THE VIABILITY AND RELIABILITY OF SOLAR WATER PUMPING SYSTEM AND ITS EMISSION REDUCTION POTENTIAL IN RURAL KEBELES OF ABAYA DISTRICT OF OROMIA REGIONAL STATE, ETHIOPIA

M.Sc. THESIS

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A THESIS SUBMITTED TO HAWASSA UNIVERSITY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN RENEWABLE ENERGY UTILIZATION AND MANAGEMENT

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APPROVAL SHEET I

This is to certify that the thesis entitled ‘‘**The Viability and Reliability of Solar Water Pumping System and its Emission Reduction Potential in Rural Kebeles of Abaya District, West Guji Zone Of Oromia Regional State, Ethiopia**.**’’** is submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in **Renewable Energy Utilization and Management**, Wondo Genet College of Forestry and Natural Resource, and is a record of original research carried out by **Geleta Jarso**, Id. No. **MSc/REUM/R009/10**, under my supervision and no part of the thesis has been submitted for any other degree or diploma. The assistances and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

Yoseph Melka (PhD)	________________	_______________
Major advisor	Signature	Date

APPROVAL SHEET II

We, the undersigned, members of the board of examiners of the final open defense by **Geleta Jarso** have read and evaluated his thesis entitled **''The Viability and Reliability of Solar Water Pumping System and its Emission Reduction Potential in Rural Kebeles of Abaya District, West Guji Zone of Oromia Regional State, Ethiopia**.**''** This is therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of masters of Science in Renewable Energy Utilization and Management.

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SGS approval	Signature	Date

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CANDIDATE'S DECLARATION

I hereby declare that this M.Sc. thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Geleta Jarso ____________________ __________________________

Signature date

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
DC	Direct Conductor
GHG	Green House Gases
GPS	Global Positioning System
IM	Induction Motors
IPCC	Intergovernmental Panel on Climate Change
KII	Key Informant Interviews
KWh	Kilo Watt Hour
KWp	Kilo Watt Peak
LCCA	Life-Cycle Cost Analysis
LCC	Life-Cycle Cost
MPPT	Maximum Power Point Tracker
NGO	Non-Governmental Organizations
NMA	National Meteorological Agency
NPV	Net Present Value
PMDC	Maximum Power Direct Conductor
PMS	Permanent Magnet Synchronous
PV	Photovoltaic
PW	Present Worth
SPV	Solar Photovoltaic
UNFCCC	United Nation Framework Convention on Climate Change
UWC	Unit Water Cost
WHO	World Health Organization
W_P	Watt-peak

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ABSTRACT

In developing countries like Ethiopia, Pumping water for domestic use, livestock drinking and farming activities is becoming common practice particularly in water deficit arid and semi-arid areas. However, diesel based water pumping motors, which predominantly adopted so far, were identified to have limitation in improving communities life due to its' unreliability and high diesel cost, and at the same times contributing to environmental pollution by emitting greenhouse gas. While the government and development partners were exerting significant efforts to convert the diesel engines with solar pumping technologies. There are limited studies on the viabilities and reliability of such cost-wise, applicable and clean energy source technologies. This study, therefore, aimed to evaluate the viability and reliability of solar water pumping system and its emission reduction potential in rural off-grid kebeles of Abaya District, West Guji Zone of Oromia Regional State, Ethiopia. From the total population, survey was conducted with a semi-structured questionnaire for 188 households that were randomly selected from five rural kebeles which were selected purposively. Due to technology based social research a mixture of qualitative and quantitative methodological approaches is applied. Both quantitative and qualitative methodological approaches were employed. The results derived from questionnaires were analyzed by Statistical Package for Social Sciences of descriptive statistics and qualitative data mainly from key informant interviews were analyzed through intensive textual analysis. In addition, the economic comparison of solar water pumping system with the most likely conventional alternative diesel powered system has been analyzed through sensitivity analysis using a life-cycle cost analysis approach. Moreover, the potential contribution of solar water pump towards emission reduction was determined. The result shows that solar photovoltaic water pumping system supplies reliable and adequate water to the community. The life cycle cost analysis clearly shows that photovoltaic water pumping systems was economically viability and attractive alternative than diesel water pumping systems with average total life-cycle cost of 112,000 US$ for photovoltaic water pumping systems compare to 191,000 US$ for diesel water pumping systems. The sensitivity analysis clearly shows that using diesel water pumping system was the worst alternative from an economical point of view. Results further show that, in the study area about, 41,000 tons of CO_2 can be eliminated by replacing diesel pumping system with solar photovoltaic pumping system per 25 years of operation. Finally, the results of all three analyses indicate that using solar energy for water pumping was viable, reliable and promising alternative over other conventional pumping systems; it avoids fluctuations in the availability of water and cost of diesel fuel, and CO_2 emissions and pollution. Comprehensive effort from the Government as well as from all the stakeholders is required for further development of solar water pumping system throughout the rural locations with limited access to conventional electricity.

Keywords: Economic Viability, life-cycle cost, Photovoltaic, Sensitivity Analysis.

1. INTRODUCTION

1.1. Background

Being renewable and clean for the environment, solar energy is and will be among the promising alternatives to meet the ever-increasing demands in the energy supply throughout the world (SELF, 2008). With its diverse applications option, having decentralized nature, and abundant availability, solar energy is considered as the most prominent option in an effort to reach rural community energy needs in particular (Argaw Neway *et al*., 2003). More specifically, solar photovoltaic (SPV) technology is considered as well-suited technology particularly for groundwater supply for both domestic use, and small-scale irrigation at rural household level; since it is economically wise, easily applicable, and based on a freely-available resource as compared to diesel-based water pumping motors (Shim, 2017). In addition to suitability, it plays a crucial role in achieving world climate change mitigation goal of switching to clean energy by reducing GHGs emission that emitted from using diesel-based water pumping motors (Sitaram *et al*., 2017).

Historically, pumping from boreholes in Ethiopia off-grid areas has been predominantly achieved with diesel pumps (Belay and Haramaya, 2008). Since most rural areas of the country do not have the opportunity to use grid electricity to drive the pumps and have instead relied on diesel driven generators to provide power (Asefa Kabade *et al*., 2013). However, Diesel based water pumps have many drawbacks such as high running and maintenance costs, unreliable and costly supply of fuel (Shim, 2017).

Replacement of diesel-based pumps with solar-powered pumps offer several advantages such as low running costs due to the almost free supply of energy offsets the incremental initial investment cost of the solar pumping system. Maintenance costs of solar systems are also low since the photovoltaic systems have been proven to be very reliable in practice (Belay and Haramaya, 2008). During normal operation, PV power systems do not emit substances that may threaten human health or the environment (Ebaid et al., 2013). Solar pump systems improve the community standard of living by providing reliable, predictable, and affordable energy for water pumping. It also contributes to addressing health, education, and gender issues (Foster and Cota, 2014).

In countries like Ethiopia with high sunshine, having high diesel prices and all year round water requirements it was found that PV pumping systems were economically viable (Argaw Neway *et al*., 2003). In addition to the economic advantages of solar pumps, benefits to the government include reduced diesel consumption and associated subsidies, savings in foreign exchange for diesel imports (Asefa Kabade *et al.*, 2013).

In the study area, developing a grid system is often too expensive because of settlement patterns of the community in the rural kebeles of the area. The kebeles are located too far from existing gridlines; as a result, fuel transportation was difficult and often risky due to poor road infrastructure development. Furthermore, diesel-based water pumping systems require not only expensive fuels but also high maintenance and operation costs create noise and air pollution. Therefore, to provide a sustainable solution to the problem related to the conventional diesel water pumping system; it is better if it substituted by a solar water pumping system to minimizes the dependence on fuel for a diesel generator. In order to decrease the environmental pollution and increasing of energy productivity, energy resources that emit less GHG to the atmosphere must be preferred (Zanab and Sada, 2016). Eventually, this study may contribute to fill the gap by evaluating the viability and reliability of the solar water pumping system and its emission reduction potential in rural kebeles of Abaya District, West Guji Zone of Oromia Regional State, Ethiopia.

1.2. Statement of the Problem

The demand for domestic water supplies is increasing. At the same time, rainfall is decreasing in many arid and semi-arid countries, so surface water is becoming scarce. Groundwater seems to be the only alternative to this problem, but the groundwater table is also decreasing, which makes traditional hand pumping difficult UN (2003). As these trends continue, mechanized water pumping will become the only reliable alternative for lifting water from the ground (Argaw, 2004). In Ethiopia since access to electric services is only about 17%, most rural areas do not have the opportunity to use grid electricity to drive the pumps and have instead relied on diesel-driven generators (Belay and Haramaya , 2008). Although considerable efforts have been made to improve and expand access to potable water supply, many Ethiopian rural communities still suffer from lack of safe drinking water (Asefa Kabade *et al.*, 2013). Water is the most precious natural resource and its relative scarcity (due to the limited accessibility and availability) is a major constraint on community development.

In many rural areas, water sources are spread over many miles of land, the installation of a new transmission line and transformers to the location will be very expensive. Hand pump, spring development, and diesel pumping system have been installed conventionally in such areas; many of them are inoperative currently due to lack of proper maintenance (Froukh, 2006). These systems are portable and easy to install. However, they have some major disadvantages, such as variable water production, and require frequent site visits for refueling and maintenance. Furthermore, diesel fuel is often expensive and not readily available in rural areas of many developing countries (Ramos and Ramos, 2009). For this reason, technology to pump groundwater in ways that are economic and environmentally friendly should be developed.

Solar pumps offer a clean and simple alternative to fuel-based generators for domestic water supply, livestock, and irrigation. Solar pumps are most effective during dry and sunny seasons, and require no fuel deliveries, minor maintenance, easy to install, naturally matched with solar radiation as usually water demand increases during summer when solar radiation is a maximum, and less expensive than other alternative sources of energy such as diesel pumping systems (Akihiro *et al*., 2005).

High investment costs, or initial system costs, represent the most important barrier to PV deployment today (Yasin, 2008). The economic viability of PV systems has been assessed throughout LCC (life cycle cost) assessment and found that with non-availability/shortage of conventional electricity, cost escalation of diesel every year and that of PV modules steadily decreasing, PV pumping systems are becoming financially attractive as compared to electricity/diesel-powered pumping systems in present times (Kolhe *et al*., 2002).

The consumption of fossil fuels also has a negative environmental impact, in particular, the release of carbon dioxide (CO2) into the atmosphere. CO2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost-competitive with fossil fuels in many situations (Kumar and Kandpa, 2007).

Abaya District communities rely on different water sources at different times of the year due to their own mobile mode of life and the variable responses of many water sources to seasonal weather variability. Since the study area has favorable solar energy resources to use for power generation, substituting conventional diesel pumps with solar PV water pumps is expected to be the appropriate technology choices for the community to sustain water supply and environmental safety which improves the community's health, social development. Therefore, this study evaluating the viability and reliability of solar water pumping system and its emission reduction potential in rural kebeles of Abaya District, West Guji Zone of Oromia Regional State, Ethiopia.

1.3.Objectives of the Study

1.3.1. General Objective

- To evaluate the viability and reliability of the solar water pumping system and its emission reduction potential in rural kebeles of Abaya District West Guji Zone of Oromia Regional State, Ethiopia.

1.3.2. Specific Objectives

- To assess the reliability of solar water pumping systems ground water supply in rural kebeles of Abaya.
- To compare the economic viability of solar water pumping system with a diesel-based pumping system.
- To estimate the potential contributions of solar water pump towards emission reduction.

1.4. Research Questions

The study attempts to address the following research questions:

- Does the solar water pumping system provide a reliable water supply for the typical rural community?
- May investing in solar water pumping systems have economic advantages compared to conventional water pumping systems at the rural community level?
- Does switching to solar water pump reduce significant carbon emission?

1.5. Significance of the Study

The study has a great significance for the rural community and government policymakers. The findings from this research provide useful information based on which the government and the many individuals who would want to consider Solar pumping Systems can make well informed financial and technical decisions.

Water is one of the primary resources necessary to support life and rural development, so this can be achieved in rural areas by supplying adequate water through solar powered pumping system. This will, therefore, cut down the consumption of fossil fuel and thus help mitigate the impact of climate change which has become a top issue in the development agenda at the international, national and local levels.

Government can benefit from saving on subsidy expenditures for diesel fuel and foreign exchange savings resulting from reduced diesel imports and the government policy makers will benefit also from the outcome since it will assist them in examining the current policies towards the renewable energy sectors and improve them accordingly.

2. LITERATURE REVIEW

2.1. Water Pumping Technology

The water pumping technologies for rural application are the hand pump, Solar, wind and diesel pump systems.

Hand pumps are used for pumping water from shallow wells particularly in the communal areas. These are rugged devices which are easy to maintain and have low capital cost. They are, however, limited in terms of the pumping volumes and depth of installation (hydraulic load limit of less than 250 m4/ day) (Dunn, 1986).

Wind pumps have a long service life, are able to deliver water from depths of 300 to 400m, require basic skills but are work-intensive to maintain. Wind pumping systems are, however, not simple to install and require larger water storage than for example a Diesel or solar pumps to provide for periods of low wind (Tesfaye Bayou, 1996).

Diesel pumps could be used at all heads with high discharge rate (Dunn, 1986). In Ethiopia the traditionally, water pumping systems powered by diesel engines have been used for a long time, but fuel cost, transportation problem, lack of skilled personnel makes the conventional water pumping system unreliable and expensive for rural communities (Misrak Girma, 2016). With the non-availability/shortage of electricity, cost escalation of diesel every year and that of PV modules steadily decreasing, PV pumping systems are becoming financially attractive as compared to diesel-powered pumping systems in present times(Sako *et al.,* 2011).

