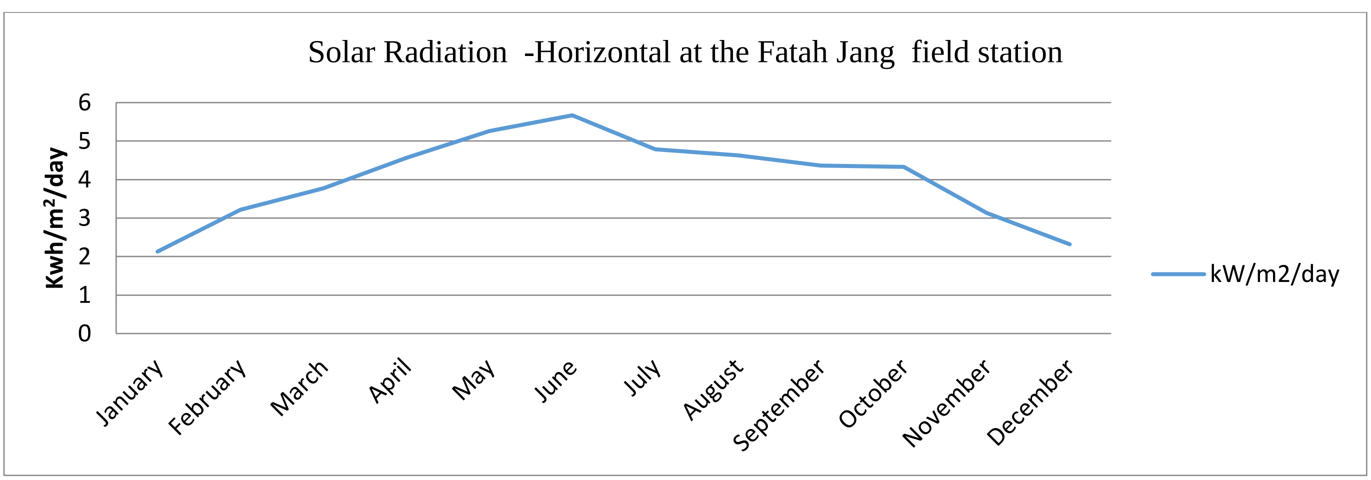
Table 1 shows the technical and economic parameters used in the financial evaluation of the project.

Table 4.1: Technical and Economic Parameters considered in the study

Parameters	**Symbol**	**Unit**	**Value**
Head of pumping	h	ft.	100
Daily needs of water	Q	m^3	
Power of Diesel Generator (AC) in coupling with centrifugal surface pump		Hp	20
Efficiency of Diesel Generator (AC) in coupling with centrifugal surface pump	ɳ	Fraction	25%
Photovoltaic modules energy	W	Watts	4800

Solar operated submersible pump unit (efficiency) Manufacturers: Lorentz PS4000 C Power of Solar operated submersible pump unit.	ɳ	Fraction hp	65% 5
Discount Rate	d	Fraction	6.5%
Lifetime of PV module		Years	20
Life time of solar motor –pump unit		Years	7
Life time of diesel motor-pump unit		Years	5
Life time of HEIS unit		Years	7

Figure 4.1: Solar Radiation at Project site (Fatah Jang)



Source: Simulated by Ret screen International using NASA database

Figure 12 depicts the spread of solar radiation (on a horizontal surface) at the project site (Thatti Gujran) over the year. The figure clearly shows energy production potential is highest in May-June where it touches the upper bends of 5-5.5 kwh/m^2/day which falls in the high range of solar radiation worldwide. (Khalid & Junaidi, 2013).

Table 4.2: Climate Parameters of Fatah Jang (as generated by Ret Screen)

Parameters	Unit	Climate data location	Project location
Latitude	˚N	33.6	33.6
Longitude	˚E	73.1	73.1
Elevation	m	508	508
Heating design temperature	°C	3.3	
Cooling design temperature	°C	39.2	
Earth temperature amplitude	°C	21.8	

Source: Simulated by Ret screen International using NASA database

4.3 Economic Analysis:

As discussed in chapter 4, the central indicators of showing economic viability of a PV pumping system in comparison to a diesel pumping system, in accordance with the literature[23] have been *Life cycle cost analysis (LCC), Net Present Value (NPV), Internal Rate of Return (IRR) and Cost – Benefit Ratio (CBR).* Details below encompass the compilation of these economic feasibility indicators.

[23] (Kolhe.,et.al,2002)

4.3.1 Life Cycle Cost (LCC): as mentioned in earlier chapters, LCC has been one the most effective tools to identify the viability of long term project. By considering all the inclusive costs over the entire working span of the project rather than concentrating on the initial investments (capital costs) only when deciding among one or more potential projects, the procedure has been well known for its thoroughness. Bouzidi (2011) quotes LCC as one of the most largely used method to assess the financial viability of a system.[24]

In this scenario, lift irrigation performed by solar powered pumping system and diesel powered pumping system have different costs incurred for the same amount of water pumped. The entire irrigation process for crops and orchards has been worked out to be divided in some basic phases of costing, mainly known *as Design and Installation cost, Maintenance Cost, Operational Cost and a fixed cost on agriculture –farm needs*. This fixed cost (agro-farm) has been part of both the analysis and has been kept constant under both pumping systems costs. Detail costs of both the pumping system has been assessed and compared for the entire life span of 20 years in table 6.

Table 4.3: Life Cycle Cost Analysis

Cost of Pumping water from water shed of 100 acre ft.	**SPPS**	**DPPS**
Total life cycle cost (inclusive of all costs) In Rupees	Rs.22,947,000	Rs.36,522,000
Total amount of water pumped in liters	1,036,800 liters	1,036,800 liters
Unit cost in Rs. per thousand liters	Rs.22.13	Rs.35.23

- [24] Studies supporting use of LCC for financial analysis of a system: (Hammad,1995) (Mahmoud & El Nather, 2003) (Bouzidi, 2011; Bouzidi, Haddadi, & Belmokhtar, 2009) (Bhuiyan, Asgar, Mazumder, & Hussain, 2000) (Khan, Sarkar, Hossain, Ahmed, & Pathik, 2014) (Gao et al., 2013) (Kelley, Gilbertson, Sheikh, Eppinger, & Dubowsky, 2010) (Kolhe, Kolhe, & Joshi, 2002) (Odeh, Yohanis, & Norton, 2006)

Calculating amount of water pumped:

= water pumped in liters per second * seconds per hour * working hours per day * working days per year

= 6*3600*8*300

= 51840000 liter per year

- water pumped in 20 years= 51840000 * 20 =1036800000
- water pumped in 20 years per thousand liters =1036800000/1000= **1036800**

Unit Cost of Water: $\dfrac{\textbf{Cost of pumping water in 20 years pumped by SPPS (or DPPS)}}{\textbf{Water pumped in 20 years (in 000' liters)}}$ **…eq.I**

Equation (I) above deduces unit cost of water pumped in Rs. per thousand liters for the life span of 20 years.

Table 4.3 discusses the life cycle cost (LCC) of both the pumping systems and it is hence clear that LCC of putting up a SPPS is Rs. 22 million whereas for the same amount of water pumped and same level of irrigation, putting up a DPPs would cost Rs. 36 million, which is quite higher than the SPPS.

Major reason behind a higher LCC of diesel based system gets evident when the breakdown of total costs are analyzed. In case of solar based pumping system, initial design and installation cost is much higher than DPPS, however, it's operational and maintenance (O & M) cost over the span of 20 years is much less than DPPS which incurs heavy O & M costs, therefore raising total life cycle cost of the diesel based system.

The main cause of higher O& M cost is non-availability of strong and reliable reciprocating generators in Pakistan. The quality of these generators and diesel based pumps are observed to be weak and require a lot of maintenance over the years. Additionally, the requirement of diesel usage, with the need of transporting it from some main fuel station has added daily expenditures for its operation, which in long run do not prove to be feasible.

4.3.2 Unit Cost Analysis: Unit cost is derived from equation I, and again as table 4.3 shows, pumping 1000 liter of water from 100 acre feet of water shed at Thatti Gujran Fatah Jang, using SPPS would cost Rs. 22 and under same scenario, using DPPS exactly same amount of water pumping would cost Rs. 35. This indicates the viability of solar as energy source for irrigation.

Table 4.4: Economic indicators showing viability

Types of Pumping Systems	NPV	IRR	Unit Cost/000 liter	Benefit-Cost ratio
Diesel	Rs.9,910,188	26%	Rs.35.23	0.47
Solar	Rs. 20,930,027	50%	Rs.22.13	1.55

4.3.3 Net Present Value: As it was mentioned in the methodology chapter, net present value is considered one of the most important tools of economic and financial viability studies, according to Linn (2010) it entails all cash flows during all periods of investment life / undertakes time value of money by discounting all the cash flows. [25] Cash flows can be categorized as cash inflow and cash outflow, (Costs and benefits respectively). As both flows are discounted to their present values and the total net sum of both categories is called Net present Value. As table 4.4 reveals the NPV of SPPS to be quite higher. The reason can be higher operational and maintenance cost of DPPS and higher social benefits attached to SPPS.

