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Direct Solar/Thermal to Electrical Energy Conversion Technologies

Utility-Scale Photovoltaic Power Plants at Three Selected Sites in Ethiopia

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Executive Summary

Imagine the world without energy. The world's natural resources are constantly diminishing, the demand for energy is rapidly increasing and the impacts of climate change require re-thinking of our practices. There is no question that we need to find sustainable alternatives that lead us into a new energy age. To ensure sustainable growth in the future, renewable energy needs to play an increasingly significant role in the global energy mix. Wind, sun, and water are three infinite resources of pure energy that are ready to be harvested to meet the demand for clean power.

The Utility-scale PV solar power is now cost-competitive with solar PV and wind energy. The cost of solar electricity continues to fall while the cost of conventional electricity increases. Advances in solar technology, conversion efficiency and installation have allowed utility-scale photovoltaic solar systems to achieve cost structures competitive with other peaking power sources

Ethiopian government invested hugely in the hydropower infrastructure, (a number of large and medium-sized hydropower stations have been completed or under construction), but it is still striving to keep up with demand due to rapid economic and social development. Affected by the global warming, the amount of rainfall in rainy season is decreasing and the reservoirs cannot be fully filled, which lead to the consequence that the hydroelectric power stations cannot provide full-loaded power supply. Also, depending on just one source of power has a high risk (lack of rainfall, climate change). Dominated by hydro, Ethiopia's electric grid system has been facing severe electricity shortages in recent years with heavy impact on the country's economy. A Hybrid energy system with hydro and solar PV modules offers greater reliability than any one of them alone because the energy supply does not depend entirely on any one source.

Ethiopia is referred as the water tower of Africa and has a tremendous amount of hydro power potential. However, with high initial investment cost and long construction periods for mega power projects, Ethiopia is able to harness only 5 % of its potential so far.

The objective of this MW-scale Solar Project is to support the country's strategy to enhance the socio-economic development of Ethiopia by increasing the availability and reliability of electricity through the generation of environmentally sustainable energy from diverse renewable sources. The Solar Project is part of a number of renewable energy projects Ethiopia is implementing to achieve this goal. For example, on a cloudy or stormy day when solar thermal generation is low, there is likely enough wind energy available to make up for the loss in solar electricity hybrid. During summer, radiation is high and the amount of solar electric production is high; and during winter, enough rainfall is more likely available leading to a lot of electric energy being extracted from hydro power plant. Hybrid solar, wind and hydro are complementary of each other. Thus, overall improvement in the reliability of power supply and diversified power generation sources for increased energy security is realized. In Ethiopia, solar radiation is high and the amount of solar electric power generation is high. In all cases, solar, wind and hydro create a very well-rounded renewable energy portfolio, which also complement each other.

The propose three solar farms that are excellent sites for a large-scale PV systems. The sites, located in Semera, Hurso and Awash 7 Kilo of Eastern Ethiopia, have large areas of relatively flat ground and are free of obstructions that might add to the cost of construction or cause shading on the systems. Additionally, road access and cap stability will facilitate construction of an array on each site. Furthermore, the eastern part Ethiopia has the highest available solar resource in the country, which makes it a suitable location for solar energy systems. On the proposed solar farms, the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 6.24 kWh/m2/day.

The three selected solar farms are all suitable locations to implement utility-scale PV systems with a higher-than-average solar resource and readily available land area.. Additionally, the PV systems will collectively create a significant distributed generation facility for the area capable of providing a combined 300MWp or more of renewable energy to the national grid system. Furthermore, installing a PV system on one or more of these sites has the potential to add a significant amount of distributed generation to the area, contribute to loss reduction, offset energy costs, and create additional revenue for the Ethiopian Electric Power (EEP).

This project will have a tremendous impact in elevating the energy mix the country is utilizing, enabling it to achieve a more stable and reliable energy generation. Solar energy is the best source of power for Ethiopia—where there is presently no fossil fuel or nuclear energy—because it is the most efficient, cleanest and the most ecologically acceptable source. Once we implement the project, the energy generated from our solar farms will have almost no other variable costs. Coming directly from the sun, it will be naturally shielded from market price fluctuations, and will not produce any waste or pollution. It will be the most reliable of all renewable energy sources in meeting the electricity needs of the country and the continent. We do, however, recognize that the nature of solar power is "intermittent" and can only be fully utilized with large-scale energy storage system.