2.1.1. Solar Water Pumping Technology

Solar water pumping is based on PV technology that converts solar energy into electrical energy to run a DC or AC motor based water pump. A SPV water pumping system consists of a PV array, DC/AC submersible floating motor pump set, and electronics (Chandel *et al.,* 2015). The PV array is mounted on a suitable structure with a provision of manual or automatic tracking. Water is pumped during the day and stored in tanks, for use during day time, night or under cloudy conditions (NREL, 2017). The water tank acts as storage and generally, the battery is not used for storage of PV electricity; however, for specific reliable requirements it can be used (Rohit *et al.*, 2013).

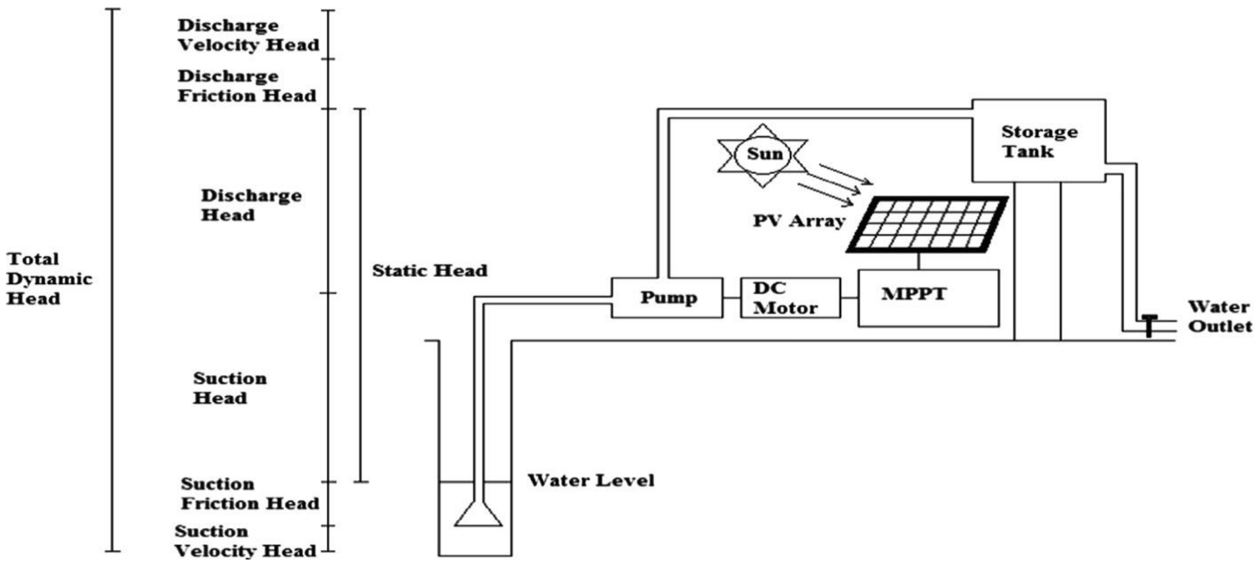

Figure 2.1.Schematic of a Direct Coupled Solar Photovoltaic Water Pumping System with MPPT (Chandel *et al*., 2015)

PV water pumping systems have shown significant efficiency improvements, driven by fundamental scientific research and manufacturing innovations, has delivered consistent decreases in cost (Martin *et al.,* 2017) and means that energy generated from PV technology is more accessible than ever before. The steady fall in prices of solar photovoltaic (PV) panels has resulted in making solar pumping economically viable for an increasingly wide range of applications (Kou *et al*., 1998).

The current solar pumping technology uses electronic systems that have further increased the output power, performance of the system and overall efficiency of the system (Protogeret and Pearce, 2000). The controller provides inputs for monitoring storage tank levels, controlling the pump speed and uses maximum power point tracking technology to optimize the water.

PV module costs have significantly declined and are available at a rate of US$ 0.59/Wp in 2014 as compared to around US$ 1/Wp in 2012 in India; this significantly affects the overall cost of the pumping system since PV modules represent 60–80% of the total cost of a PV system (Foster and Cota, 2014).

2.1.1.1. Principle of Solar Water Pump

Solar water pumping is based on PV technology that converts sunlight into electricity to pump water (Figure 1). The PV panels are connected to a motor (DC or AC) which converts electrical energy supplied by the PV panel into mechanical energy which is converted to hydraulic energy by the pump. The capacity of a solar pumping system to pump water is a function of three main variables: pressure, flow, and power to the pump (Rohit *et al.*, 2013). The various types of current configurations of direct coupled DC and AC solar water pumping systems being used worldwide are shown in Figure 2.2–2.4.

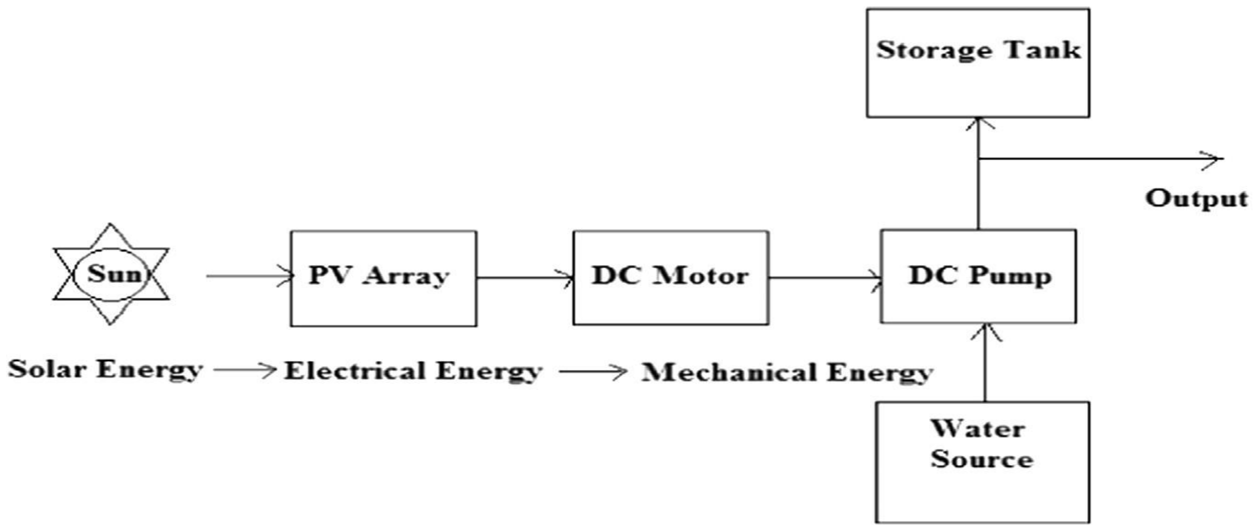

Figure 2.2. Block Diagram of a Direct Coupled PV DC Water Pumping System. (Jayakumar, 2009)

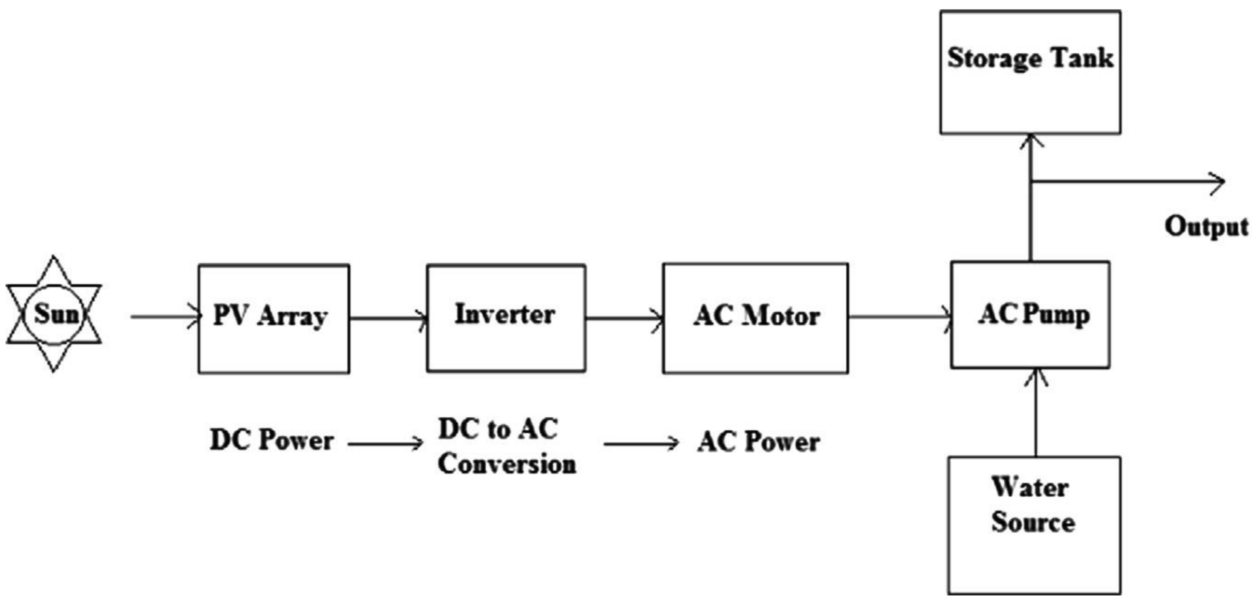

Figure 2.3. Block Diagram of a PV AC Water Pumping System (Jayakumar, 2009).

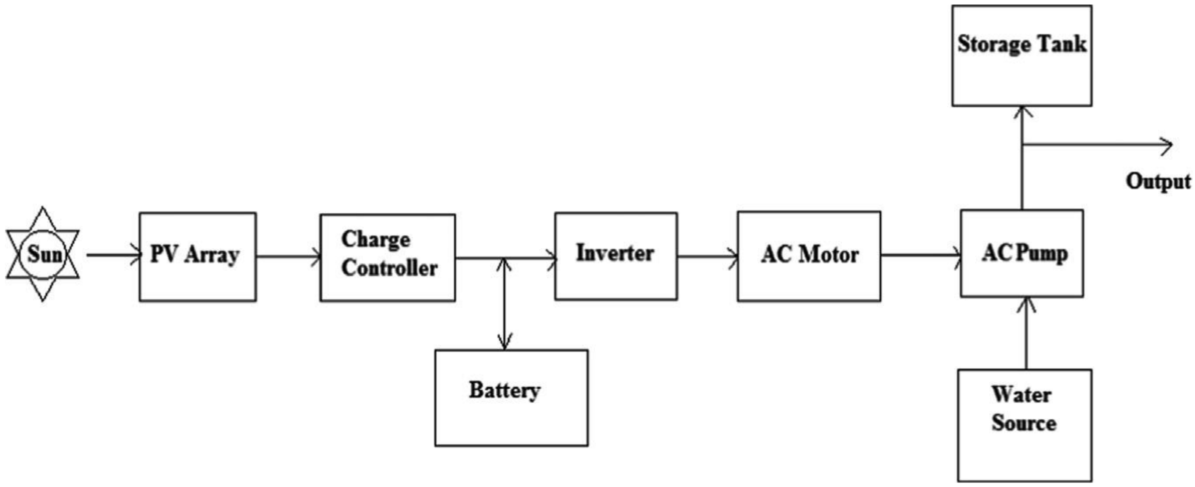

Figure 2.4. Block Diagram of a PV Water Pumping System with Battery Storage (Jayakumar, 2009)

PV Generator: PV generator of a solar pump consists of PV modules connected in series and parallel combination as per motor voltage requirement. A PV module consists of solar cells that convert solar radiation into direct electricity. In order to extract maximum power from a PV module, it is connected to the DC-DC converter or DC–AC converter (inverter) controlled by MPPT (Abouda *et al*., 2013). A pump will only require a certain power to produce a certain amount of pressure and flow. A higher capacity PV generator will allow the pump to start earlier and operate for longer period during the day under low insolation conditions (Chandel *et al.,* 2015). However, adding more PV panels than actually required will add to the cost.

Motors for PV Based Pumps: There are two major categories of motors, DC and AC. For a simple PV system (i. e. smaller PV applications), a DC motor is the best option compares to AC motor as the modules produce direct current and less specialized power conditioning equipment is needed (Barlow *et al.,* 1993). AC motors in general, are limited to high power applications in PV-powered pumping systems because they require inverters and thus introducing additional costs and some energy loss within the system. They are cheaper and less efficient than DC motors (Thomas, 1993).

Solar Pumps: Solar pumps are classified into three types according to their applications: submersible, surface, and floating water pumps. A submersible pump draws water from deep wells, and a surface pump draws water from shallow wells, springs, ponds, rivers or tanks, and a floating water pump draws water from reservoirs with adjusting height ability (EmCon, 2006). The motor and pump are built-in together in submersible and floating systems. The best type of pump for a particular application depends on the daily water requirement, total head and the water source (Argaw Neway *et al.*, 2003).

Controller: A controller is an electronic device which matches the PV power to the motor and regulates the operation of the PV pump. It is mostly installed on the surface but some solar PV pumps have the controller integrated in the submersible motor-pump set (Chandel *et al.,* 2015).

Water storage versus Energy storage in Battery: Usually, PV systems rely on battery bank for energy storage to power solar home systems and other appliances at night and in cloudy weather when the solar radiation is absent or fluctuates erratically. (EmCon, 2006) reports that it is more economical to store water in the reservoir than energy in the battery bank. This observation is in tandem with (SELF's, 2008) assertion that when water is stored in reservoir and batteries are eliminated from the system, about 1/3 of the system cost and most of the maintenance is eliminated.

2.1.2. Application of PV Water Pumping Systems

The major demand for water supply falls into three fairly distinct categories: Village water supply, Irrigation, livestock (Rohit *et al*., 2013). Potable water supply and livestock watering are the commonest uses of solar PV pump particularly in arid and semi-arid areas which often have very high levels of insolation (solar radiation) year-round (AFREPREN/FWD, 2012). Solar photovoltaic (PV) for water pumping particularly in a rural setting has a lot of advantages; the first of which is that it is environmentally sound in performance on a life-cycle basis. The solar PV is very clean; it helps mitigate some of the most serious environmental problems including air pollution and climate change (Anderson *et al*., 2006).