The details of benefits considered and quantified in case of SPPS and DPPS are given as below.

Social Benefits quantified in case of SPPS

- **Agricultural Production yield** (Value= price per unit * agro-farm produced units)[26]
- **Fish Production:** (Value= price of fish per unit * aquaculture produced units)
- **Reduced Greenhouse gas emissions**: This benefit has been quantified by estimating the amount of fossil fuel (diesel here) use as an alternative (of SPPS) and hence using the calculator available on internet to find annual reduction in GHGs by opting for a clean energy.
- **Recreation**: The water shed at Thatti Gujran is located amongst the mid of the green Potohar plateau. Agro-farm plantation adds to the much needed greenery of the place. Furthermore, installation and working of a solar based pumping system irrigating the area (being an innovative technology) has enhanced its total recreational value. This total recreational value is counted as an advantage of SPPS, which is calculated by assuming a

[25] studies such as (Odeh et al., 2006) (Purohit & Kandpal, 2005) (Harder & Gibson, 2011) (El-Shimy,2009) (Hrayshat,2009) (Khalid and Junaidi,2013) have considered NPV essential for viability studies and have included them to indicate viability.

[26] The quantified benefit of agricultural yield and fish production are assumed constant while calculating NPV of SPPS as well DPPS.

certain level of potential visitors per year, this cost has been estimated and added in the quantification of benefits[27]

- **Salvage Value:** Salvage value of HEIS and SPPS is calculated and quantified to be added in benefits.[28]
- **Social Awareness:** Social benefit of technology awareness in case of SPPS in a rural area like Fatah Jang field station cannot be overlooked. According to resource person (Program leader of the Fatah Jang project, NARC)[29] during and after the execution of SPPS for irrigation, neighboring farmers and interested common pupils visited and inquired about this innovative project. This addition to their technical knowledge and innovative knowhow can be quantified and has been a part of social benefits in case of SPPS.
- **Technology Awareness:** PARC has been attempting to create awareness by conducting training sessions at the field station, regarding the new technology of SPPS and its practical implementations at the project site. This technological awareness has been quantified as a social benefit for the project attendees.[30]

Social Benefits quantified in case of DPPS

- **Agricultural Production yield** (Value= price per unit * agro-farm produced units)
- **Fish Production:** (Value= price of fish per unit * aquaculture produced units)
- **Recreation:** The recreational aspect of the wetland in Thatti Gujran cannot be ignored even without the installation of an innovative technology like SPPS at work. The scenic view of

[27] Derivation for the travel cost has been elaborated in the annexure section
[28] Details of estimation are included in the Annexure
[29] Engineer Muhammad Saleem Ahmed Malik (Program Leader, Integrated Watershed Management Program, CAEWRI)
[30] Quantification for the technological awareness has been carried out in Annexure.

water shed along amidst Potohar plateau with agro farming in the middle can be a potential recreational spot in coming years.

- **Salvage Value :** Salvage value of HEIS and DPPS is calculated and quantified to be added in benefits[31]

As the tables A7 to A 12 in the Annexure demonstrate the detail about the quantified costs and benefits in DPPS and SPPS, it is thus clear from table 4.4, where economic indicators are summarized that NPV of SPPS is higher than NPV of DPPS. As discussed in chapter III of data and methodology, higher NPV illustrates higher viability and it is a key criteria of selection of a project. (E.g. in this case the option to choose solar or diesel as a source of energy for lift irrigation). Net Present Value here has been calculated by MS. Excel.

4.3.4 Internal Rate of Return (IRR): Internal rate of return is that discount rate at which investor has the surety of investment making more money in return than its actual cost. In other words, it is the rate at which NPV is zero. If the IRR value is less than the discount rate used, then the project (SPPS or DPPS here) is not credited to be feasible and vice versa. IRR in this study has been calculated by MS. Excel. Yet again, as the table 6 suggests, IRR is found to be higher (50%) in case of SPPS than DPPS (26%) thus again depicting feasibility of the solar based pumping system.

4.3.5 Cost Benefit Ratio (CBR): last part of table 4.4 shows the cost benefit ratio, which is yet another indicator to measure feasibility of a project. This ratio is estimated by taking a ratio of present value of total costs and benefits (in both the cases of SPPS and DPPS). CBR should be greater than 1 for the project to be reckoned feasible. It is thus evident that CBR is greater than 1

[31] Details of estimation a part of the Annexure

in SPPS. However, if to choose between either of the options, clearly CBR is higher for SPPS than DPPS.

4.4 Results from RET screen

As discussed in the chapter II and IV, multiple studies in the consulted literature have used Ret screen for feasibility analysis. This study has therefore also made an attempt to evaluate the viability of SPPS in comparison to DPPS by using this software as well, apart from manual and MS. Excel based results as mentioned and discussed above. Derived from the software of Ret screen, table 4.5 demonstrates the economic indicators output sheet.

Table 4.5: Results from RET Screen Analysis

Indicators	**Unit**	**Values**
Simple payback period	Year	1.7
Net Present Value (NPV)	Rupees	3,801,106
Annual life cycle savings	Rs./yr.	344,975
Benefit-Cost (B-C) ratio		2.30
Net annual GHG emission reduction	Ton/CO^2/yr.	25.9
Annual GHG reduction cost	Rs./tCO^2	(13,307)

The simulations from the Ret screen provide financial sheet as output which deduces some economic /financial and environmental indicators .The input data to run viability analysis for a pumping system based on PV technology is financial as well as technical in nature. The software requires technical details and economic cost data for both cases: proposed case i.e. SPPS and base case i.e. DPPS.

- **Simple payback period:** The model computes the simple payback (year), which depicts the number of years it takes for a proposed project to recover its own initial cost, from the income or savings it produces. The basic idea of the simple payback method is that the more rapidly the cost of an investment are expected to recover, the more desirable is the investment. For example, in the case of an energy project, a negative payback period indicates that the annual costs are higher than the annual savings generated. In this case, the simulation results in a final output sheet of table 4.5 which shows simple payback period (SPP) to be less than 2 years which is rendered as a decent time given the whole life of project is 20 years, and SPP is less than one third of whole life project and indicates feasibility.
- **Net Present Value (NPV) estimated through RET screen:** Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows related to the project investment. The difference between the present value of these cash flows, called the NPV, assesses project financially as or not an acceptable investment. For a project to be potentially feasible, the NPV should be positive. In this chapter earlier, social quantified benefits have been taken as cash inflows so NPV assessed by MS. Excel is Rs. 20 million. These social benefits have not been a part of Ret screen data input entrée , hence NPV is around Rs. 3 million which still recommends the SPPS as a pumping option as the amount calculated is positive.
- **Benefit-Cost (B-C) ratio:** The simulation model calculates the net Benefit-Cost (B-C) ratio, which is the ratio of the net benefits to costs of the project. Net benefits represent the

present value of annual income and savings minus the annual costs, ratios greater than 1 suggest profitability of proposed project. The net benefit-cost ratio, points to the same conclusion as the net present value NPV indicator. Table 4.5 here reveals the value of B-C ratio to be 2.3 which is higher than 1, thus according to simulations carried out by Ret screen feasibility software, SPPS is more appropriate for this project.

- **GHG reduction cost:** Based on the input data regarding the base case pumping system relying on fossil fuel, this model calculates the annual reduction in GHG emissions when the base case system DPPS is displaced with the proposed case system SPPS. Here, net annual GHG emission reduction is found to be 25.9 tCO_2/yr. (tons of carbon dioxide per year, and GHG reduction cost is Rs.13, 307.

4.5 Sensitivity Analysis:

Sensitivity analysis is one of the methods acclaimed for energy and water conservation schemes by U.S Federal Energy Management Policy (FEMP). Sensitivity analysis is beneficial for recognizing from the input factors, which among them has the potential to affect economic valuation of the project, assessing the range of variation that an input parameter can have on results and viability of the investment, and examining diverse scenarios to answer "what if" questions. (Fuller, 2010).

In this study, majorly two input parameters have been selected to check the sensitivity of the economic valuation of the project.

a) **Change in fuel cost**: As comparison in this study is made with diesel based pumping system, the rate of fuel escalation becomes crucial in checking the economic viability. Here, the variation in fuel cost has been undertaken for study is 10% and -10% to analyze the impact on economic indicators. The effect is naturally measured upon the indicators of DPPS and hence it can be seen in table 8 that NPV, IRR and CBR slightly fall with rise in fuel cost as expected, and show a slow rising trend with simulated drop in fuel cost. This shows the significance of fuel cost as an important indicator in the study.