This paper presents the feasibility study of Utility-Scale Photovoltaic Power Plants at three selected sites in Ethiopia.

Techno-economic feasibility analysis was done for 3x100MWp, 100MWp each site connected Utility-Scale Photovoltaic Power Plants at eastern parts of Ethiopia. PVsys computer tools and monthly average solar radiation data from METEONORM was used for this study. The Levelized unit cost of electricity and NPV were the key financial measures used to rank the technologies and projects. Levelized unit cost is derived by taking the present value of the capital and O&M costs, and dividing it by the present value of the electrical energy (kWh) generated over the lifetime of the project. No taxation expenses, debt interest costs (excluding interest during construction), depreciation or revenue streams are included in this calculation. The levelized costs of energy indicate how much it costs to generate one kWh via the Utility Scale Photovoltaic Power Plants at the three selected sites of Semera, Hurso and Awash 7 Kilo, considering investment costs discounted over the lifetime of the solar-PV systems. The base case levelized costs of Photovoltaic Power Plants at 10 % discount rate with CDM revenue is 6.64 USc/KWh and 6.93 USc/KWh without CDM revenue. The total annual

greenhouse gas reduction is estimated to be 540,300 tons for 300 MWp utility scale solar PV systems.
A levelized cost sensitivity analysis has been carried out with 8%, 10% and 12% discount rate. The summary result of Levelized Cost is presented in the table below:

Discount rate	Levelized Cost (USc /KWh)	
	Semera, Hurso and awash 7 Kilo Solar PV with CDM revenue	**Semera, Hurso and awash 7 Kilo Solar PV without CDM Revenue**
8%	**6.61**	**6.90**
10%	**6.64**	**6.93**
12%	**6.68**	**6.98**

The annual energy production from each of the 100MWp Utility-Scale Photovoltaic Power Plants, located in Hurso, Awash 7 Kilo and Semera, will be 180,000 MWh per site, or a total of 540,000 MWh combined for the three sites
Finally, Utility-Scale Photovoltaic Power Plants at the three selected sites were found to be both technically and economically feasible option for the existing national grid system.

List of Acronyms and Abbreviations

AC	Alternating Current
GDP	Gross Domestic Product
DC	Direct Current
EA	Environmental Assessment
EAP	Environmental Action Plan
EEP	Ethiopian Electric Power
EEPCo	Ethiopian Electric Power Corporation
EIA	Environmental Impact Assessment
FNPV	Financial Net presents Value
FDRE	Federal Democratic Republic of Ethiopia
GHG	Green House Gas
EV-GTDC	Energy Ventures -Global Trade and Development Consulting
FNPV	Financial Net presents Value
KV	Kilo Volt
MoWEI	Ministry of Water, Energy and Irrigation
MW	Mega Watt
PV	Photo Voltaic
CDM	Clean Development Mechanism
B/C	Benefit to Cost Ratio
FIRR	Financial Internal rate of return
EIRR	Economic Internal Rate of Return
US	United States

1. Introduction

Imagine the world without energy. The world's natural resources are constantly diminishing, the demand for energy is rapidly increasing and the impacts of climate change require re-thinking of our practices. There is no question that we need to find sustainable alternatives that lead us into a new energy age. To ensure sustainable growth in the future, renewable energy needs to play an increasingly significant role in the global energy mix. Wind, sun, and water are three infinite resources of pure energy that are ready to be harvested to meet the demand for clean power.

Volatility in oil price while oil/gas reserves are depleting, growing concerns of global warming, and rapid growth in global energy demand, have made it possible for renewable energy alternatives such as solar energy, wind energy, bio-energy, and hydropower to become a better way of producing energy for sustainable development.

Photovoltaic (PV) and wind energy systems are the most promising candidates of the future energy technologies, and it has been widely accepted that stand alone and grid connected PV and wind energy markets have grown rapidly.