Technically, solar PV requires low maintenance and can operate for long periods unattended. The modular nature of the solar panel facilitates additional energy generating capacity which makes them a good choice for electricity generation in remote applications (Pelt *et al.,* 2012). Apart from those advantages, Khatib (2010) also notes that the PV pumping system is easy to install, it is reliable and has the capability to be matched to demand. He, however, states its disadvantage is that it has a high initial cost and its water production fluctuates.

2.1.3. Economic and Environmental Aspects of PV Water Pumping System

Energy is essential for economic development and providing vital services that improve the quality of life. (Sopian *et al.*, 2011) argue that it is required for meeting all of the basic needs of mankind and it shows a clear correlation with the Human Development Index. (Jayarkumar, 2009) argues that energy has an established positive correlation with economic growth. Energy has also been said to be an important tool for socio-economic development (Hayes and Schofield, 2002). It is required for the production of all goods and services.

The demand for energy keeps on increasing; fossil fuels (oil, gas, coal) are being depleted (Jennings, 2009) points out that there is an unprecedented concern about fuel prices and oil depletion coupled with concern about high level of global warming and how best to respond to it. He suggests a great reliance on renewable energy for power generation as renewable energy is seen by many as part of the appropriate response to these concerns (Jennings, 2009). Jayarkumar (2009) also notes that the unavoidable increase use of non-renewable energy along with a country's economic growth does not only threaten a nation's energy security but also promote its environmental degradation (Jayarkumar, 2009). According to Hayes and Schofield (2002), energy systems contribute most to the environmental burden being faced by the world, leading to rapid environmental degradation. Vindis *et al.* (2007) the increasing demand for energy, rise in oil prices, exhaustion of fossil fuel and the growing concern for environmental issues have challenged researchers to develop new technological processes to obtain cleaner and more sustainable energy sources (Chynoweth *et al.*, 2000).

The provision of sufficient, reasonably priced and clean energy is a critical requirement for alleviating poverty and improving productivity. Hayes and Schofield (2002) suggest this would be achieved by applying best practices in sustainable development to the energy sector. Therefore economic growth can be sustainable if it is fuelled by energy systems that are increasingly more efficient, less expensive and cleaner. Razykov *et al* (2011) observed that Photovoltaic (PV) electricity is one of the best options for sustainable future energy requirements of the world.

2.2. Empirical Review

Foster *et al.* (1998) studied more than 130 types of PV water pumping systems of about 2kWp size installed in eight states in Mexico. The increased viability of installations led to low prices, high quality and gaining foothold in Mexico. Kaka and Gregoire (2012) studied the performance of a PV water pumping system in a village at 30 km of Keita (Niger) to meet the water needs of 500 persons and reported that the cost of one cubic meter of water pumped by the PV system is more advantageous than other systems. PV water pumping is found to be well suited for arid and semi-arid areas due to the existence of underground water potential and large solar energy potential of more than 6kWh/m². Meah *et al.* (2008) highlighted the need for using PV pumping in drought prone states. Wyoming, Montana, Idaho, Washington, Oregon, and part of Texas in USA which could use solar PV water pumping systems to supply water to livestock in remote locations and presented the initiative of using PV pumping systems in western USA state Wyoming. The study analyzed the performance of 75 systems in operation and showed excellent performance and cost effectiveness besides the benefit of reduction of carbon emissions.

Foster *et al.* (2014) Surveyed 46 water pumping systems installed under Mexican Renewable Energy Program (MREP) - a collaborative program sponsored by the U.S. Agency for International Development (USAID) and the U.S. Department of Energy (DOE). The results obtained prove that the majority of systems were functioning after 10 years and have proven to be an excellent option to meet water pumping needs in rural Mexico where electrical grid services are not available. The average investment payback for the PV water pumping systems was found to be 5–6 years, with some systems reporting paybacks in half that time. Jamil *et al*. (2012) proposed three different options water pumping system to meet the water requirements of an academic institution in New Delhi, India. The techno-economic analysis of PV based water pumping system is carried out and compared with an existing system.

Thomas (1993) stated that the method of the life cycle cost (LCC) is an efficient method to be used to evaluate the financial viability of a PV water pumping solar system. Mahmoud and Natherb (2003) studied the economical aspects of solar photovoltaic (PV) water pumping compared to diesel system, by using the method of LCC. The results indicated that the PV solar water pumping, in terms of cost, is better than the diesel pumping systems. Mahjoubi *et al.* (2013) investigated the economic viability of remote PV water pumping systems in the desert of Southern Tunisia, which will have to satisfy an average daily volume of $45m^3$ throughout the year compared with diesel genset by using the method of the LCC. Their study indicated the economic viability of PV water pumping systems in the desert of Tunisia. Benjamin *et al.* (2010) Analyzed the life-cycle cost of diesel-photovoltaic hybrid power systems for off grid residential buildings in Enugu Nigeria. The main aim of the analysis is to compare the Life Cycle Cost (LCC) hybrid system with that of single stand alone photovoltaic system and stand-alone diesel generator options. The life cycle cost analysis of the systems has been done by comparing the Net Present Value (NPV) and the Internal Rate of Return (IRR) of the three options. The result shows that the diesel/photovoltaic hybrid system has a small LCC when compared to that of standalone single source Photovoltaic and diesel generator options. Moreover, apart from the economic gain, the hybrid system is also environmentally friendly because of the reduced emission of greenhouse gasses and other pollutants associated with diesel.

Ammar *et al.* (*2010)* used the method of the LCC to evaluate the financial viability of a PV pumping system in the desert of Tunisia. The study shows that the life cycle cost of the diesel genset system is higher than that of the PV system for pumping water. It is found that the life cycle cost for a PV system is 0.500 TND/m3 and 0.900 TND/m3 for using diesel Genset. Concerning the environmental side the PV systems are clean and renewable sources of energy; they do not cause pollution of any type during their use. Misrak

Girma *et al.* (2015) investigated the economic viability of rural PV water pumping systems using life cycle cost analysis in Ethiopia and shows that the SPV water pumping system was more economical and feasible compared to Diesel system. The results indicate that more SPV systems can be installed in the country, replacing the existing more expensive Diesel systems, which would play a significant role in achieving the country's MDG targets Misrak Girma *et al.* (2015).

Kumar and Kandpal (2007) developed a method for quantification of CO_2 emissions and estimation of PV pump cost mitigation in India. The study shows that for a 1.8 kWp SPV pump at 5.5 kWh/m^2 daily solar radiation availability, the unit cost of CO_2 emissions mitigation is estimated at US$ 169.38/ton and US$ 405.06/ton in case of diesel and electricity substitution respectively. Krauter and Ruther (2003) conducted a CO_2 comprehe nsive balance within the life-cycle of a photovoltaic energy system. Calculations of the possible effect on CO_2 reduction by PV energy systems were made in Brazil and Germany. Roy (2012) demonstrated that the test results on the application of solar PV DC system provided satisfactory performance on water pumping, and moreover, it is user and environmentally friendly. Together with decreasing PV module costs and increasing efficiency, PV is getting more pervasive than ever.

2.3. Conceptual Framework

The conceptual framework highlights the interconnectedness of energy supply within the water-energy and links with the factors that affect the reliability of water supply, viability of the system and environmental issues at the community levels from the renewable energy supply perspectives.

The people without access to electricity are principally the same as those who lack access to safe water. The reason for the link between drinking water and electricity systems is that most water supply systems need to be powered by electricity. On the other hand considering the relation between water and energy, energy is needed to supply water to people. Geographically, most of the arid and semiarid regions with water scarcity receive high solar radiation, thus providing sufficient sustainable solar energy for the water supply process. Water supply activities, such as water extraction from surface and groundwater, account for the largest share of water-related energy consumption

The use of energy has a direct impact on water scarcity and thus on providing access to safe water. Solar energy is a locally available renewable resource. It does not need to be imported from other regions of the country or across the world. This reduces environmental impacts associated with transportation and also reduces our dependence on imported oil. And, unlike fuels that are mined and harvested, when we use solar energy to produce electricity we do not deplete or alter the resource. Since, photovoltaic energy is from renewable energy source which is quiet and visually unobtrusive. Most importantly, Strong link between community participation is a key factor believed to improve the long term sustainability of energy-water supply system.

Even though, economically the capital cost of solar energy is somewhat more expensive than conventional energy due to the high cost of PV system components, the operation and maintenance of conventional system has direct impact on water-energy as well as the community.

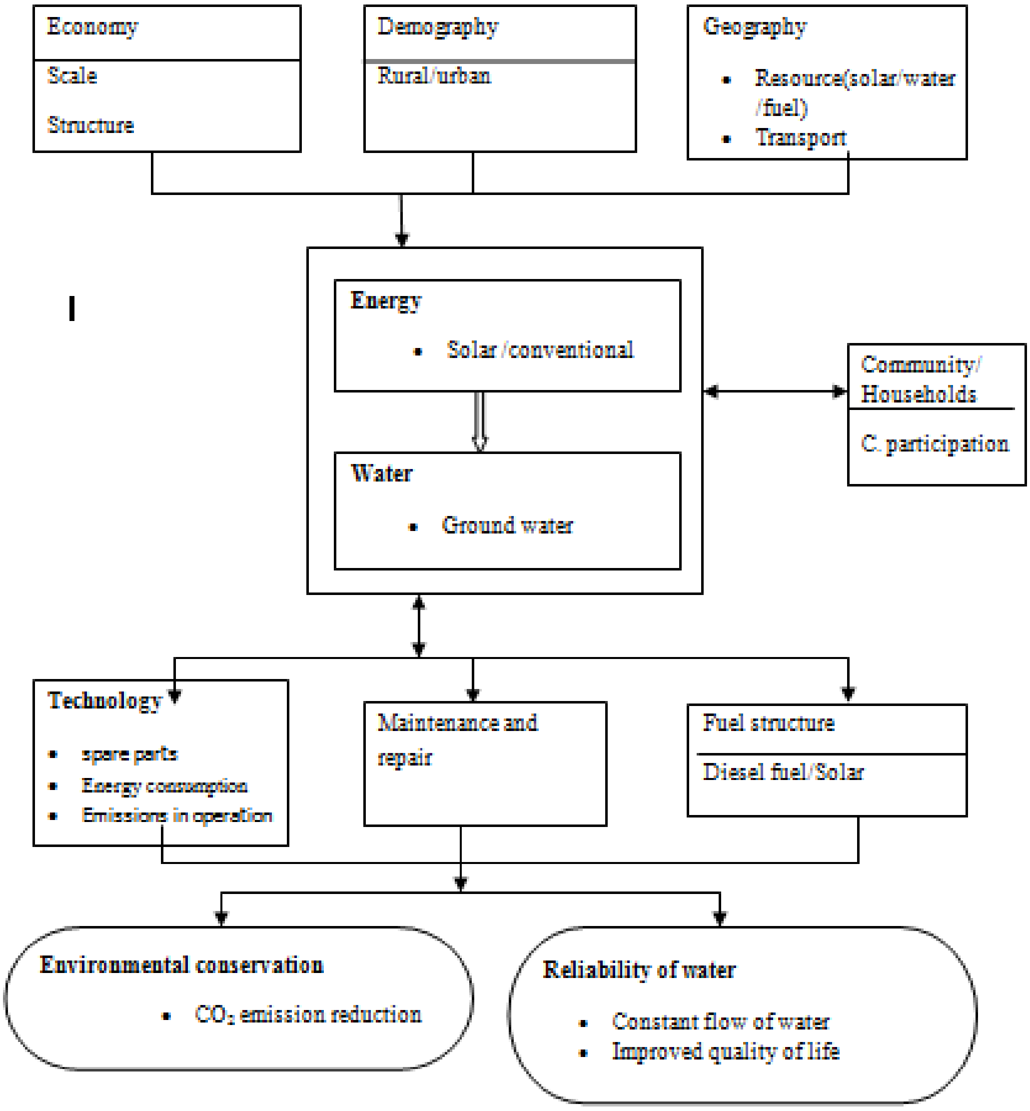

Figure 2.5. Conceptual Frame Work of the Study

3. MATERIALS' AND METHODS

3.1. Description of the Study Area

3.1.1. Location and Topography

This study was conducted in Abaya District of the West Guji zone which is found in Oromia Nation Regional State of Ethiopia (Figure 3.1). The District found at 486 KM from Addis Ababa and 100 KM far from Zonal town Bule Hora. This District is bounded with Dilla District of Gedeo zone in the North, and three West Guji zone Districts like Bule Hora District in the South, Galana and HambalaWamana in the East. The District has 4 towns and 26 rural kebeles with rural population of 125,691 and urban population of 10,850.