Table 4.6: Sensitivity Analysis (case 1): change in fuel cost

Range of variation	**NPV**	**IRR**	**CBR**
10% rise in fuel cost	9,596,822	26%	0.45
base case	**9,910,188**	**26%**	**0.47**
10% drop in fuel cost	10,257,271	27%	0.5

b) **Change in discount rate**: In multiple studies, the discount rate has been observed to have an impact on the feasibility of the studies. In this study, fluctuations in discount rate (currently sought to be 6.5% as per announced official rate by GOP)[32] have been checked in sensitivity analysis to be 8% and 10 % respectively. The impact is summarized in both cases of pumping systems in tables 4.7 and 4.8.

i) **The case of DPPS:** The rise to 8% discount rate shows a huge drop NPV of DPPS, IRR reduces significantly and CBR also shows a heavy decline. Reduction to 8% and then 10% discount rate simply dismiss any possible feasibility of DPPS to be considered as an alternate strategy, as NPV, IRR and CBR all show negative signs.

[32] Source : Economic Survey of Pakistan (2014-15)

ii) **The case of SPPS**: In case of SPPS, change in discount rate from 6.5 to 8% as well as 10% still keeps the SPPS as a viable option, the simulation does reveal significant drops in the values of indicators but still remain positive and lie in the optimal range of being acceptable as an economically feasible option. Major reason for the difference in impact of discount rate change on SPPS and DPPs is the significant amount of social benefit attributed to SPPS, and higher operational and maintenance cost of DPPS.

Table 4.7: Sensitivity Analysis (case 2): Impact of change in discount rate on DPPS viability

Range of Variation	NPV(diesel)	IRR(diesel)	CBR(diesel)
base case :6.5%	**9,910,188**	**25%**	**0.47**
scenario a) 8%	(7,852,227)	5%	-0.22
scenario b) 10%	(11,922,760)	-0.60%	-0.34

Table 4.8: Sensitivity Analysis (case 2): Impact of change in discount rate on SPPS viability

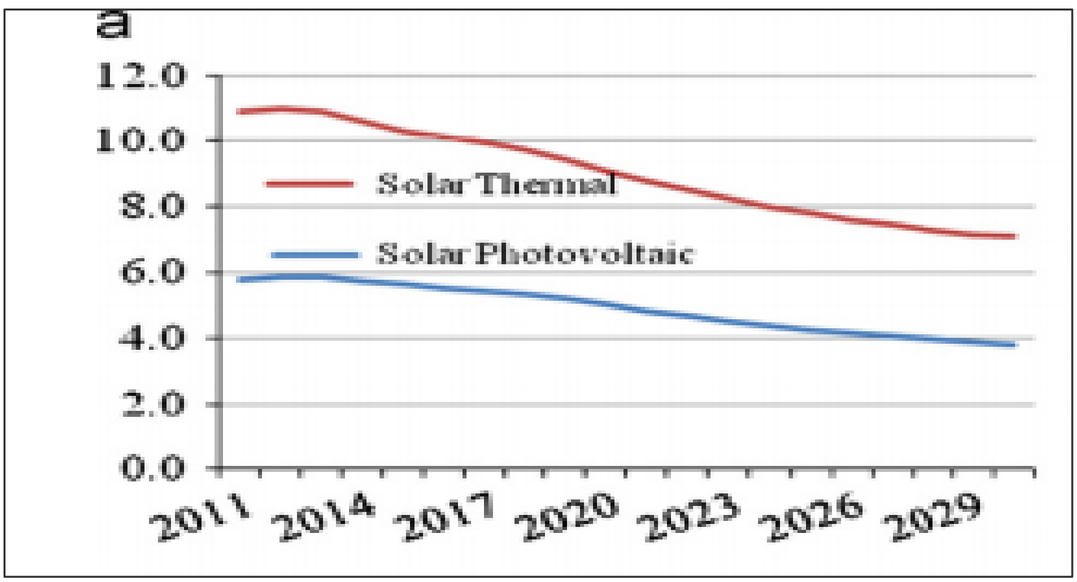
Range of Variation	NPV(solar)	IRR(solar)	CBR(solar)
base case :6.5%	20,948,681	50%	1.55
scenario a) 8%	18,035,456	48%	1.47
scenario b) 10%	14,919,223	45%	1.37

c) **Change in SPPS capital cost**: As technology advancements and rise in industrial scale and refinement take over the horizon in solar PV manufacturing industry, the cost of PV cells has dropped consistently since the solar cell industry started . Although the energy generation cost of PV is still greater than its alternate options, this cost is forecasted to drop further in future. (Devabhaktuni, V. et.al, 2013)

Table 4.9: Sensitivity Analysis of capital cost of SPPS

Range of variables	NPV	Growth rate	IRR	CBR
10% rise in prices of installation cost of SPPS	Rs.20848181	-0.47%	0.48	1.53
Base case	Rs.20948681	0	0.5	1.55
10% drop in prices of installation cost of SPPS	Rs.21049181	0.47%	0.52	1.57

Fig.4.2: Prices of Solar thermal and Solar PV technologies forecasted



Source: (Devabhaktuni, V. et.al, 2013)

Fig. 4.2 shows the improvement in affordability of both solar thermal and solar PV systems worldwide, so third parameter taken here is solar installation cost; there are two cases taken under consideration in this case as well. A 10% rise and 10% drop in the capital cost of SPPS is simulated on M.S. Excel and results indicate relevant change in the economic indicators. A 10% rise in capital cost of SPPS reveals NPV, IRR and CBR to change accordingly, drop in 10% capital cost enhances these three indicators, and a 10 % rise in capital cost reduces them proportionately as shown in table 4.9.

CHAPTER V

CONCLUSION AND POLICY RECOMMENDATION

5.1 Summary

Energy is the backbone of an economy. Most of the new technologies and innovations in almost all fields of life require the presence of efficient and sustainable energy to compliment and travel swiftly along the road of development and economic growth. Rising population, rapid urban sprawl, increasing social and economic inequality and dependence of human needs and necessities on the use of energy has put the current and previously in use sources of energy under immense pressure. The sources of energy in use at present are observed to decline and may become absolutely unavailable for future generations, if their level is not sustained today or new resources of energy are discovered and brought on surface for domestic and commercial use.

Scientists have been studying earth and its temperatures for as long as they can interpolate the data and finding clues to connect the dots of climatic events on earth. This search has led the scientists to the horrible fact that our home planet is consistently rising in temperature (global warming) and that a major part of this rise has been caused by human behavior itself, which is commonly called as anthropogenic behavior. To help minimize global warming and reduce its possible impacts in the form of extreme events from hitting the planet (floods, hurricanes, drought etc.), its major source i.e. carbon emissions in atmosphere caused by burning fossil fuels, needs to be replaced.

Renewable energy has been a serious consideration for some past decades now. The major reasons for research and innovation in this domain have been not just the deficiency of under pressure conventional energy resources, but also the deeper realization of the impacts of climate change on earth. Pakistan has immense potential to generate energy from solar power, (5 to 5.5 $kwh/m^2/day$) and falls on the few places on map who can reap high benefits using solar energy.

Realizing the fact that Pakistan is an agrarian country, and impact of efficient energy has huge impacts on agriculture, this study assesses the social, economic and environmental viability of a solar powered pumping system for irrigation at an agro-farm (area of 20 hectares) near a water shed at Thatti Gujran (Fatah Jang), this project had been up taken by CAEWRI. This assessment of feasibility is made in comparison to a diesel powered pumping system as an alternate option for the same quantity of lift irrigation to take place at the same field station.

Numerous economic indicators, as considered by the literature, have been taken into account to test the viability of the SPPS against DPPS such as life cycle costing (LCC), unit cost of water pumped, NPV, IRR, CBR and GHG reduction cost. The data used has been primary in nature that was collected by the department of CAEWRI (NARC). To quantify and estimate the economic indicators, the data used has been simulated through M.S. Excel. Another simulation has been run using Ret screen, which is specially designed and used to evaluate the financial feasibility of the project related to Renewable Energy.

5. 2 Conclusion

Major Findings of the study are summarized as below:

- The social , economic and environmental costs and benefits pertaining to solar as well as diesel powered pumping systems have been studied and compared
- Net Present Value of Solar powered pumping system has been observed to be much higher than net present value of diesel powered pumping system.
- Internal Rate of return for SPPS is found to be higher and indicates financial feasibility of SPPS against DPPS.
- Cost –Benefit ratio (CBR) for both cases has been deduced and is found to be greater than one (indicating viability) only in the case of SPPS.
- Life Cycle cost (LCC) has been calculated for both pumping systems and SPPS is found to be incurring a lower LCC in the total life span of 20 years than LCC of DPPS.
- Similarly, unit cost of water calculated in Rupees per thousand liters is higher for DPPS and lower (less costly) for SPPS.
- Sensitivity analysis has been carried out using discount rate, fuel cost, and solar panels cost as input parameters.
- Results of sensitivity analysis reveals all mentioned parameters to be significantly affective on corresponding economic indicators.
- Ret screen has been used to simulate a financial and environmental feasibility analysis.
- Deductions from Ret screen also portray SPPS to be the financially more lucrative and environmental friendly (as GHG reduction cost is also given as an output)

- Results from M.S. Excel and Ret screen are different in numeric quantification as a result of difference in inputs required as per analysis, but both reveal same result in deduction i.e. both prove SPPS to be more feasible than DPPS.

5.3 Policy Recommendations

- Pakistan is a blessed country in terms of natural endowments, specifically solar energy, with an average capacity to generate 5-5.5/kwh/m^2/day. This amount of potential has not been reaped in Pakistan properly. There is a dire need to consider this potential seriously specially to bring the country out of energy crisis and act as a catalyst in economic growth.
- There is a huge need to understand the potential of solar energy in Pakistan, at state level as well as in the mindset of common public. There are certain myths attached to the decision of installing a solar power plant. Awareness programs, in the form of documentaries on government TV channels as well as practical workshops at local level about its long run feasibilities, can be an educating effort to harness basic awareness in masses.
- Community based instructing programs by government can help spread the awareness of a simple and self-sufficient solar technology to be installed and used at distant rural and energy deprived areas of the country.
- This model can be replicated in other parts of Potohar as well as other provinces with the help/subsidy and support of ministries of agriculture and energy, appropriate steps in the form of training workshops and collaboration with private sector at technical level (in ministries) taken in this regard, can prove helpful.

- Appropriate information and insight regarding renewable energy and its long term benefits on a debt stressed and energy deficient country like Pakistan, should be a part of science syllabus at school level for next generation to understand and value natural resources.

- Ministry of Finance should make serious considerations for subsidizing and supporting projects of solar and other renewable energies, when working upon annual budget of Pakistan.
- Ministry of Climate change and ministry of science and technology can help support any indigenous and local step to practically implement and set up a solar energy project (for commercial purposes).
- Qualified scholars on renewables from across the world should be invited at different platforms (NGOs and universities) to highlight its success and validity for students and masses at local level.

5.4 Limitations of the study

The study has been conducted on limited scale because of following constraints.

- Numerous studies related to renewable energy and project evaluation tend to conduct Life Cycle Assessment (LCA) for a thorough comparison, however it was not possible to conduct in this case due to unavailability of required data.
- Interview with other farmers of the Thatti Gujran, Fatah Jang was planned to get a knowhow of the social impacts of SPPS as a new technology being adapted for lift irrigation and pumping , which was later on not possible due to absence of concerned moderator (resource person; program leader).

5.5 Recommendations for future research

Research in renewable energy is an emerging field in Pakistan, where lot of areas in the country are rich with naturally endowed resources. Basic resources of energy generation in Pakistan are fossil fuels. With rising awareness of global warming in perspective and Clean Development Mechanism (CDM) potential programs in progress for developing countries, it is indeed high time to quantify economic costs and benefits, and help monetize them for a sharper understanding. This would bring authentication and simplification to the understanding of economics of renewable energy. Comparison can be made among different renewable energy options for a specific power project, or specific sites in Pakistan.

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Appendix

A1: the details of depreciation carried out for LCC

Depreciation of design & Installation of SPPS: The cost of Rs. 1,005,000 has been depreciated over a period of 6 years, till the asset is replaced in the beginning of 7th year. The depreciation charge is taken from year 1 till the end of year 6. The asset is replaced at the start of the 7th year for a cost of Rs. 400,000 therefore the whole year depreciation charge is taken in year 7 and depreciated up to year 13. The same asset is replaced in year 14 on the same principal up to year 20.

Depreciation of Installation of HEIS: The cost of Rs. 500,000 has been depreciated over a period of 6 years, till the asset is replaced in the beginning of 7th year. The depreciation charge is taken from year 1 till the end of year 6. The asset is replaced at the start of the 7th year for a cost of Rs. 400,000 therefore the whole year depreciation charge is taken in year 7 and depreciated up to year 13. The same asset is replaced in year 14 on the same principal up to year 20.

Depreciation of Installation of DPPS: The cost of Rs.250, 000 has been depreciated over a period of 4 years, till the asset is replaced in the beginning of 5th year. The depreciation charge is taken from year 1 till the end of year 4. The asset is replaced at the start of the 5th year for a cost of Rs. 150,000 therefore the whole year depreciation charge is taken in year 5 and depreciated up to year 9. The same asset is replaced in year 10 on the same principal up to year 20.

Table A3: Value of Recreation with SPPS using Travel Cost method

Travel COST method SPPS	Unit		
Number of visitor in a month	In number	15	
Average distance from nearby cities	km	60 km	
price per km (through cab/own car)	Rs.	Rs.25/km	
Total travel cost for SPPS=	Rs.	22500	per month
Total travel cost for SPPS=	Rs.	270,000	per year

Table A4: Value of Recreation with DPPS using Travel Cost method

Travel Cost Method DPPS	Unit		
Number of visitor in a month	In number	8	
Average distance from nearby cities	km	60 km	
price per km (through cab/own car)	Rs.	Rs.25/km	
Total travel cost for DPPS=	Rs.	12000	per month
Total travel cost for DPPS=	Rs.	144,000	per year

Table A5: Value of Social Awareness of SPPS using Travel Cost method

Awareness benefit :	Unit		
Number of visitor in a month	In number	30	
Average distance from nearby towns/villages	km	10 km	
Price per km	Rs./km	15	
Total travel cost for awareness=	Rs.	4500	per month
Total travel cost for awareness=	Rs.	54,000	per year

Table A6: Value of Technological Awareness of SPPS

Technological Awareness:		
Number of participants in each workshop		25
Cost of training workshops per person		1000
Number of Training workshops annually (omitting extreme months)		5
Cost of Training workshops annually (omitting extreme months)		Rs.125,000