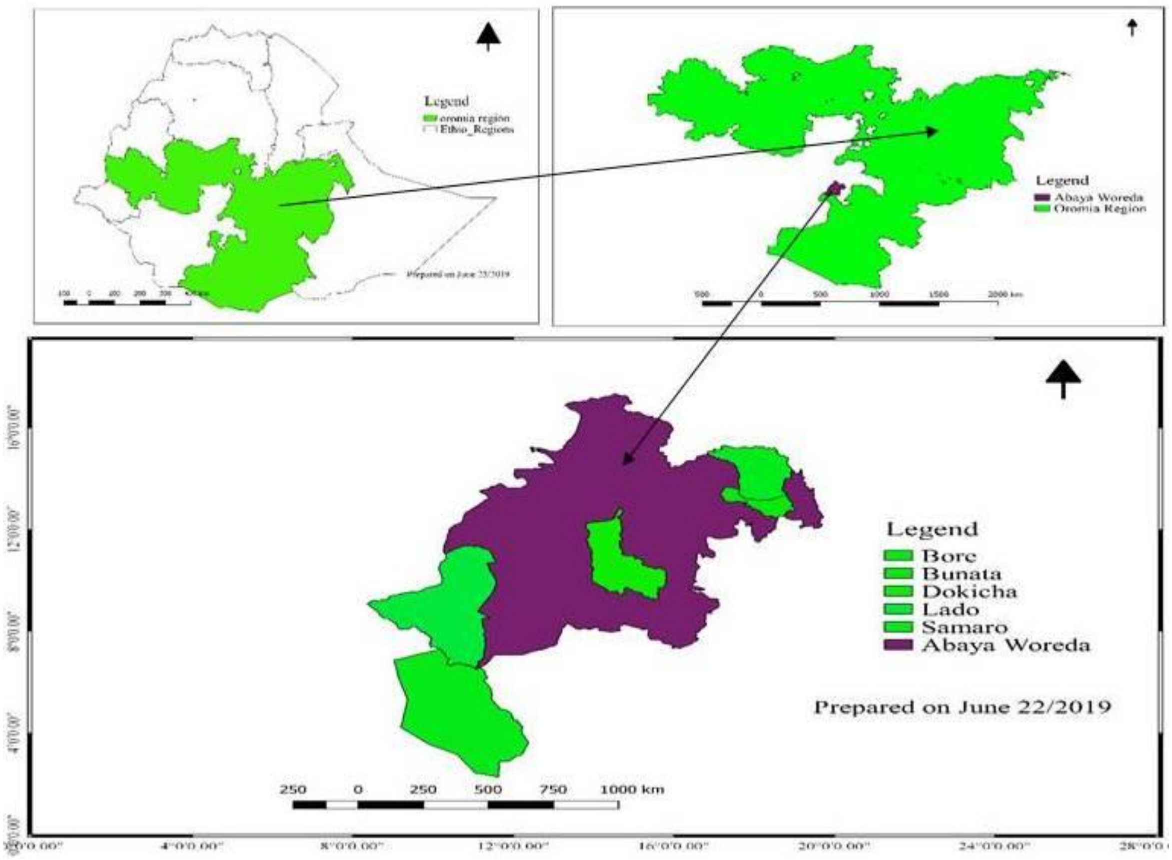

Figure 3.1. Location Map of Abaya District

3.1.2. Climate of the Area

The climatic condition is characterized by arid and semi-arid. The mean annual temperature level of the District ranges from 21 – 27 °C. The area has two rains seasons summer (march to May) stand spring (September to October.), besides the above rainy seasons small rainy occur during July and August, and southwest depressed lands of the District earn lesser depth of annual rainfall and high-temperature condition with rough 300-700 mm annual precipitation rate. The District is located 04621845 N (latitude), UTM 0702965 E and within the altitudinal range of 5116 M meter above sea level

3.1.3. Livelihood and Socio-Economic Characteristics

As far as economic condition of District is concerned, the livelihoods of communities living in Abaya District highly depends on traditional crop and livestock production that cannot fulfill the needs of farmers beyond feeding themselves but, only for survival. Adequate potable water supply and sanitation services are the most component of socio-economic development; they play a vital role in maintaining the wellbeing of the population. However, existing water resources have not been developed to meet the supply need of the society in a steady area. Concerning water scheme data, there are few motorized scheme and unprotected water source (river, ponds) in the District (abaya District water and energy office desk file, 2010-2018).

With regard to access to health services, both the public and livestock health facilities in the study area is poorly equipped in terms of human and material resources. Energy supply plays a crucial role in any development purpose. The sources of energy of the society are firewood, crop residue, charcoal, and kerosene in order of their potential respectively use for cooking and lighting purposes which has a negative impact on the environment (Oromia water and energy bureau document, 2008).

3.2. Research Design

The proposed study employed a descriptive type of research design. The reason for select this design the main target of the researcher was to collect, analyze, describes and concludes the characteristics or behavior of the existing conditions. The study was followed by a mixed approach of both quantitative and qualitative approaches with the justification that such the combined approach provides a better understanding of research problems than either approach alone (Creswell and Clark, 2007) and this is considered to be efficient for answering the research questions.

3.2.1. Sampling Techniques and Sample Size Determination

The study used both purposive and random sampling techniques. The study District was purposively selected based on the information from officials of water and energy office of West Guji Zone. Abaya was selected since it's the only District where the solar pump water supply system was practiced throughout the zone. Five rural kebeles that use solar water pump was selected purposively by considering their familiarity with the system from 26 total kebeles; the rest 21 kebeles was not familiar with the technology of solar water pump because the system is not installed there.

Sample households were selected through Random Sampling techniques based on Probability Proportional to Size (PPS) method. HH list of each selected kebeles collected from a list of households obtained from the administrative records of each kebele. From the total of 2,412 households of the five samples rural kebeles, 188 households, which were proportionally allocated for the respective sample kebeles, were included in the sample population using the formula proposed by Yamane, 1967. The precision level assumed to be committed in this study would be taken 7% (0.07), with a confidence interval of 93% (Table 3.1).

$$n = \frac{N}{1 + N(e)^2}$$

Where n is the sample size, N is the population size (total HHs in sampled kebeles) and e is level of precision

$$n = \frac{2412}{1 + 2412(0.07)^2}$$

n=188

The respective numbers of households will be allocated for each sampled kebele based on PPS of each selected kebeles as indicated in the table 3.1

Table 3.1. Household Sample Size

District	Kebele uses the water scheme	Total Number of HHs	Number of Sample HHs
Abaya	Samara	N_1= 502	$\frac{N_1}{N} * n$ =39
	Lado	N_2= 494	$\frac{N_2}{N} * n$ =39
	Bore	N_3= 552	$\frac{N_3}{N} * n$ =43
	Bunata	N_4= 480	$\frac{N_4}{N} * n$ = 37
	Doqicha	N_5= 384	$\frac{N_5}{N} * n$ =30
	Total	N= 2412	n=188

3.3. Data Types and Sources

In this study, both primary and secondary data were used. Primary data obtained through household surveys using semi-structured questionnaires, Key Informant Interviews (KII), NMA and field observation. Whereas, Relevant secondary sources pertinent to the study were obtained from District water and energy official statistics, Oromia water and energy bureau and reports available in water projects implementing agencies' offices.

3.4. Method of Data Collection

The study involved a range of data collection methods from both primary and secondary sources.

3.4.1. Primary Data

Primary data obtained from the household survey, KII and direct field observations. The household survey was conducted with the sample HHs. A detailed and well-designed semi-structured questionnaire was developed in a way that enables to gather full information about the study's objectives. So the data was collected through direct interviews of the sample HHs.

KIIs were qualitative in-depth interviews with key individuals who could give sufficient information about what is going on in the community concerning the study. The key informant's interviews respondents were selected purposively based on the researcher judgment with their particular knowledge and understanding of the reliability and Contribution of the solar water pumping system to the socioeconomic activity of the community. Generally, the interview was carried out with a total of 25 KII respondents (two from zone water and energy expert, three from District water and energy expert, ten from Kebele administrations representative and ten from samples rural Water Committee).

In addition to key informant interview, field observation was conducted to overview the functionality of the water scheme, the available number of panels and its capacity, PV stands, inverter and charge controller. This method particularly was used as a supportive or supplementary technique that can complement the information gained from documents and key informants. In addition, this observation was used to counter-check information provided by household respondents.

3.4.2. Secondary data

In an effort to supplement the primary data and make this research work more valid and worthy, relevant secondary sources pertinent to the study were consulted. The relevant secondary data were collected from different sources such as published and unpublished books, journals and reports. Other data are available at District water and energy official statistics, Oromia water and energy bureau and reports available in water projects implementing agencies' offices were also used.

3.5. Data Analysis

First, the mobile recorded information, and the note from the informal discussion and field observation was transcribed and translated from the local language (Afan Oromo) to English. Second, by reading through all of the qualitative and quantitative data, it was reviewed and organized to develop a general understanding of the data set and short memos were prepared which will best help in organizing and categorizing the data into concepts. Then, through the narrative description, the results of the entire quantitative and qualitative data were organized, analyzed and interpreted in a way that first the responses for the semi-structured questionnaire was edited, coded and feed to the computer by applying appropriate software (SPSS version 20). Then descriptive statistics mainly percentage and mean values are considered to present the respective results.

The life cycle cost analysis (LCCA) method was used for quantitative data collected for economic analysis to find the most profitable alternative that is to identify which alternative of pumping option achieves the maximum benefit for the least cost. This approach allows systems to be compared on an equal basis by reducing all future costs, which occur at different intervals of the systems life, to one value, referred to as the LCC of a system. Future costs include operating costs (diesel fuel consumption, transport), maintenance costs (engine oil, filters, brushes, labor, and transport) and replacements (diesel engine, pump and inverter). In order to calculate all costs in today's US$, the future costs were reduced to the present value using a discount rate. Therefore, LCC is the sum of the capital cost and the present worth of the recurrent and replacement costs (Chandel *et al.*, 2015)

LCCA = IC + OC + MC + RC ……………………………………………………..… (1)

Where LCCA is life cycle cost analysis, IC is initial Cost, OC is operation cost, MC is maintenance cost and RC is replacement cost

There are two types of calculation that are commonly used in life-cycle costing when expressing a future cost as its present worth. The first is used to calculate the total present net worth of a recurring cost, such as annual fuel consumption, maintenance and repair costs (Ammar *et al*., 2010).

$$\text{PW of Annunity } = V_{ann}[\frac{1-\frac{1}{(1+d)^n}}{d}] \qquad (2)$$

Where V_{ann} is the initial value of the annuity, d is the discount rate and n is the years. The present value of any money to be received in the future can be computed by Equation 2. The second is used to calculate the present worth of a single payment, say the replacement of a diesel generator or pump set after ten years for diesel pumping system (Ammar *et al*., 2010).

$$\text{PW of futer cost} = V_{init}(\frac{1}{(1+d)^n}) \qquad (3)$$

Where d is the discount rate and V_{init} is the initial value of the component. Future costs must be discounted because of the time value of money.

Sensitivity analysis is used to determine how the LCC varies from the base case as the key parameters such as conventional fuel cost; discount rates, expected lifetime and solar radiation are changed.

To conduct the greenhouse gas (GHG) emission reduction analysis from the District data that capacity of diesel system replaced by PV pumps, PV peak power and number of PV used, fuel consumption per liter and solar radiation data from NMA of Ethiopia. A solar PV system can only reduce GHG emissions when they are producing electricity that is when the sun is shining, which is only a proportion of the time (Frank, 2014). Based on Denis Lenordic data for CO_2 emission reduction by the top 200 SPV Plants the amount of GHG emissions avoided by an SPV plant is measured in tones and calculated (Naskar and Manda, 2016). To estimate the specific Average annual CO_2 reduction per MWh of electricity produced, for the top 100 SPV apply the CO_2 emission factor to 0.932 tons of CO_2 emission reduction per MWh of electricity produced. The carbon dioxide equivalent is a measure used to compare the emissions from various GHGs based on their global warming potential (OECD Paris, 2001). The amount of electricity generated annually by the solar PV system, E_S (kWh), is calculated using the following equation (Arif, 2012)

$$Es = [N * I * \eta * A] \text{ (KWh/day)} \quad \ldots \quad (4)$$

Where Es is electricity generated, N is no. of Modules Used, A is area of Single Module, η is Efficiency of the Modules and "I" Solar Insolation

$$\text{Actual electricity Output (YA)} = \frac{\text{culated Nominal elc.Output (YC)} * \text{Performance Ratio}}{100\%} \quad \ldots \quad (5)$$

Lastly, the analysis and interpretation of qualitative and quantitative data are integrated to handle the research problem.

4. RESULTS AND DISCUSSIONS

4.1. Demographic and Socio-Economic Characteristics of the Respondent

In the communities, women perform most of the house chores such as the collection of water, washing clothing and cooking for the family, which requires water. In the sample kebeles fetching of water is usually the responsibility of women and youth females. Of the total respondents, 67.8 % and 14.7 % of the sample households fetching water was the responsibility of female youth and women respectively (Table attached in Appendices 4).

The remaining 17.5% reported that fetching water was the responsibility of others (relatives or male youth). Men or husband fetches water only when female youth and women are not able to do so (for example when they get sick). This result is supported by the report of (Short and Thompson, 2003) in many developing countries there is a strong link between gender and water. The result was also consistent with previous work by Tadesse Lencha (2012) that women and young girls are supposed to assume the responsibility of fetching water for household use.

The survey further has been shown that farming is the major occupation of the people indicating 65 %, followed by pastoralists 26 % in the communities within the case study area. The income level of the people in the communities can be seen that most of the inhabitants are poor (84.9 %) that is their average monthly income was less than 56US$ which was below US$1.90 a day World Bank (2017).

4.1.1. Water Supply in Study Area

Regarding water supply situation, the result obtained indicate that the main sources of water in the study areas are ground and surface water, constituting 52.1 % and 38.9 % respectively, while rainwater harvested during rainy seasons constituting only 9 %. Water supply situation in the study communities is seasonal for most people. Respondents were also asked about the purpose of water they use for; almost more than half (76 %) of water used for domestic purposes; only 24 % of them use water for livestock and irrigation purposes.

The amount of water consumed per day was also the other area of interest. Hence, respondents were asked about the average amount of water they use per day for domestic consumption (drinking, cooking, bathing, washing clothes and dishes). Accordingly, the survey finding indicates that the majority of the respondents (39 %) consume 60 or fewer liters of water per day per household which is below the standard stated by WHO (2010). The next great proportion of respondents (38.7 %) consumes 60 to 80 liters per day per household (Table attached in Appendices 4). Whereas, 18.2 % of the respondents reported as their household consumes 80-100 liters of water per day and the remaining 4.1% of the respondents consume more than 100 liters of water per day per household. This may be due to the difference in family size, the level of income and their consumption behavior.

4.2. Reliability of Solar PV Water Pumping System

4.2.1. Solar Water Pumping Facility

The results on the water facilities used within the District and their performance as indicated by the respondents, 84% of the respondents stated that they have mechanized piped solar pumping systems, 9.6% mentioned gravity-fed water system and 7.4% hand-dug well. It has been shown that 81.4% of respondents indicated they have a constant flow of water year-round with solar pumping facilities. The communities agreed (88.2 %) that the stability of water supplies as being a major improvement (Table attached in Appendices 4). This stability or constant flow of water was a result of the large reduction in operational and maintenance challenges and the complete removal of reliance on fuel.

They said “installation of solar pump has made life easier for us since the supply of power was on daily basis, there is constant flow of water, we don’t have to use the unclean water from other sources as was the case when we use to go without water for a number of days as we wait for fuel to be purchased or wait for a mechanic to fix the diesel system”. This result is in line with the report by Foster and Cota (2014) that states they have assessed the reliability of solar pumping systems in the field and have confirmed that it has high survivability, even with little care or no care at all; they will likely run for months or years unattended.

The responses from total respondents, 87.4 % (Appendices 4) of them indicated that the people pay for water they fetch from their solar water pumping facilities while 11.6% indicated they did not (Table attached in Appendices 4). It was revealed from the field that communities did not pay for water from facilities use: rivers, ponds, and streams. Regarding uses of the tariff, respondents believed that the tariff realized from the sale of water is used for repair and maintenance of the facilities 75.2 %, community development 8.2% and others 15.6 %(Table attached in Appendices 4). Similarly, the report by Meah *et al.* (2008) states that the tariff collection is carried out in order to plan for longer-term maintenance issue and extend the constant supply of water to preserve the reliability of the system. Responses on how much the community inhabitant‘s pay for a 20 liter container of water, 38.4 % of the respondents indicated that they pay 0.018US$ while 29.4 % said they pay 0.036US$ and 22.6 % said they pay 0.072US$ for the same quantity of water, this may be the price of water from private tap and public tap varies within the community.

The response from the respondents about who is responsible for the maintenance of water facility illustrates that the maintenance and repairs of the water facilities in the communities are carried out through the rural water committees and District facility team experts; this has been shown with a percentage of 84 %. Clearly this should be expected because the responsibility of management, maintenance, and repairs of the water facilities is vested in the elected rural water committee and District's water facility team experts for each community or kebeles to facilitate constant and reliable supply of water. However, 12.7% of the respondents could not provide any response (Table attached in Appendices 4). The result is similar to the report by Dessalegn Chaine (2012) if water scheme is to be managed efficiently and is to be sustainable, it is important to promote beneficiary participation in the sense that the main stakeholders should be actively involved in the management of water scheme.

The responses about the preference of solar energy for water pumping shows that, most of the respondents 89.2 % (Table attached in Appendices 4) mentioned that they prefer solar energy as a source of power for pumping water. However, 5.9 % of them indicated that they had no idea. The reason why the respondents preferring solar energy as a source of power supplies for water pumping was that those who said they prefer solar energy said the reasons behind their choice are that it was regularly available most of the time and its supply is constant and cheap, in contrast to the high cost of diesel fuel and regular maintenance requirements resulting from diesel water pumping systems they experiencing for over years. This result is in line with (Singh and Mishra, 2015) One of the main advantages of a solar-powered pumping system is its simplicity, constant flow of water, maintenance-free, freely availability of solar and durability. In addition to this (Ramos and Ramos, 2009) In order to provide a reliable water supply, the system must be familiar with the water source and the topography surrounding the source. Those said no 4.9 % provide the reason that during cloud day we had no water supply.

Figure 4.1. Bunata SPV water pumping scheme photo

4.2.2. Result from the Key Informant Interview

As part of the assessment of the reliability for adequate provision and constant supply of water, interview results generate the following core point. From the interview, the study revealed that the respondent is to facilitate the provision of safe drinking water activities, constant supply of water and they generate revenue from the sale of water for repairs of the facility when its failure to operate. Similarly, the study by (Tadesse Chaine, 2012) revealed that concerning financial sustainability, facility user fees were set up by pay based on the amount of water fetched was generally accepted as the best method for generating revenue for maintaining the systems as the interviews said. The whole issue behind applying an appropriate tariff structure is to create a sense of ownership in the community and ensure continued water supply service over time.

According to interviews in the sample kebeles, they experienced several water scheme types such as hand dug well, spring development and motorize scheme for deep well, they mentioned inaccessibility and intermission of water as big challenge predominantly due to the geographic location of their District and other problem. During dry season the District gets high solar radiation due to the geography of the area similarly the demand for water is high at this time, this why solar pumps are preferred by the community there. The result was supported by the report of (Zanab and Sada, 2016) that states solar pumps are most effective during dry and sunny seasons.

When the respondents were to state what they considered to be the strength of the PV system, the response was that: They state as solar PV system is durable, because from the day system was installed and they started using it, they did not face any problem as such unless small maintenance like fitting, get valve other miner issue. They also do not cost for purchased diesel fuel as they do for diesel generator in their water supply power usage, since sunshine is available and free, so that water supply is regular. This result was in concordance with the study by Kaka and Gregoire (2012) that states PV water pumping is found to be well suited for arid and semi-arid areas due to the existence of underground water potential and large solar energy potential. However, on the issues about the weaknesses they found with the PV system, the respondents said: During winter season sunshine was not always available on some days; they suffer a little from irregular water supply from the solar PV pumping system but the influence of these days does not last long, so they said solar is ok.

When the interviewees were asked whether the solar PV has brought any change in their behavior in relation to the use of water, their response was that a lot of changes: modernity, no longer suffer from water related diseases, Long hours spent in search of water from long distances has stopped and the women who normally collect water and who go round searching for water are also relieved. They were now going to school regularly and on time. This result was supported by the study of Foster and Cota (2014) that states the service they receive by the continues flow of water from the solar water pumping system increase the satisfaction of the user and changes their perception towards the reliability of the system. They use more water at relatively lower cost than it used to be when the system was not installed. Some surrounding people also come to buy water from them.

Finally, the respondent was asked if they had any other comments and they responded as solar PV for water pumping was what is good for them. We never use to have any savings before; the revenue collected was never enough to provide for all our monthly needs i.e. fuel purchase, salaries, diesel system servicing, cost of transporting fuel from town. Since the installation of solar pump, we've been able to save the money and support the community development (constructing the road and additional school rooms for student)
They also have recommended the SPV pumping for other communities who are not having access to clean water and they were appealing for help if any, or to advise them as to how they can help those communities and as government and NGOs focused on this issue.

In Generally Solar water pumps contribute to social development in several ways; the use of solar water pumps, therefore, provides a reliable, safe and adequate water supply which improves the community's health and living condition so that SPV pumping system was considered to be reliable source of power for rural water supply in Abaya District.

4.3. Economic Analysis of PV Water Pump System

Economic comparison between PV pumps and diesel-driven generator pump options was compared by considering 25 years of pumping time. The comparison was made by the LCCA method based on the assumption that both pumping systems would satisfy the volume of water required by the user community.

4.3.1. Initial System Costs

Solar PV Pumping System Component Initial Cost[1]: The major elements in the costs of the capital of a PV system of water pumping are shown in Table 4.1 below. The costs of capital for the Bunata site, which include type and rating, quantities, the unit price cost, and the total cost, are all listed in Table 4.1. below. Similarly, for the rest of the water scheme, PV system component initial costs are US$88,308.4 for Samara, US$123,763 for Doqicha, US$73,264 for Lado and US$95,991 for Bore. (Where 1US$ = 27.5 Ethiopian birrs as on 14th oct 2017)

Table 4.1. PV System Initial Costs for Bunata site (prices in US$)

Cost Item	Description	Unit	Quantity	Unit Price	Total Price
1. Solar panels	250	Wp	180	306	55,080
poly-crystalline modules	*SW 250*				
2. Charge Controller	100	A_C	1	408	408
3. Inverter		Number	1	4,444	4,444
Min. operating voltage (V)	*430*				
Maximum input voltage(V)	*750*				
Maximum input current (I)	35				
4. Pump (solar pump)	11.5	kW	1	11,481	11,481
Type of pump	*Submersible*				
5. Water pipes , fittings, Conductors and accessories					19,946
6. Array support Structure					7,407.7
7. Transportation and installation of Equipment cost					11,111
Total cost of system					109,877.7

Source: own computation based on data from Oromia water and energy bureau

[1] Solar pump for Bunata, Samara, Doqicha, and Bore are all installed in 2014 with similar specification model

Diesel Pumping System Initial Cost: The major's elements in costs of capital of a diesel system of water pumping for the Bunata site are shown in Table 4.2. below including all accessories and it comprises the cost of transportation and installation of Equipment cost. Similarly, for the rest of the water scheme system, the Diesel system's initial costs are US$ 66,127.7for, Samara, US$ 68,346.6for Doqicha, US$68,720.1for Bore and US$ 70,201.7 for Lado.

Table 4.2. Diesel System Initial Costs

Diesel system component initial costs for the Bunata site (prices in US$)					
No	Cost Item	Description	Quantity	Unit Price	Total Price (US$)
1	diesel generator	50KVA	1	9,818	9,818
2	submersible pump with switch board	18.5kW	1	10,909	10,909
3	Water pipes , fittings, Conductors and accessories				41,369
4	Batteries	80Ah	1	129.6	129.6
5	Transportation and installation of Equipment cost				4,629
Total cost of system for Bunata					66,855

Source: own computation based on data from Oromia water and energy bureau

From Table 4.1. and 4.2. the initial system costs occur once at the beginning of the project. It comprises the cost of the equipment and accessories, the cost of the installation and the cost of transport. The storage of water, drilling and the system of distribution are ignored in this analysis (since it's identical for both systems). Table 4.1, 4.2. and Figure 4.2 clear that the initial cost of the systems is high with the use of the PV pumping system considerably compared to the diesel pumping systems, this was maybe due to the higher capital costs of the PV pumping system components. This result was in agreement with the report by (Shouman *et al.*, 2016) the fact that the PV costs decrease with the increase of its efficiency, one can consider the great advantages of using this kind of energy in the future. The capital cost of the solar PV water pumping system can be considered as the major barrier for the application of the system in a developing country like Ethiopia (Misrak Girma, 2016).

4.3.2. Operation Costs

PV System Operation Costs: PV system operational costs include on-site guards and laborers for cleaning the modules and regular component checks. The life cycle operational cost of a PV system assumed to be US$0.49/Wp Goodrich *et al*. (2011) for ground-mounted panels. But in this work, the life cycle cost of US$0.2/Wp is to be considered for available manpower and skill needed based on system distribution and local labor costs at the study area. Considering, the total size of 250Wp of PV panels used at each water scheme, a total operational cost for the PV system during the 25 years of operation period is shown in Table 4.3. The study may be not in line with study by (Misrak Girma *et al*., 2015) that follows the assumption PV operation cost (1%) of its capital cost. This is maybe due to variation of the labor cost from place to place and the capacity or how large the distribution system at the location.

Table 4.3. Operational Cost for the PV Alternative

Site name	operational cost for the PV(US$/year)
Bunata	9,000
Samara	6,000
Doqicha	11,000
Bore	7,000
Lado	4,000
Average	7,400

Source: own computation based on data from district water and energy office

Diesel Pumping System Operation Costs: The main source of cost for the diesel system operation is diesel fuel. The life cycle fuel consumption was calculated by summing the consumptions of all years of the study period (25 years). The pricing of fuel costs should be made on present worth bases using the discount rate d = 10 % in the time value of money. Then, to calculate the present worth (PW), each fuel consumption period should be considered separately and its fuel costs are to be reduced to the present worth by using equation 2, For example, the calculations for Bunata the annual cost of fuel at the current diesel cost US$0.87/liter is given by:

- $ACF = C_f * H_O * F_d * 365$

Where

ACF is Annual cost of diesel fuel,

H_o is the operating hours of the diesel generator,

C_f the diesel cost per liter provides to the site and

F_d (l/h) is the estimated average consumption of diesel[2] .

=0.87US$/l*6h*3l/h*365=5,715.9US$

To calculate the present worth of total fuel cost on the lifetime of the system using equation 2

=5,715.9US$(9.0789)

=51,894.08451$ for 25 years of operation at Bunata scheme

Similarly, for the rest of water schemes, costs of diesel for the whole 25 year operation period are shown in Table 4.4. The result was in line with the study by (Chandel *et al.*, 2015), (Misrak Girma *et al.*, 2015) and (Ammar *et al.,* 2010).

Table 4.4. Operational Cost for the Diesel System

Site name	operational cost for the diesel system(US$)
Bunata	51,894.084
Samara	86,490.142
Doqicha	86,490.142
Bore	103,788.16
Lado	103,788.16
Average	86,490.14

Source: own computation based on data from district water and energy office

[2] For the generators approximated General Fuel Consumption Chart, (Worldwide Power Products 2012) can be used as a reference available on appendices II

As shown in Tables 4.3. and 4.4. the operation cost of diesel water pumping system is quite large which is 86,490.14 US$ on average compared to 7,400 US$ for PV water pumping system this is mainly due to high fuel cost and its associated high fluctuations. This is likewise explained by Guda and Aliyu (2015).Similarly, the report by Odeh *et al.* (2014) states that the Diesel pumping system has the highest operating cost while solar PV has the lowest operating cost comparatively.

4.3.3. Maintenance and Repair Costs

PV System Component Maintenance and Repair Costs: For this study, maintenance and repair costs for a PV system was predictably taken as 12 % of operational costs for the whole life cycle based on the available distribution system on the site, which was calculated and shown in Table 4.5. for each water scheme. Similarly According to the report by Hansen *et al.* (2005), Maintenance and repair costs for a PV system can usually be estimated as 10–15 % of the operational costs for the whole life of the PV system.

Table 4.5. PV System Maintenance and Repair Cost

Site name	Maintenance and repair costs(US$)
Bunata	1,080
Samara	720
Doqicha	1,320
Bore	840
Lado	480
Average	888

Diesel Pumping System Maintenance and Repair Costs: Based on the data from district senior experts, the amount and costs of preventive-maintenance materials are listed under Table 4.6. The estimated diesel system maintenance cost was multiplied by 30 % to compensat e for spare parts that would be necessary for repairs and overhauls along with manpower relate d to maintenance work. This result is similar with the report presented by (Ebaid *et al*. 2013) and (Chandel *et al.*, 2015). Taking the Bunata site as a sample to calculate the maintenance and repair cost, including the 10% discount rate the results is shown in Table 4.6.