Fig.A1: Impact of change in fuel cost on NPV of DPPS

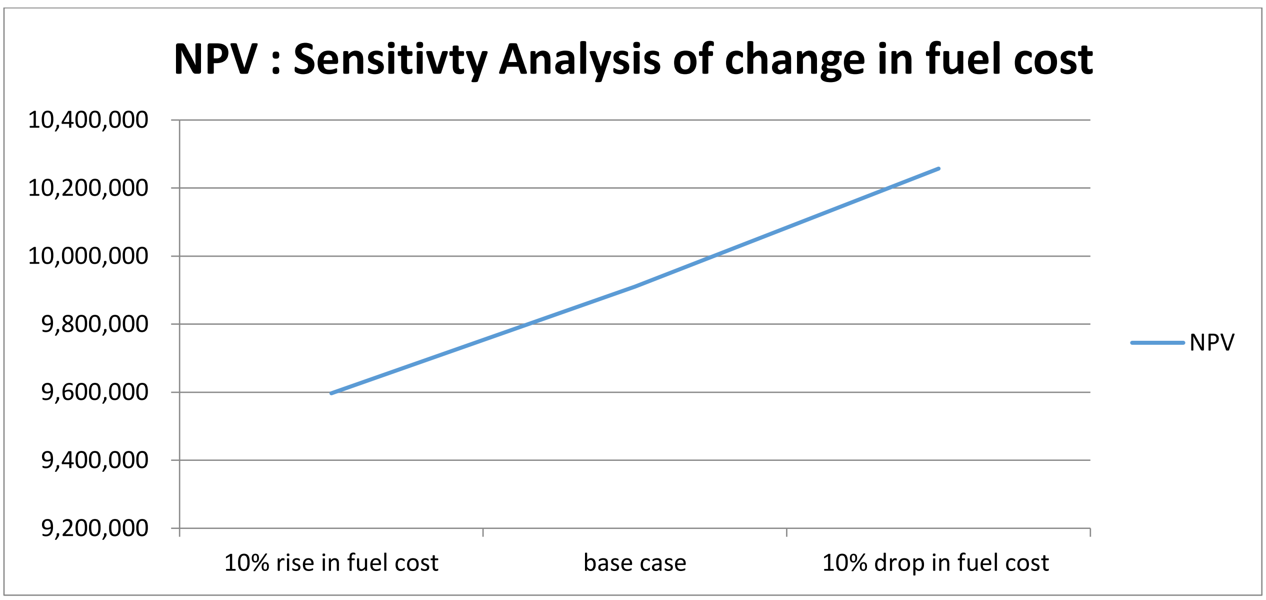

Fig.A2: Impact of change in fuel cost on IRR of DPPS

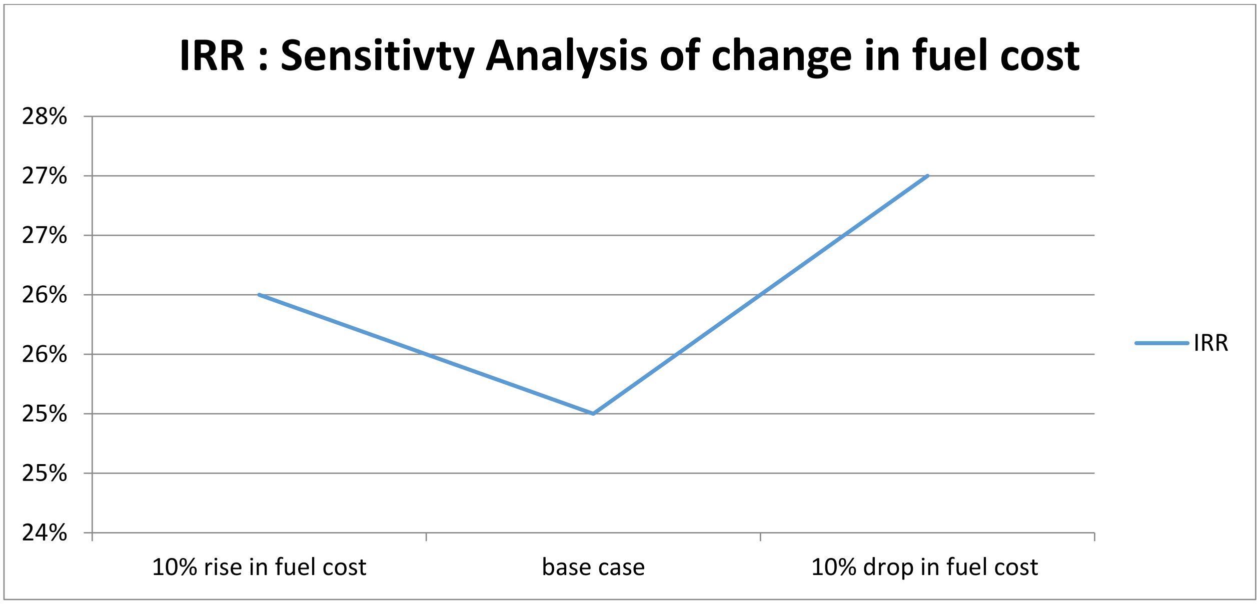

Fig.A3: Impact of change in fuel cost on CBR of DPPS

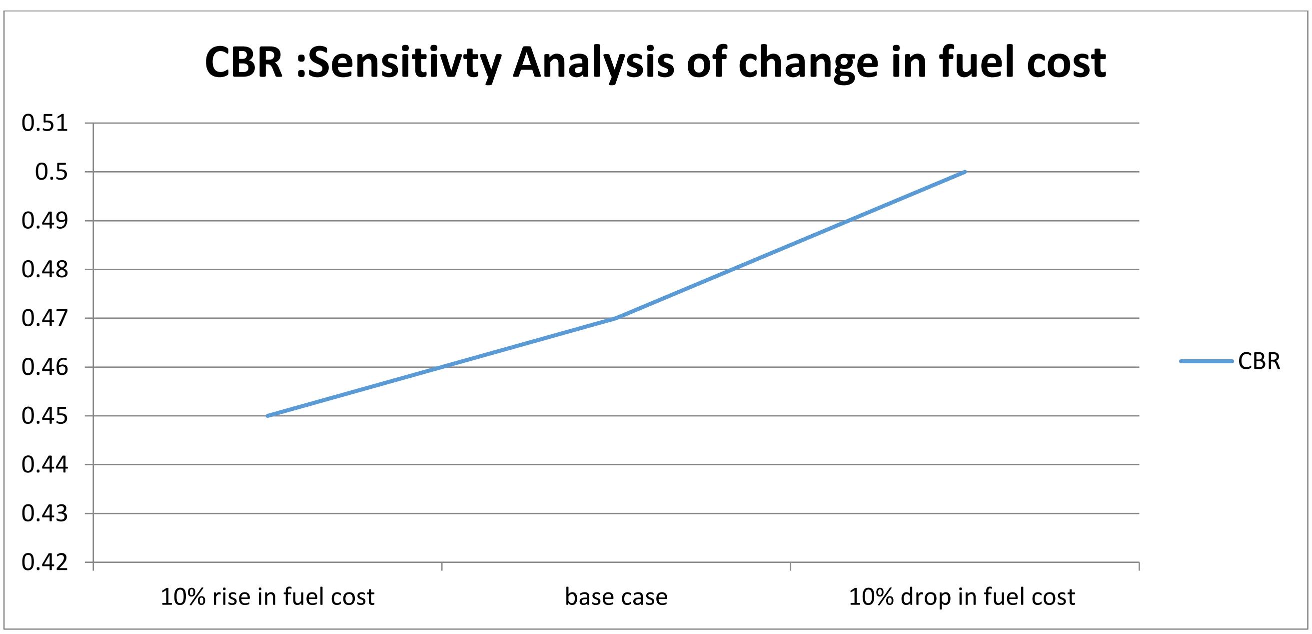

Fig.A4: Impact of change in discount rate on NPV of DPPS

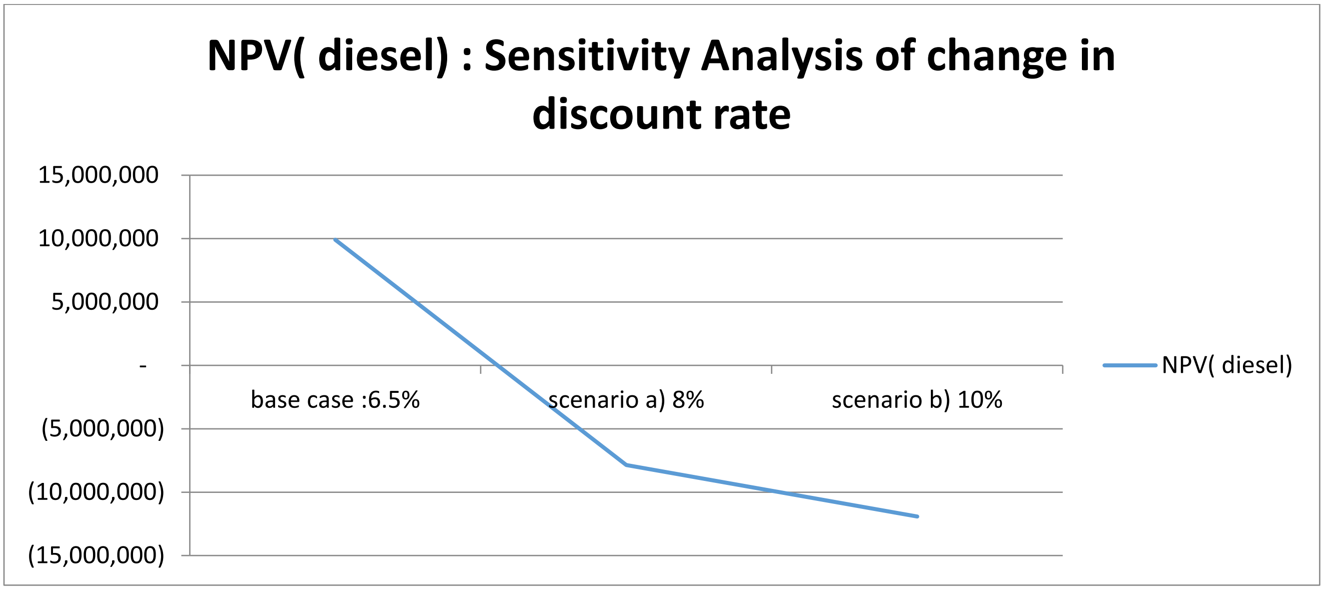

Fig.A5: Impact of change in discount on IRR of DPPS

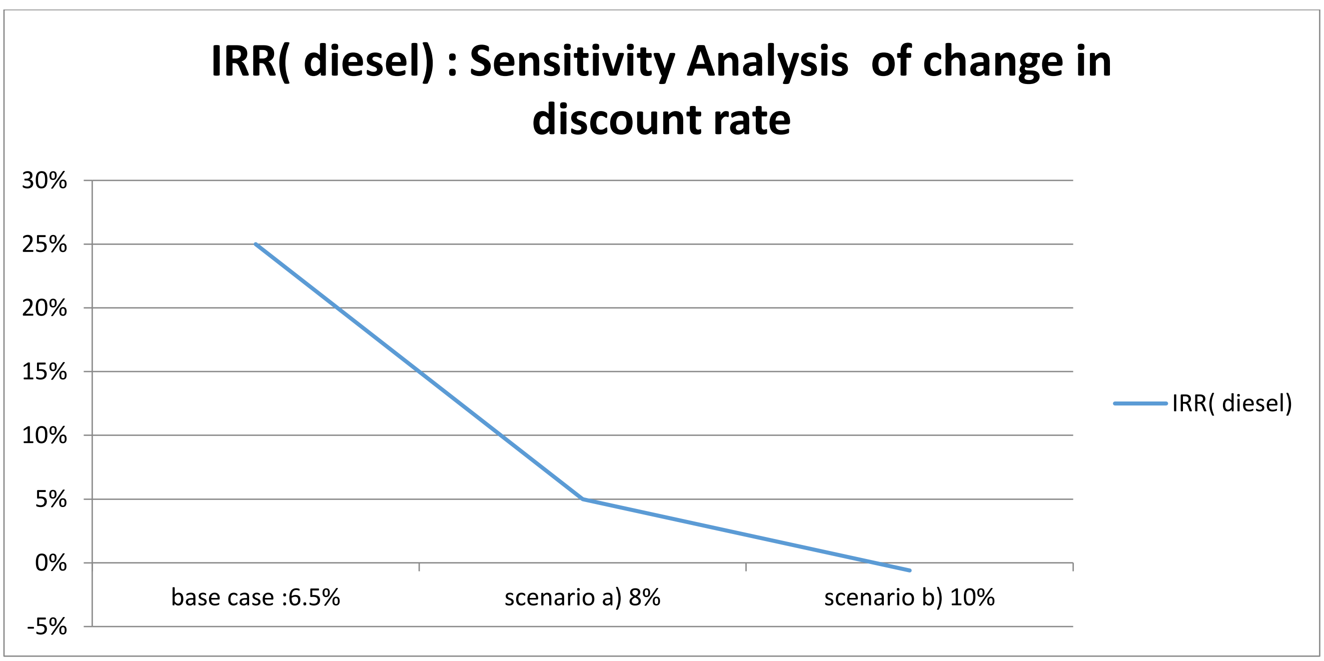

Fig.A6: Impact of change in discount rate on CBR of DPPS

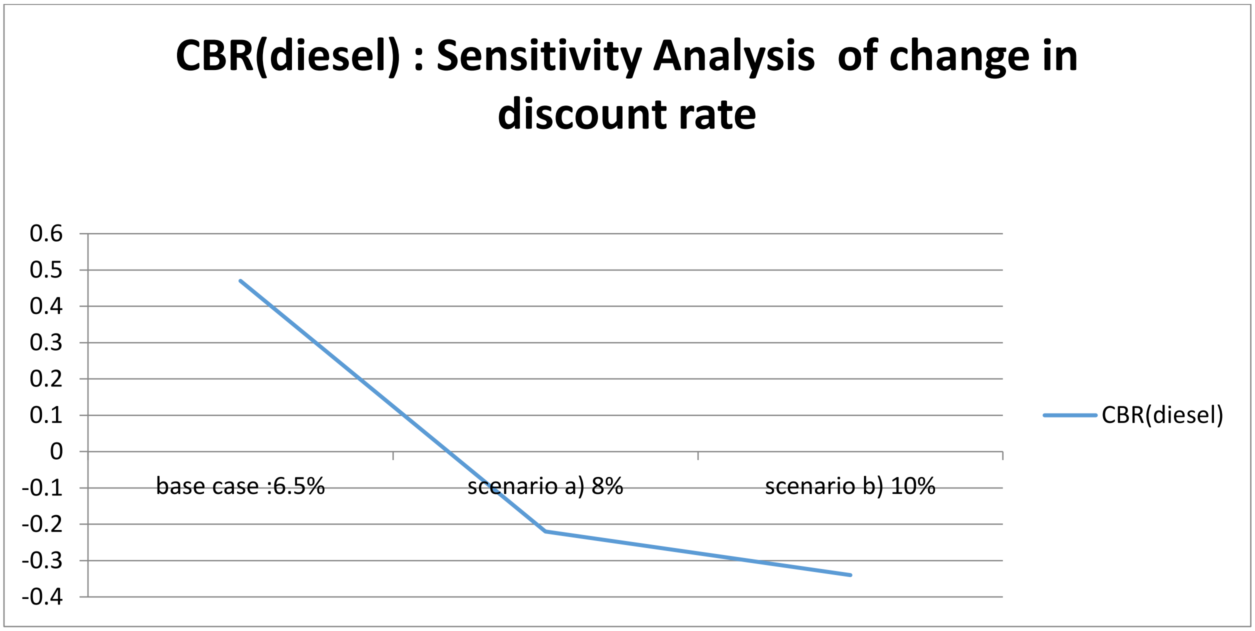

Fig.A7: Impact of change in discount rate on NPV of SPPS

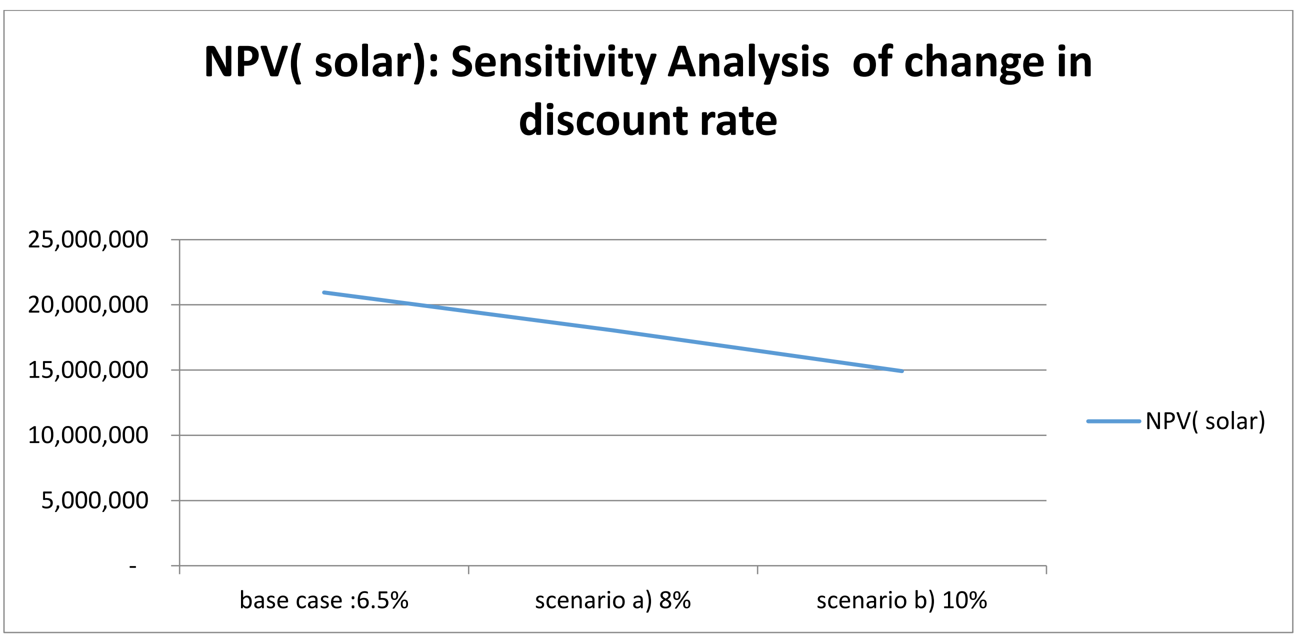

Fig.A8: Impact of change in discount on IRR of SPPS

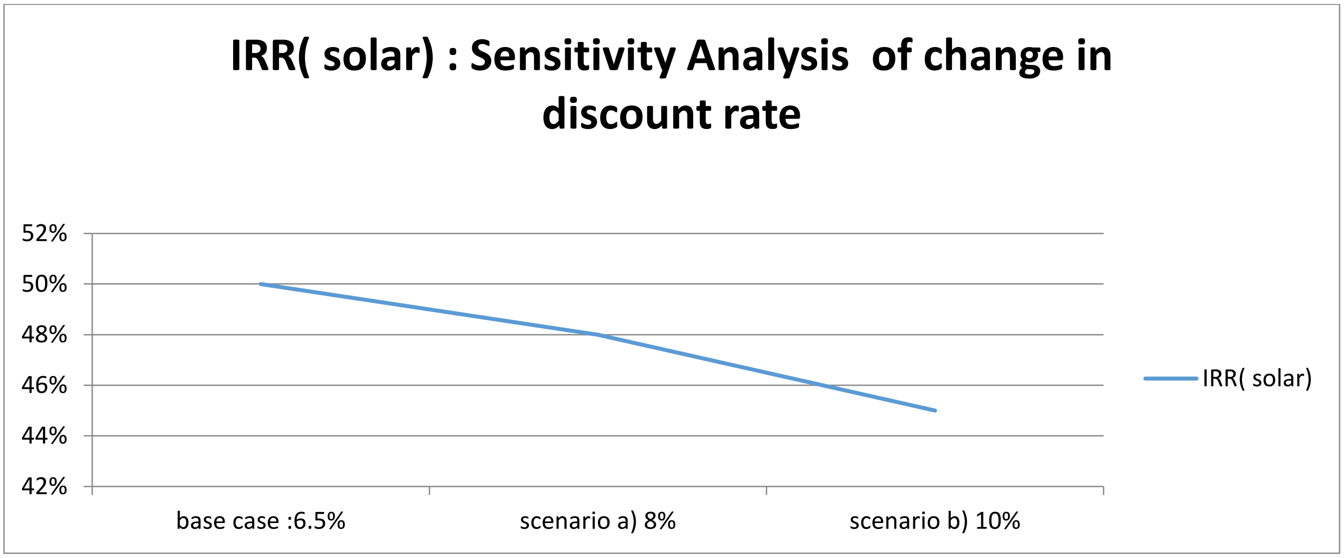

Fig.A9: Impact of change in discount rate on CBR of SPPS

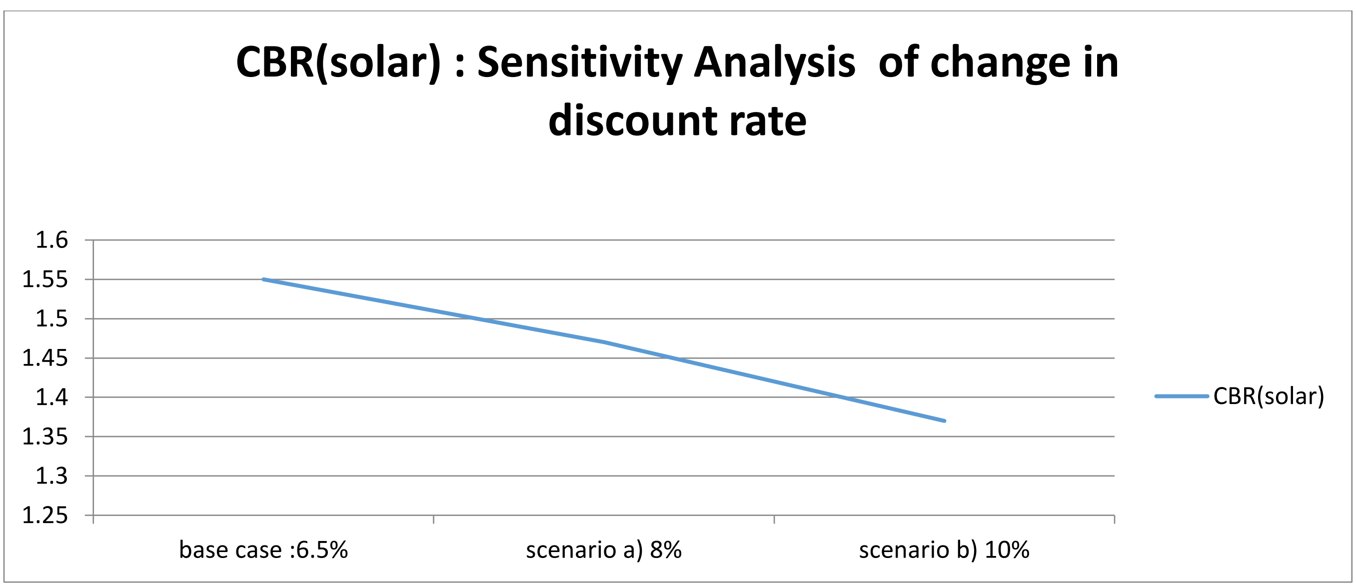

Fig.A10: Impact of change in solar capital cost on NPV of SPPS

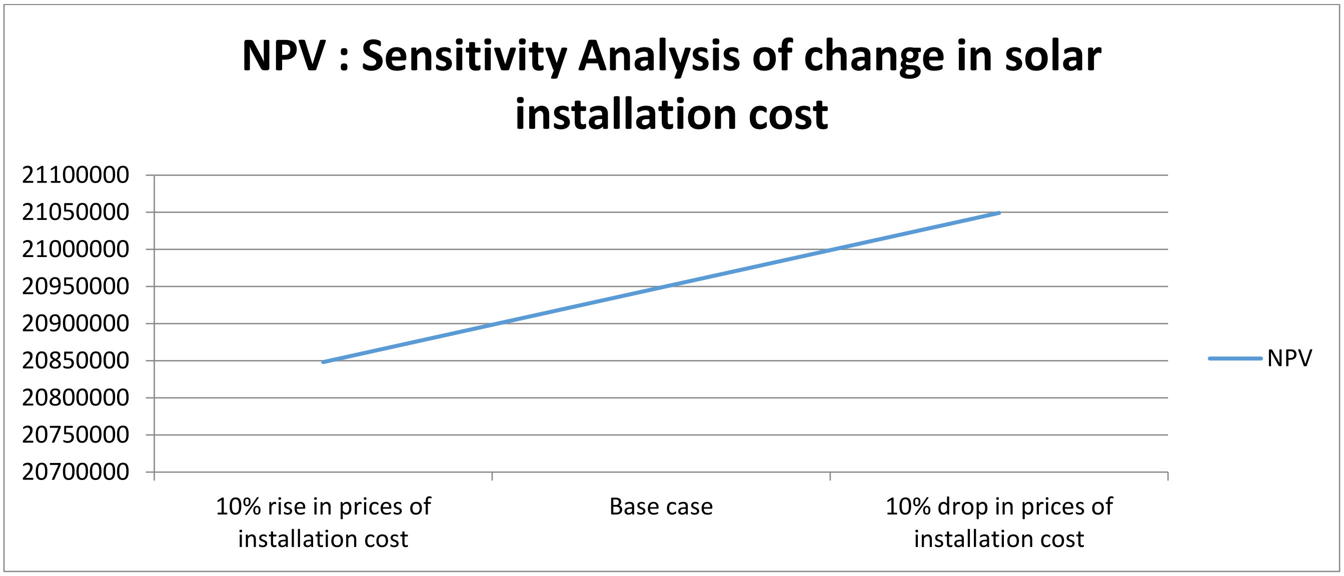

Fig.A11: Impact of change in solar capital cost on IRR of SPPS

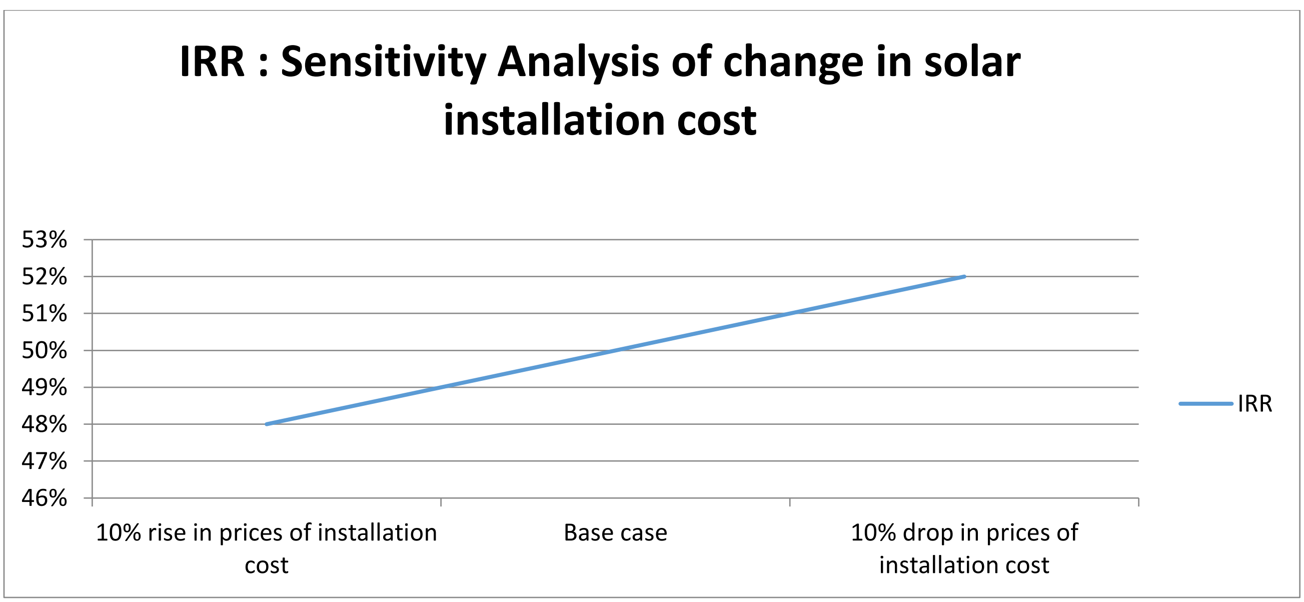

Fig.A12: Impact of change in solar capital cost on CBR of SPPS

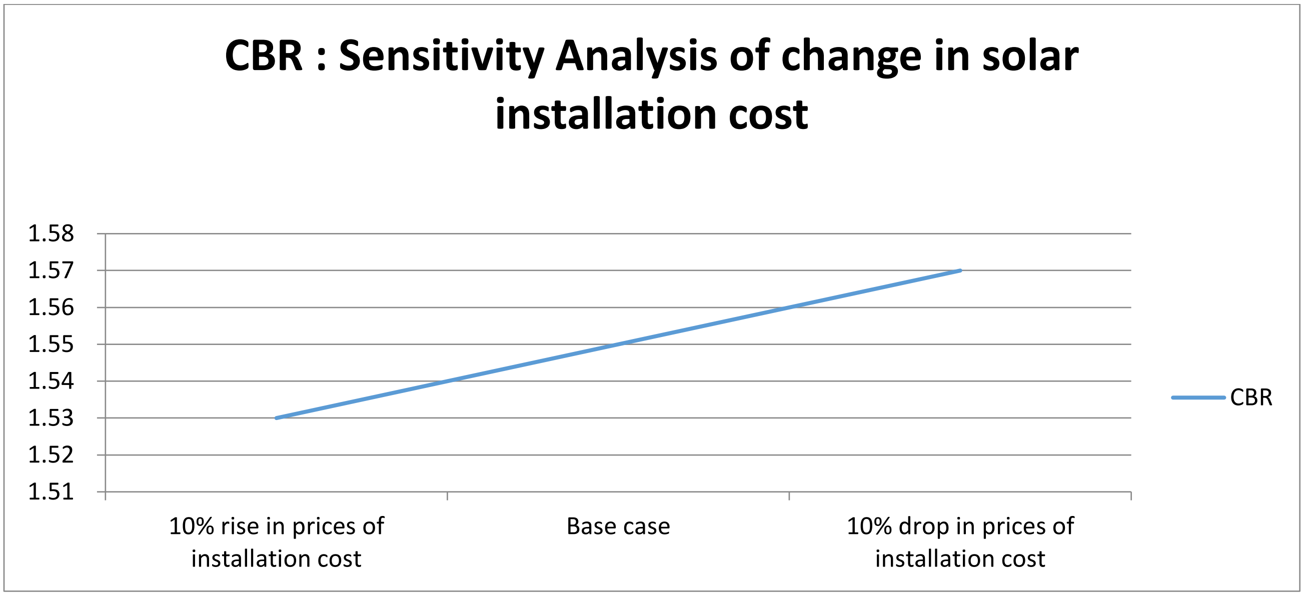

Table A7: Life cycle cost of Diesel powered pumping system

Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
Diesel (OC*)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)	Rs. (000)
Design & Installation of DPIS	250	-	-	-	-	150	-	-	-	-	150	-	-	-	-	150	-	-	-	-	-	700
Design & installation of HEIS	500	-	-	-	-	-	-	350	-	-	-	-	-	-	350	-	-	-	-	-	-	1,200
Operational Expenses of DPIS+HEIS	-	930	930	930	930,000	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	18,600
dep DPIS	-	62.5	62.5	62.5	62.5	30	30	30	30	30	30	30	30	30	30	25	25	25	25	25	25	700
dep HEIS	-	83.333	83.333	83.333	83.333	83.333	83.333	50	50	50	50	50	50	50	50	50	50	50,	50	50	50	1,200
Maintenance cost of DPIS +HEIS	-	190	190	190	190	190	190.000	190	190	190	190	190	190	190	190	190	190	190	190	190	190	3,800
Agro-Farm cost	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	582	12,222
Totals	582	1,847.833	1,847.833	1,847.833	1,847.833	1,815.333	1,815.333	1,782	1,782	1,782	1,782	1,782	1,782	1,782	1,782	1,777	1,777	1,777	1,777	1,777	1,777	**36,522**

Table A8: Life cycle cost of Solar powered Pumping system

Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
SOLAR (OC*)	Rs. (000)	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
Design & Installation of SPPS	1,005,000							400,000							400,000							1,805,000
Design and Installation of HEIS	500,000							350,000							350,000							1,200,000
Operating of HEIS & SPIS		240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	4,800,000
dep SPIS		167,500	167,500	167,500	167,500	167,500	167,500	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	57,143	1,805,000
dep HEIS		83,333	83,333	83,333	83,333	83,333	83,333	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	1,200,000
Maintenance of SPSS and HEIS		146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	2,920,000
Agro-Farm cost	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	12,222,000
Total	582,000	1,218,833	1,218,833	1,218,833	1,218,833	1,218,833	1,218,833	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	1,075,143	22,947,000

Table A9: Present Value Cost Analysis of DPPS

Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	TOTAL
Diesel (OC*)	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
Design & Installation of DPIS	250,000					150,000					150,000					150,000						700,000
Design & installation of HEIS	500,000							350,000								350,000					1,200,000	2,400,000
Operational Expenses of DPIS+HEIS		930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	930,000	18,600,000
Maintenance cost of DPIS +HEIS		190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	190,000	3,800,000
Agro-Farm cost	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	12,222,000
Totals	1,332,000	1,702,000	1,702,000	1,702,000	1,702,000	1,852,000	1,702,000	2,052,000	1,702,000	1,702,000	1,852,000	1,702,000	1,702,000	1,702,000	1,702,000	2,202,000	1,702,000	1,702,000	1,702,000	1,702,000	2,902,000	37,722,000
PV OF COSTS	**1,332,000**	**1,598,122**	**1,500,584**	**1,408,999**	**1,323,004**	**1,351,739**	**1,166,439**	**1,320,475**	**1,028,401**	**965,635**	**986,609**	**851,361**	**799,400**	**750,611**	**704,799**	**856,196**	**621,392**	**583,467**	**547,856**	**514,419**	**823,579**	**21,035,087**