Table 4.6. Costs of Preventive Maintenance Material for Diesel Pumping System for Bunata water scheme

Item	No. Of changes/year	Q/change	Price/item	Cost/year(US$)	Cost/25 years (US$)
Engine O[3]	12	12L/change	5	655	16,375
O and fuel f	2	1 set/change	40	73	1,825
Coolant	2	1 L/change	15	27.3	683
Air f	2	1 piece/change	20	36.4	910
Batteries	Once Per 2 years	1 piece/change	129.6	59	1,475
Sub total					21,268
Total cost (US$) for Bunata water scheme= Maintenance cost + Spare parts costs (21,268×30%)= US$27,648.4					

Source: Own computation based on data collected from senior experts of Abaya district water facility team

Table 4.5. shows that since the PV water pumping system has no moving parts, the water reservoir is used to store water instead of battery that is Eliminating battery from the system eliminates most of the maintenance costs as a result, PV pumping system was highly reliable and low maintenance cost. In contrast, the diesel pumping system requires regular maintenance services listed in Table 4.6. This result was in agreement with those of (Ahmad *et al.*, 2015) diesel system has several components that must be repaired periodically as fuel, lubricants and water separator filters. Lubricating and cooling fluid should be repaired periodically with a certain frequency. Similarly, Asefa Kabade *et al.*

[3] Where O=oil, f= filters and Q= Quantity

(2013) report that PV maintenance cost for pumping system is more economical than the diesel pumping system.

4.3.4. Replacement Costs

PV Component Replacement Costs: The system inverter and pump would be replaced once in the 15th years. The photovoltaic panels would not require replacement during the system lifetime since their expected life is 25 years. Major PV system components that could be considered for the replacement costs include inverters and pumps so that the life of inverters and pumps is usually taken as 10–15 years (Hansen *et al*., 2005). Table 4.7. shows the result of all schemes in present worth considering a discount rate of 10% for both solar pump and inverter using equation 3.

Table 4.7. PV Component Replacement Cost

Replaced component	Site name									
	Bunata		Samara		Doqicha		Bore		Lado	
	Q[4]	Cost	Q	Cost	Q	Cost	Q	Cost	Q	Cost
Solar P	1	2,748.5	1	2,660	1	2,748.5	1	2,748.5	1	2,660
Inverters	1	1,063	1	975.3	1	1,063	1	1,063	1	975.3
Total		3,811.5		3,635		3,811.5		3,811.5		3,635
Total replacement costs in average (US$) 3,740.9										

Source: own computation based on data from Oromia water and energy bureau

Diesel Pumping System Replacement Costs: For this alternative, a generator and pump would probably need to be replaced by a new one every 10 years based on the weather conditions of Abaya District and expert's experience, Table 4.8. shows the result of all schemes in present worth considering a discount rate of 10% for both water pump and generator. Generators lifespan or maximum working hours depend on how well the engine is being maintained and the surrounding weather conditions, and it is strongly recommended the generator and pump should be replaced after 10 years of continuous duty

[4] Q= Quantity , P=Pump

based on weather conditions, to ensure the reliability of the Diesel System parts, Arif *et al.* (2010).

Table 4.8. Diesel System Component Replacement Cost.

Replaced component	Site name									
	Bunata		Samara		Doqicha		Bore		Lado	
	Q[5]	Cost	Q	Cost	Q	Cost	Q	Cost	Q	Cost
Pumps	2	5,827.5	1	3,787.9	1	4,661.78	1	4,661.78	1	5,438.5
Generator	2	5,244.7	1	5,438.5	1	5,438.5	1	5,827.5	1	5,827.5
Total		11,072		9,226.4		10,100.3		10,489.3		11,266
Total replacement costs in average (US$) 10,431										

Source: own computation based on data from Oromia water and energy bureau

Replacement costs are anticipated expenditures to major system components that are required to maintain the operation of a facility. As shown in Table 4.7. and Table 4.8. the replacement costs of diesel water pumping systems are higher than that of solar water pumping since inverter and pump replaced once throughout the life cycle for solar PV and twice for diesel water pumping system. This result is in agreement with the study by Narale *et al*. (2013) who report that the replacement cost of diesel water pumping system was really high compared with solar water pumping system costs. This is maybe due to the short life span of diesel pumping system components.

Final LCCA Summary for Power Alternatives: Once all pertinent costs have been established and discounted to their present value, the costs can be summed up to generate the total life cycle cost of the system alternative by applying Equation 1 for both the PV and diesel system alternative to yield the results listed in Table 4.9.

[5] Q=quantity

Table 4.9. Final PV and Diesel System LCC Values of each Water Scheme in Present Worth (US$)

Costs (US$)	Site name									
	Bunata		Samara		Doqicha		Bore		Lado	
	PV[6]	DS	PV	DS	PV	DS	PV	DS	PV	DS
IC	109,877	66,855	90,778	66,854.6	122,118	63,399.6	97,638	65,035.6	79,119.7	67,217.6
OC	9,000	51,894.1	6,000	86,490.14	11,000	86,490.1	7,000	103,788	4,000	103,788.1
MC	1,080	27,648.4	720	27,648.4	1,320	27,648.4	840	27,648.4	480	27,648.4
RC	3,811.5	11,072	3,635	9,226.4	3,811.5	10,100.3	3,811.5	10,489.3	3,635	11,266
LCC	123,769	157,469	101,133	190,219.5	138,250	187,638	109,290	206,961	87,234.7	209,290.1

Table 4.9. summarizing the final results of the LCC analysis of each alternative, Figure 4.2. combines those results in Table 4.9. to simplify the comparison. It's clear from Table 4.9. that the PV pumping system has a higher initial cost than the diesel-powered pump but its recurrent cost (Operations, Maintenance and Replacement Cost) proved to decline over their initial cost. However, aspects such as lower operation, maintenance costs and Replacement Cost of PV systems, could economically justify the higher initial cost of PV systems. In contrast the replacement, maintenance and operation cost of diesel systems are higher than the PV system. Similarly the study by (Kolhe *et al.*, 2002) reported that this shift in the crossover occurs because of the nature of the PV and diesel system cash flows, in terms of recurring vs. capital costs. Moreover, if it is considered that fuel prices are increasing, these numbers could keep going up. The bar chart in Figure 4.2. shows that the operation cost of the diesel system was really high compared with other costs within the system such as initial, maintenance as well as replacement cost.

The total average cost of all five schemes for both systems throughout the 25 years life cycle was shown in Table 4.10. Generally, the result in Table 4.10. clearly shows that the

[6] PV= photovoltaic, DS=diesel system, IC=Initial Cost, OC= Operations Cost, MC= Maintenance Cost, RC=Replacement Cost

average LCC of systems concerning the economy, the overall PV water pumping system is cheaper than diesel water pumping system this implies that the PV pumping system was economically viable than diesel system in the study area. The result is supported by the report presented by Shouman *et al.* (2016) which state that the running cost of the PV systems is almost very low compared to diesel system which leads to an optimum cost of operation and maintenance.

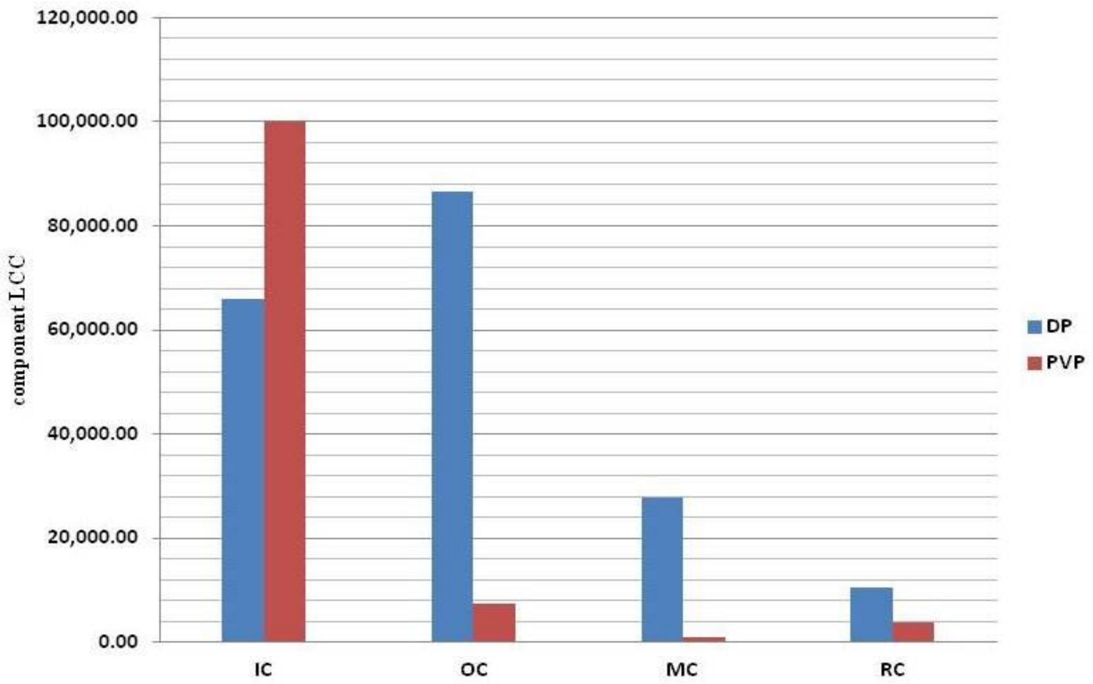

Figure 4.2. LCC Summary for Power Alternatives

Table 4.10. Final Average LCC Summary

Power alternative	Average LCC(US$/25 years)
PV pump system	111,935
Diesel pump system	190,316

4.3.5. Sensitivity Analysis

The sensitivity analysis is conducted to identify parameters which have a major impact on the results presented in section 4.3 and therefore qualify the results shown accordingly. The sensitivity analysis assesses the impact on variations of the following parameters

- Discount rate: 7%, 10% (reference case) and 13%.
- System life: 20 years, 25 years (reference case) and30 years.
- Diesel price inflation rate: 0 %(reference case), 2.9% and 5%.

Discount Rate: The sensitivity to changes in the discount rate is shown in Figure 4.3. A lowering of the discount rate from the reference case results in higher LCC as future values are reduced to a lesser extent. The diesel system shows a higher sensitivity to changes in discount rate. This is to be expected since most of the costs of a diesel pumping system are the future costs which are therefore, more affected by the discount rate than the solar PV option with higher upfront costs. Actual changes in the discount rate over the system will therefore; impact more significantly on the LCC of the diesel system than on the LCC of the solar PV. This result was in agreement with the study by Asefa kebede *et al.* (2013) and (Ebaid *et al*., 2013) which state that the discount rate would make a crucial difference to the LCC analysis of the system alternative.

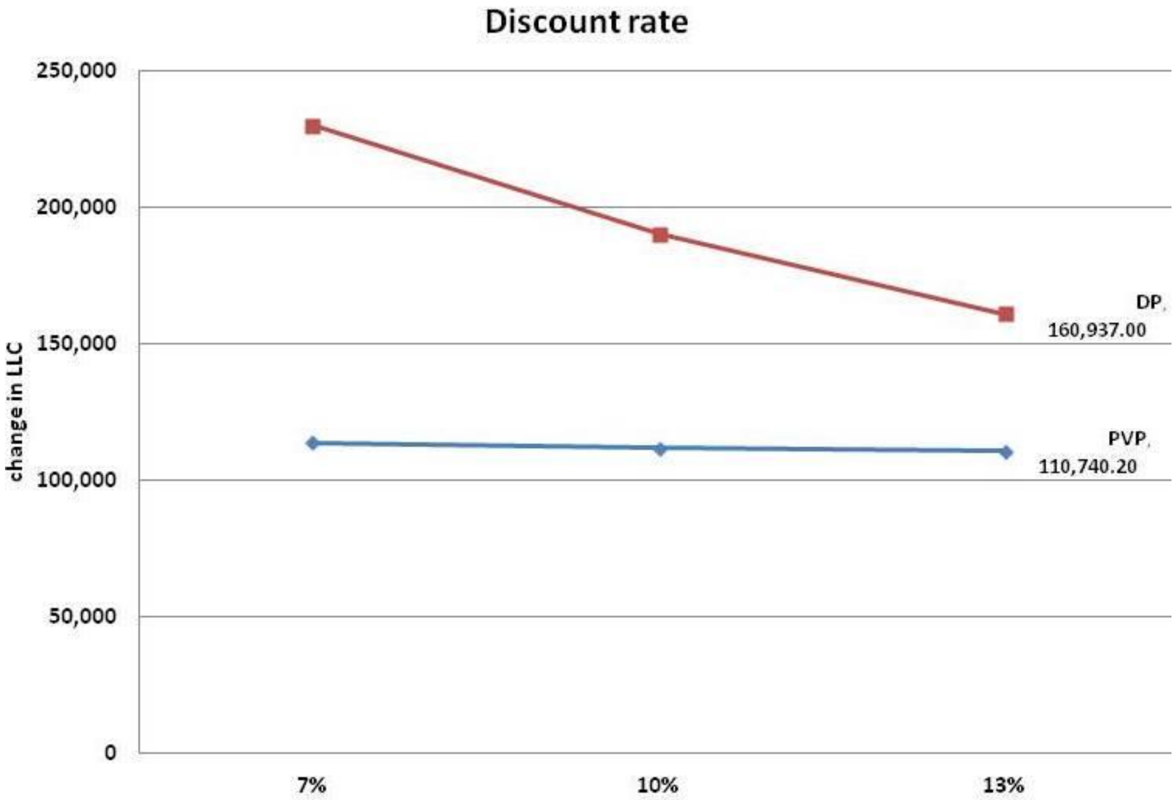

Figure 4.3. Sensitivity Analysis of Discount Rate

System Life: The sensitivity to system life follows the same reasoning as the discount rate. As shown in figure 4.4. a shorter the water pumping system life will reduce the costs of a diesel pumping system more significantly due to lower accumulated operating, maintenance and replacement costs, in contrast, longer system life to 30 years have less impact on the LCC of diesel pumping system as the result of the absent in replacement costs of generator and pump in this phase. The solar PV however, is less affected by changes in the system life than the diesel system since the major solar PV cost was capital cost. These result was in line with the study by Asefa kebede *et al*. (2013) and Setiawan *et al. (* 2015) who reported that the LCC of diesel system was highly affected by operation, maintenance and replacement cost in contrast to solar PV system.