Table A10: Present Value Benefit analysis of DPPS

Diesel (BENEFITS)	Agricultural Returns		-	496,600	1,826,750	1,826,750	1,826,750	1,826,750	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	49,548,600
	Fish Production			350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	7,000,000
	Recreation		-	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	2,880,000
	Salvage	diesel System	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48,000	48,000
		HEIS	-	-	-	-	-	-	-	-	-	-	30,655	-	-	-	-	-	-	-	-	-	30,655	61,310
		Pump	-	-	-	-	-	-	-	-	22,500	-	-	-	-	-	-	-	22,500	-	-	-	-	45,000
	Total Benefits		-	**990,600**	**2,320,750**	**2,320,750**	**2,320,750**	**2,320,750**	**3,277,000**	**3,277,000**	**3,299,500**	**3,277,000**	**3,307,655**	**3,277,000**	**3,277,000**	**3,277,000**	**3,277,000**	**3,277,000**	**3,299,500**	**3,277,000**	**3,277,000**	**3,277,000**	**3,355,655**	59,582,910
	Total Present Values of benefits		-	930,141	2,046,111	1,921,231	1,803,973	1,693,871	2,245,840	2,108,770	1,993,661	1,859,217	1,762,074	1,639,196	1,539,151	1,445,212	1,357,007	1,274,185	1,204,632	1,123,397	1,054,832	990,453	952,325	30,945,275
	NPV		**(1,332,000)**	**(667,981)**	**545,527**	**512,232**	**480,969**	**342,132**	**1,079,401**	**788,295**	**965,259**	**893,581**	**775,465**	**787,834**	**739,750**	**694,601**	**652,208**	**417,989**	**583,240**	**539,930**	**506,976**	**476,034**	**392,677**	**9,910,188**

Table A11: Present Value cost analysis of SPPS

Solar (OC*)	Design & Installation of SPPS	1,005,000							400,000							400,000							1,805,000
	Design and Installation of HEIS	500,000							350,000								350,000						1,200,000
	Operating of HEIS & SPIS	-	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000	4,800,000
	Maintenance of SPSS and HEIS	-	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	146,000	2,920,000
	Agro-Farm cost	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	582,000	12,222,000
	Total COST	2,087,000	968,000	968,000	968,000	968,000	968,000	968,000	1,718,000	968,000	968,000	968,000	968,000	968,000	968,000	1,368,000	1,318,000	968,000	968,000	968,000	968,000	968,000	22,947,000
	Total PV OF COSTS	**2,087,000**	**908,920**	**853,446**	**801,358**	**752,449**	**706,525**	**663,403**	**1,105,544**	**584,896**	**549,198**	**515,679**	**484,205**	**454,653**	**426,904**	**566,489**	**512,473**	**353,412**	**331,843**	**311,589**	**292,572**	**274,716**	**13,537,274**

Table A12: Present Value Benefit analysis of SPPS

Agricultural Returns	**With SPIS**		496,600	1,826,750	1,826,750	1,826,750	1,826,750	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	2,783,000	49,548,600
Recreation			270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	5,400,000
Fish Production			350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	350,000	7,000,000
Social Awareness			54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	54,000	1,080,000
Technological Awareness			125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	
Salvage	PV System		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100,000	100,000
	HEIS		-	-	-	-	-	-	-	-	-	30,655	-	-	-	-	-	-	-	-	-	30,655	61,310
	Pump		-	-	-	-	-	-	-	22,500	-	-	-	-	-	-	-	22,500	-	-	-	-	45,000
GHG Reductions			15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	300,000
Total Benefits			**1,310,600**	**2,640,750**	**2,640,750**	**2,640,750**	**2,640,750**	**3,597,000**	**3,597,000**	**3,619,500**	**3,597,000**	**3,627,655**	**3,597,000**	**3,597,000**	**3,597,000**	**3,597,000**	**3,597,000**	**3,619,500**	**3,597,000**	**3,597,000**	**3,597,000**	**3,727,655**	66,034,910
Present Values of benefits			1,230,610	2,328,242	2,186,142	2,052,716	1,927,433	2,465,147	2,314,692	2,187,015	2,040,770	1,932,546	1,799,263	1,689,449	1,586,337	1,489,519	1,398,609	1,321,463	1,233,097	1,157,837	1,087,171	1,057,897	34,485,955
Net Present Value		**(2,087,000)**	**321,690**	**1,474,796**	**1,384,785**	**1,300,267**	**1,220,908**	**1,801,743**	**1,209,148**	**1,602,119**	**1,491,572**	**1,416,867**	**1,315,058**	**1,234,796**	**1,159,433**	**923,029**	**886,136**	**968,050**	**901,254**	**846,248**	**794,599**	**783,182**	**20,948,681**