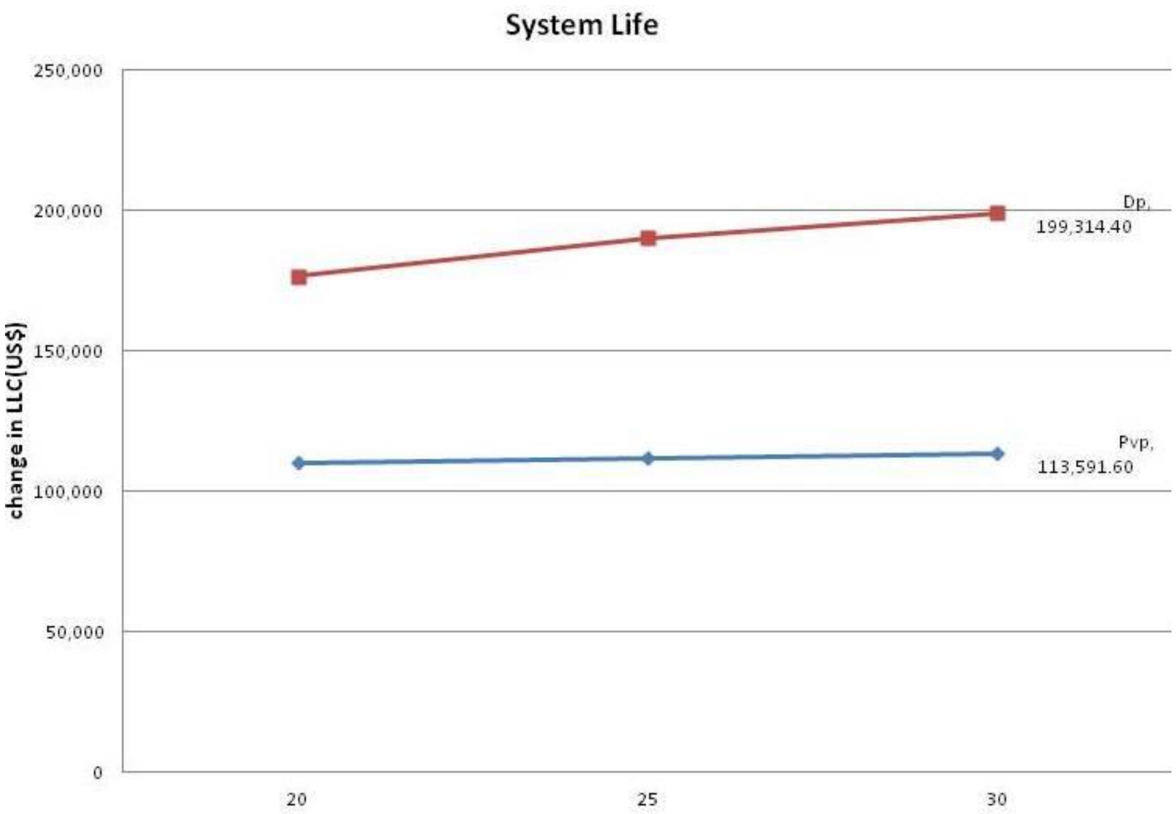

Figure 4.4. Sensitivity Analysis of System Life

Diesel Price Inflation Rate: The sensitivity analysis for diesel price inflation is shown in Figure 4.5. The diesel price fluctuates in Ethiopia, trend shows 8.4% in 2015, 10.7% in 2016, 15.6% in 2017 and 17.9 in 2019 (MOM, 2019). Asefa Kabade *et al*. (2013) reports that due to the instability of oil producing counties the diesel price was increased in Ethiopia by 22% only in three months(2012), which is 7.3% per month on average. Figure 12 illustrate what will happen if the current price of the fuel was increased in the coming life cycle of the systems by different percentage by taking the 0% diesel price inflation rate as a reference from the result presented in Table 4.4. As shown in Figure 4.5. the LCC of diesel system was highly sensitive to variations in the diesel price inflations. The LCC of the solar PV is slightly affected due to the costs associated with inspection trips. The transports are all linked to the diesel price and therefore the changes in diesel cost will impact on the transport costs. This result is in agreement with the study by Asefa Kabade *et al*. (2013) that states the life cycle cost of water pumping system was sensitive to price infilation of diesel that cause high annual operation and maintenance cost to diesel generator. The steady increase in cost of diesel prices over the years and decrease in PV system component costs make PV pumping attractive from economic perspective (Foster and Alma, 2014). The result further supported by the report presented by Kolhe *et al.* (2002) that reports the cost of diesel is highly subsidized, if the governments were to remove the subsidy at the consumer end, the cost of diesel would increase and the PV system would become more attractive.

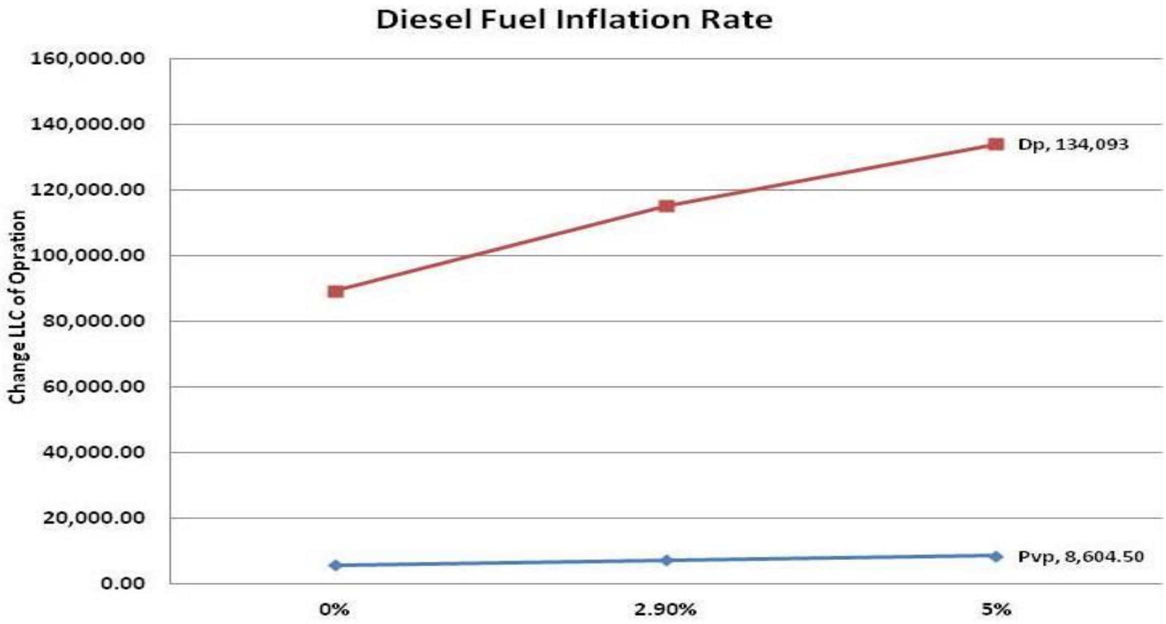

Figure 4.5. Sensitivity Analysis of Diesel Inflation Rate

4.4. Greenhouse Gas Emission Reduction Potential of Solar PV

The reduction of CO_2 by the Solar Photovoltaic pump system installed in sampled rural kebeles has been compiled 185kWp (Appendices 2) standalone PV for solar pump was established at the sampled kebeles of Abaya district. To find out the solar potential available at Abaya, reading of solar radiation for the site was taken from the Ethiopian NMA. The geographical coordinates of the site is:

- ✓ Latitude: 04621845 N, Longitude: 0702965 E
- ✓ No. of Modules (N) Used at Bunata water scheme (Each of 250W_P) = 180
- ✓ Area of Single Module (A) = 1.609498 m2
- ✓ Efficiency of the Modules (η) = 15%

Let Solar Insolation be "I"

- Therefore energy generated by the PV system = [N * I * η * A] (KWh/day)

The Table 4.11 shows the monthly solar insolation data from Ethiopian NMA and calculated energy generated by SPV.

Table 4.11. Monthly Solar Insolation and the Calculated Energy Generated by Solar PV of Bunata water scheme.

Months	Solar Insolation in KWh/m2/day	Energy Generated (KWh)
January	8.40	65,706
February	8.52	66,646
March	8.40	65,703
April	6.48	50,685.9
May	5.35	41,847
June	4.64	36,293.6
July	4.53	35,433.2
August	5.93	46,383.8
September	6.05	47,322.5
October	6.20	48,495.8
November	7.75	60,619.7
December	7.67	59,993.9

Source: own computation based on data from National Metrology Agency

Performance Ratio (depending on the site, technology and sizing of the system) loss factors are given as follows (Tiwari, 2008) and (Arif, 2012).

- Dust loss factor = 3%
- PV loss due to irradiance level = 3.2%
- PV loss due to temperature = 5% to 15%
- Module Quality Loss = 1.5%
- LID (Light Induced Degradation) = 2%
- Module Array Mismatch Loss = 1%
- wiring loss = 0.3%
- Inverter Loss during operation (efficiency) = 4.7%

We get Performance Ratio (PR) of the system = 76%

$$\text{Actual scheme Output (YA)} = \frac{\text{culated Nominal scheme Output (YC)} * \text{Performance Ratio}}{100\%}$$

Therefore, Actual scheme Output (Y_A) = 475,098.8KWh

So, we can say actual yearly output of Bunata water scheme = 475,098.8KWh

Since, the life span of the PV panel to be 25-years. Thus total energy generated in 25-years by this scheme = 11,877MWh. Similar to the above sample calculations was performed for the rest of four water scheme and total energy generated for all water scheme in 25-years period is 44,098MWh.

CO_2 Reduction: Average annual carbon emission reduction per MWh of electricity produced can be performed as follow. Carbon Dioxide reduction by Solar Photovoltaic Power Plants installed all over the world has been compiled by Denis Lenordic. Data for Carbon Dioxide emission reduction by the top 200 Solar Photovoltaic Power Plants are available at http://www.pvresources.com/en/top50pv.php. The data available includes power produced per annum in MWh, annual carbon emission reduction. Average annual carbon emission reduction per MWh of electricity produced and emission reduction per annum for which are available, comes to 0.932 tons of carbon dioxide emission reduction per MWh of electricity produced (Naskar and Mandal, 2016). Similarly Substituting diesel generator by PV system could avoid 0.85–1 kg CO_2/kWh being emitted (Krauter and Ruther, 2003). Taking this average value of 0.932 tons of carbon dioxide emission reduction per MWh of electricity produced for the SPV pump installed in Abaya. The carbon dioxide emission reduction for Bunata scheme = 0.932tons/MWh* 11,877MWh = 11,069tons of CO_2/25 year. Total carbon dioxide reduction for all water schemes in 25 years = 41,099tons. The higher the energy generated by the PV system the greater the amount of emissions reduced per MWh of the generated energy. This result is in line with the result by (Frank, 2014) and (Zenab and Sada, 2016) Solar PV system can reduce GHG emissions of the overall generation system when they are producing electricity, that means when the sun is shining, which is only a proportion of the time.

Replacing solar water pumps with diesel generated pump have convinced climate related benefits. Over 1,825,000 liters of diesel fuel have been saved throughout life cycle operation of the system. Not only has this but diesel fuel involved in transportation for inspection trip also saved. The elimination of indicated CO_2 emissions during the operation period for all water schemes of sample kebeles of Abaya has a huge positive influence on the environment. The reduction of environmental costs by reducing contamination has much importance and it eventually gives a great advantage of using renewable energy over conventional types of energy. Extensive use of solar water pumps would therefore lead to substantial greenhouse gas emission reductions. Thus when this system implemented on all off-grid rural areas surely considerable amount of co_2 emission has been eliminated throughout the country. Similarly the study by (Zenab and Sada, 2016) shows that diesel water pumps emits more greenhouse gas that increase the atmospheric temperature, with adverse consequences for components of the climate and finally cause global warming but no emissions are associated with the operation of solar water pumps itself.

5. CONCULITION AND RECOMMENDATIONS

5.1.Conclusion

The study focuses on the viability and reliability of solar water pumping system and its emission reduction potential in rural areas of Abaya District west Guji Zone of Oromia. The reliability of solar water pumping systems for domestic water supply in rural kebeles was assessed by taking 188 households randomly and 25 Key Informant Interviews respondents. It was clear from the study that solar water pumping technology was found reliable, easy to operate by less skilled persons, it should require no fossil fuel and has very little maintenance which match the characteristics of rural community so that, using solar water pumping system increases the satisfaction of inhabitants in the study area.

Life cycle cost method was used for economy evaluation of solar water pumping system with diesel pumping system and show that there are very distinct differences between the two power sources in terms of cost. The average initial cost (99,906 US$) of solar water pumping system was found higher than that of diesel water pumping system (65,873US$) but its recurrent cost proved declining over in progress. The operation, replacement, repair and maintenance cost are higher for the diesel pumping system in contrast to solar pumping system, and it was considered that the result from sensitivity analysis show that the key parameters such as discount rates and fuel price inflation rate has significantly impact on the LCC of the diesel pumping system than solar pumping system, this is as a result of, most of the costs of a diesel pumping system are the future cost. Therfore, PV water pumping systems was found economically viable and attractive technology chooses than diesel water pumping systems in all sampled Kebeles of Abaya District. Further, the potential contribution of solar water pump towards emission reduction was determined. The result shows over 1,825,000 liters of diesel fuel have been saved and 41,000 tons of

CO_2 emissions have been eliminated throughout life cycle operation of the system. CO_2 emissions can be greatly reduced through the use of solar water pumping system, which was already cost effective with fossil fuels in many situations. Thus PV water pumping systems are an environment friendly alternative source of energy.

Generally solar water pumping systems are strictly reliable for domestic water supply application, economically viable compare to diesel water pumping system and consequently beneficial for the environment in the rural areas of Abaya District.

5.2. Recommendations

The research has examined the viability and reliability of solar water pumping system and its emission reduction potential in rural Kebeles of Abaya District. Based on the findings of the research, the following recommendations were forwarded: -

- ❖ However, because of the high initial cost of the system and the fact that people in such rural locations are usually low income earners, they should not be expected to pay for their off-grid electricity supply systems. The provision of capital subsidies is imperative and hence enough grant fund must be mobilized by the government, NGOs and development partners to create the PV infrastructure while the beneficiary communities must also be willing to pay realistic water tariffs to enable operational cost recovery in order to prolong the reliability of the system.
- ❖ It is also recommended that solar pumping system should be implemented in all off-grid areas if possible. It would be better for the spare parts supply, as solar pumping equipment cannot be purchased everywhere in the country yet. Maintenance and repair of the pumps would then also have lower costs as there would be less need to travel between the schemes.

- Government policies and program on energy that takes renewable energy (particularly solar PV) technologies into consideration must be coherent and properly coordinated in order to create a favorable and enabling environment for easy implementation of such policies to promote technology of the PV water pumping system.
- **Further study:** The researcher recommends further study on the role of PV powered water pumping systems for livestock and agriculture applications in rural locations with limited access to conventional electricity.

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APPENDICES

Appendices 1: Questionnaire for Sample Household Survey and Key Informant Interview

Questionnaire for sample Household survey on the viability and reliability of solar photovolt aic pumping system and its emission reduction potential for rural water supply in Abaya District west Guji Zone of the Oromia Region

Note that:

- All your responses will be held confidential;
- Your name will not be written on this form;
- Feel free to ask any question you may have about the questionnaire;
- You have the right to obtain information about the findings of the research.

Your genuine participation by responding patiently to the questionnaire is highly appreciated and thanks you for giving your time and willingness to participate in filling this questionnaire.

Name of kebele____________________

Name of data collector ___________________

This questionnaire has been designed to elicit relevant information on the use of solar energy to pump water for rural resident in Abaya kebeles.

Please tick (√) the option that fits your views; where appropriate write down your view.

A) DEMOGRAPHIC INFORMATION

1. Community: ……..
2. Name of Respondent (Optional): …………..
3. Gender: Male [ ] Female [ ]
4. Age: i) 16-19 yrs. [ ] ii) 20 -26 yrs. [ ] iii) 27 years and above [ ]
5. Level of education: i) illiterate ii) elementary School [ ] iii) High School [ ] iv) college diploma [ ]
6. Marital Status: i) Married [ ] ii) Single [ ] iii) Divorced [ ] iv) Widow [ ]

B) GENERAL INFORMATION

7. What is the major occupation for people in your community? i) Farming [ ] ii) pastoralist [ ] iv) Fishing [ ] v) Trading [ ]

8. Which categories of people usually go out to fetch water for domestic use? (Please you may choose more than one) (i) Female youth [ ] (ii) Male youth [ ] (iii) Women [ ]   (iv) Men [ ]
9. What is the level of your monthly expenditure? --------------------------
10. What is the main sources of water in your area i) ground [ ] ii) surface water iii) rain water harvesting
11. Do you get enough water all year round including dry season? Yes [ ] No [ ]
12. What do people in your household use water for? (i) Domestic (i.e. cooking and washing) [ ], (ii) livestock [ ] (iii) irrigation [ ]
13. How much quantity of water do you use per day for domestic consumption? (i) 60l/day [ ] (i) 60-80l/day [ ] (iii) 80-100l/day (iv) more than 4
14. Water supply facility for drinking in your community. Please you may choose more than one. (i) Dam [ ] ii) Borehole [ ] iii) Hand-dug well [ ] iv) Stream / River [ ] v) mechanized Piped solar pump [ ] vi) others, please specify …………..
15. Is the water facility stated in Q14 are all functional? Yes [ ] No [ ].
16. Are you using solar pumping water supply facility? i) Yes [ ]. ii) No [ ].
17. Do you get enough water supplies all year round with solar pumping facility? i)Yes [ ] ii)No [ ]   iii, No response [ ]
18. Has this changed before and after the new system was installed? Yes [ ] No [ ] If so or yes, why?
19. Do you pay for the water you use? Yes [ ] No [ ]. No response [ ]
20. How do you pay for the water? Using the new system (solar PV) (i) Fixed monthly levy [ ] (ii) Pay the amount you fetch [ ] (iii) we don't pay for solar PV v) No idea [ ]
21. How much is the water sold per 20 liter container? i) 50cent [ ] ii) 1birr [ ] iii) 2 birr [ ] iv) no idea [ ]
22. What does your community use the water tariff (i.e. the money collected) for? i) Maintenance/Repairs [ ] ii) Personal gains [ ] iii) Community development [ ] iv) Bills payment [ ] v) Treatment of water [ ] vi) No idea [ ]

23. In your opinion, who maintains the facility? i) Community [ ] ii) kebele manager [ ] iii) water committee [ ] iv) District facility team [ ] iv) No response [ ]
24. Do you know the source of power for your water supply? Yes [ ] No [ ]
25. If yes, what is the source of power for your water supply? (i) Generator [ ] (ii)National Electricity [ ] (iii) solar iv, Others, please specify …………………
26. How regular is the power supply to the water facility? (i) Daily [ ] ii) Weekly [ ] (iii) Daily but intermittently
27. Would you like to use solar power for your water supply needs? Yes [ ] No [ ] don't know [ ].
28. Reasons for Preferring Solar Power for Water Pumping?

    ____

Thank you very much for your time and participation

2. Interview Guide

This interview guide was designed to elicit relevant data from Water Rural Committee in the Community, kebele representative and senior experts in the District and zone water and energy office

1. What kind of support do you normally give to beneficiary communities as water committee/expert?

2. How do communities fund operation, maintenance and repair costs?

3. What is the source of power for supply of your water in your kebeles?

4. What are major constraints in the provision water to rural communities?

5. What do you feel are the strengths of the pumping system?

6. What are the weaknesses of the pumping system?

7. How do you think the weaknesses you have identified could be addressed?

8. If yes, what are these and why might they be better?

9. Do you think there are better sources of energy for pumping water?

10. How regular is the power supply to the water facility?

11. In your view are communities managing their water facilities in a sustainable way?

12. If yes, give reason, if no give reasons

13. Has the solar water pumping system brought any change in your behavior in relation to the use of water? Give details:

14. Would you like to use solar power for the rural water supply needs?

Q: Can you give reasons for your answer given in above?

Q: What recommendations would you make towards the sustainability of community rural water systems in your district?

GENERAL COMMENT

Do you have any other comments about the solar water pumping system?

Appendices 2: **Data to Evaluate Economic Viability of Solar Water Pumping System**

i, Diesel system component costs

Diesel system component costs (prices in USD)				
	Generator			
Site name	Quantity	capacity	Unit price	Total cost
Bunata	1	30kv	9,818	9,818
Samara	1	40kv	10,181	10,181
Doqicha	1	40kv	10,181	10,181
Bore	1	50kv	10,909	10,909
Lado	1	50kv	10,909	10,909
	Submersible pump kw			
Site name	Quantity	Capacity	Unit price	Total cost
Bunata	1	18.5kw	10,909	10,909
Samara	1	7.2kw	7,091	7,091
Doqicha	1	10.5kw	8,727	8,727
Bore	1	10.5kw	8,727	8,727
Lado	1	21.5kw	10,181	10,181
	Battery			
Site name	Quantity	capacity	Unit price	Total cost
Bunata	1	80Ah	129.6	129.6
Samara	1	80Ah	129.6	129.6
Doqicha	1	80Ah	129.6	129.6
Bore	1	80Ah	129.6	129.6
Lado	1	80Ah	129.6	129.6

ii, PV component costs

PV component costs (prices in USD)				
	PV panels			
Site name	Quantity	capacity	Unit price	Total cost
Bunata	180	250Wp	306	55,080
Samara	120	250Wp	306	36,720
Doqicha	220	250Wp	306	67,320
Bore	140	250Wp	306	42,840
Lado	82	250Wp	306	25,092
	Submersible pump			
Site name	Quantity	capacity	Unit price	Total cost
Bunata	1	11.5kw	11,481.5	11,481.5
Samara	1	7.5kw	11,111	11,111
Doqicha	1	11.5kw	11,481.5	11,481.5
Bore	1	11.5kw	11,481.5	11,481.5
Lado	1	7.5kw	11,111	11,111
	Charge controllers			
Site name	Quantity		Unit price	Total cost
Bunata	1		408	408
Samara	1		402	402
Doqicha	1		512	512
Bore	1		396	396
Lado	1		385	385

Inverters			
Site name	quantity	Unit price	Total cost
Bunata	1	4,444	4,444
Samara	1	4,074	4,074
Doqicha	1	4,444	4,444
Bore	1	4,444	4,444
Lado	1	4,074	4,074

iii, Estimated quantities and costs of preventive maintenance material for diesel system for each sampled kebeles

Item	No of changes/year	Quantity/change	Price /item (US$)	Cost/year (US$)	Cost/study period(US$)
Engine oil		________L/change			
Oil and fuel Filters		________set/change			
Coolant		________L/change			
Air Filters		_______Piece/change			
Battery		_______Piece/change			

IV, Parameters

some parameters that will be used in the LCC	
discount rate (d)	10%
Inflation rate	2.9%, 5%
Lifetime of the PV system (Years)	25
Module efficiency	15%
Lifetime of the diesel system (Years)	10
Fuel Cost ($/L)	0.87

V. charts for fuel consumption versus the load factor

Generator Size (kW)	1/4 Load (gal/hr)	1/2 Load (gal/hr)	3/4 Load (gal/hr)	Full Load (gal/hr)
20	0.6	0.9	1.3	1.6
30	1.3	1.8	2.4	2.9
40	1.6	2.3	3.2	4.0
60	1.8	2.9	3.8	4.8
75	2.4	3.4	4.6	6.1
100	2.6	4.1	5.8	7.4
125	3.1	5.0	7.1	9.1
135	3.3	5.4	7.6	9.8
150	3.6	5.9	8.4	10.9
175	4.1	6.8	9.7	12.7
200	4.7	7.7	11.0	14.4
230	5.3	8.8	12.5	16.6
250	5.7	9.5	13.6	18.0
300	6.8	11.3	16.1	21.5
350	7.9	13.1	18.7	25.1
400	8.9	14.9	21.3	28.6
500	11.0	18.5	26.4	35.7
600	13.2	22.0	31.5	42.8
750	16.3	27.4	39.3	53.4
1000	21.6	36.4	52.1	71.1
1250	26.9	45.3	65.0	88.8
1500	32.2	54.3	77.8	106.5
1750	37.5	63.2	90.7	124.2
2000	42.8	72.2	103.5	141.9
2250	48.1	81.1	116.4	159.6

Appendices 3: Data to Determine the Potential Contributions of Solar Water Pump Towards Emission Reduction.

1 Data for CO_2 Emissions Calculations

Diesel pumping CO2 emissions	
diesel fuel consumption (l/y)	
diesel cost ($/l)	0.87$
Area of Single Module	1.609498 m2
Efficiency of the Modules	15%

2 solar radiation data from Ethiopian national metrology agency

Name	Elevation	Geogr1	Geogr2	element	Year	Month	1	2	3
Abaya									
Abaya									
Abaya									
Abaya									
Abaya									
Abaya									
Abaya									
Abaya									

Appendices 4: Result From SPSS for HH Survey

who fetch water for domestic use					
		Frequency	Percent	Valid Percent	Cumulative Percent
	Female youth	127	67.8	67.8	
	Women	28	14.7	14.7	
	Male Youth	21	11.3	11.3	
	Men	12	6.2	6.2	
Valid	Total	188	100	100	
Occupation of Community					
	Farming	122	65	65	
	Pastoralists	49	26	26	
	Trading	13	7	7	
	Fishing	4	2	2	
Valid	Total	188	100	100	
Main Source of Water					
	ground	98	52.1	52.1	
	surface water	73	38.9	38.9	
	rain water harvested	17	9	9	
Valid	Total	188	100	100	
purpose of water they use for					
	domestic	143	76	76	
	livestock	34	18	18	
	Irrigation	11	6	6	
		188	100.0	100.0	
water consumed per day per HH					
	60l/day	73	39	39	
	60-80l/day	73	38.7	38.7	
Valid	80-100l/day	34	18.2	18.2	

	>100l/day	8	4.1	4.2	
		188	100	100	
Do you pay for Water?					
Valid	Yes	164	87.4	87.4	
	No	22	11.6	11.6	
	Non Response	2	1	1	
	Total	188	100	100	
Does solar PV supply constant water year round					
	Yes	166	88.2	88.2	
	No	12	6.6	6.6	
	Non Response	10	5.2	5.2	
	Total	188	100	100	
Does solar PV water bring any change in your living/behavior					
	Yes	148	78.9	78.9	
	No	9	4.5	4.5	
	Non Response	31	16.6	16.6	
	Total	188	100	100	

Why do you pay? What is the water tariff used for?					
	Maintenance / Repairs	141	75.2	75.2	
	community development	16	8.2	8.2	
	water treatment	10	5.2	5.2	
	payment of bills	15	8.1	8.1	
	personal gains	4	2.3	2.3	
Valid	Non Response	2	1	1	
	Total	188	100	100	
who is responsible for the maintenance					
	water committees	136	72.5	72.5	
	District facility team	22	11.5	11.5	
	No response	24	12.7	12.7	
	Community	6	3.3	3.3	
preference of solar energy for water pumping					
	Yes	168	89.2 89.2		
	No	9	4.9 4.9		
	No response	11	5.9 5.9		