Energy generation system reliability is one of the most important issues in any system design process. However, natural energy resources are unpredictable, intermittent, and seasonally unbalanced. Therefore, a combination of two or more renewable energy sources may satisfy bigger share of electricity demand and offer reliable and consistent energy supply. The Hybrid PV and Wind Electricity Systems are well suited to conditions where sunlight and wind have seasonal shifts. For example, in summer, sunlight is abundant but wind is less available, while in winter, wind resources increase complementing the solar resource. The reliability of the stand-alone hybrid Solar PV-Wind-Hydro Systems in producing dependable energy has been proven by earlier studies. In the last two decades, solar energy and wind energy have become an alternative to traditional energy sources. These alternative energy sources are non-polluting, free in their availability and renewable. But high capital cost, especially for photovoltaic, has made its growth a slow one; although recent advance in technology is making it highly competitive by reducing the cost.

The Ethiopian government has allocated huge investment in the hydropower infrastructure, (a number of large and medium-sized hydropower stations have been completed or under construction), but all these power stations do not meet the growing demand for energy due to the rapid economic and social development.

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As a result of adverse weather and catastrophic conditions occurring due to the global warming, the amount of rainfall in rainy seasons is decreasing and the reservoir water levels of each hydro power station is reduced. Hence, all hydro power stations are not operating at full load capacity. Moreover, depending on just one source of power, has a high risk (lack rainfall, climate change). Hydro dominated Ethiopian electric grid system is facing severe electricity shortages in recent years with heavy impact on the country's economy. A Hybrid energy system of hydro wind and solar PV Technology offers greater reliability than any one of them alone because the energy supply does not depend entirely on any one source.

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1.1 Country Overview

Ethiopia is located in the eastern part of Africa between 3o to 15o north and 33o to 48o east (approximately 820 km from north to south and 130 km east to west) with a surface area of 1.1 million square Kilometers, it is the third largest country in Africa. It is the second most populous country in Sub Saharan Africa with an estimated population of about 84.9 million, which is mostly distributed in northern, central and southwestern highlands.

Ethiopia has a federal country composed of nine regional states. The country has a bicameral parliamentary system, and government headed by a prime minister. Addis Ababa is the capital city of the country, and is the seat of many international and regional organizations, like the African Union, and the UN ECA (Economic Commission for Africa).

The country follows an agricultural led industrialization strategy, and is achieving encouraging results. The economy has been growing at a rate of more than 10% for the last eight years consecutively, and large number of development projects is underway. The agriculture sector is the leading source of foreign exchange for Ethiopia. Coffee, distantly followed by hides and skins, oil seeds, and recently, cut-flower, are the major agricultural export commodities. At present, the per capita income in Ethiopia is USD 1100.

The National energy policy of the country emphasizes the need for equitable development of the energy sector in parallel with other social and economic developments. Specific policy lines include the attainment of self-sufficiency through the development of indigenous resources with minimum environmental impact and equitable distribution of electricity in all regions. The policy envisages the development of hydro, geothermal, wind and solar energy resources based on their techno-economic viability, social and environmental acceptability.

2.Approach to this Study

This feasibility study is based on some potential sites, which have been identified and assessed. The study starts from assessment of potential sites in the region and investigate a renewable and conventional power generation facilities with a least-cost alternative power generation projects and environmental impacts. Hence, we have found that Hurso, Awash 7 Kilo and Semera are highly potential for solar energy resources to develop utility-scale photovoltaic power plants. This study also introduces solar energy technologies for electricity generation and estimates the total investment cost of the Solar PV power plants, which could be constructed in Hurso, Awash 7 Kilo and Semera with a total installed capacity of 300MWp.

The Levelized unit cost of electricity and NPV were the key financial measures used to rank the technologies and projects. Levelized unit cost is derived by taking the present value of the capital and O&M costs, and dividing it by the present value of the electrical energy (kWh) generated over the lifetime of the project. No taxation expenses, debt interest costs (excluding interest during construction), depreciation or revenue streams are included in this calculation.

3. Project Objectives and Justifications

Energy plays a great role inhuman life activities and a significant factor in economic development. And at this time energy is considered to be the fourth fundamental resource for human beings to live next to Air, Food and Shelter. Limited fossil resources and environmental problems associated with them have emphasized the need for new sustainable energy supply options that use renewable energies. Solar PV power generation systems also known as Solar PV Electricity (SPE) generating systems are emerging renewable energy technologies and can be developed as viable option for electricity generation in future. Thus, Utility-Scale Photovoltaic Power Plants has not yet familiar in Ethiopia. Ambitious goals for Utility-Scale Photovoltaic Power Plants development have been set by the Ethiopian Government.

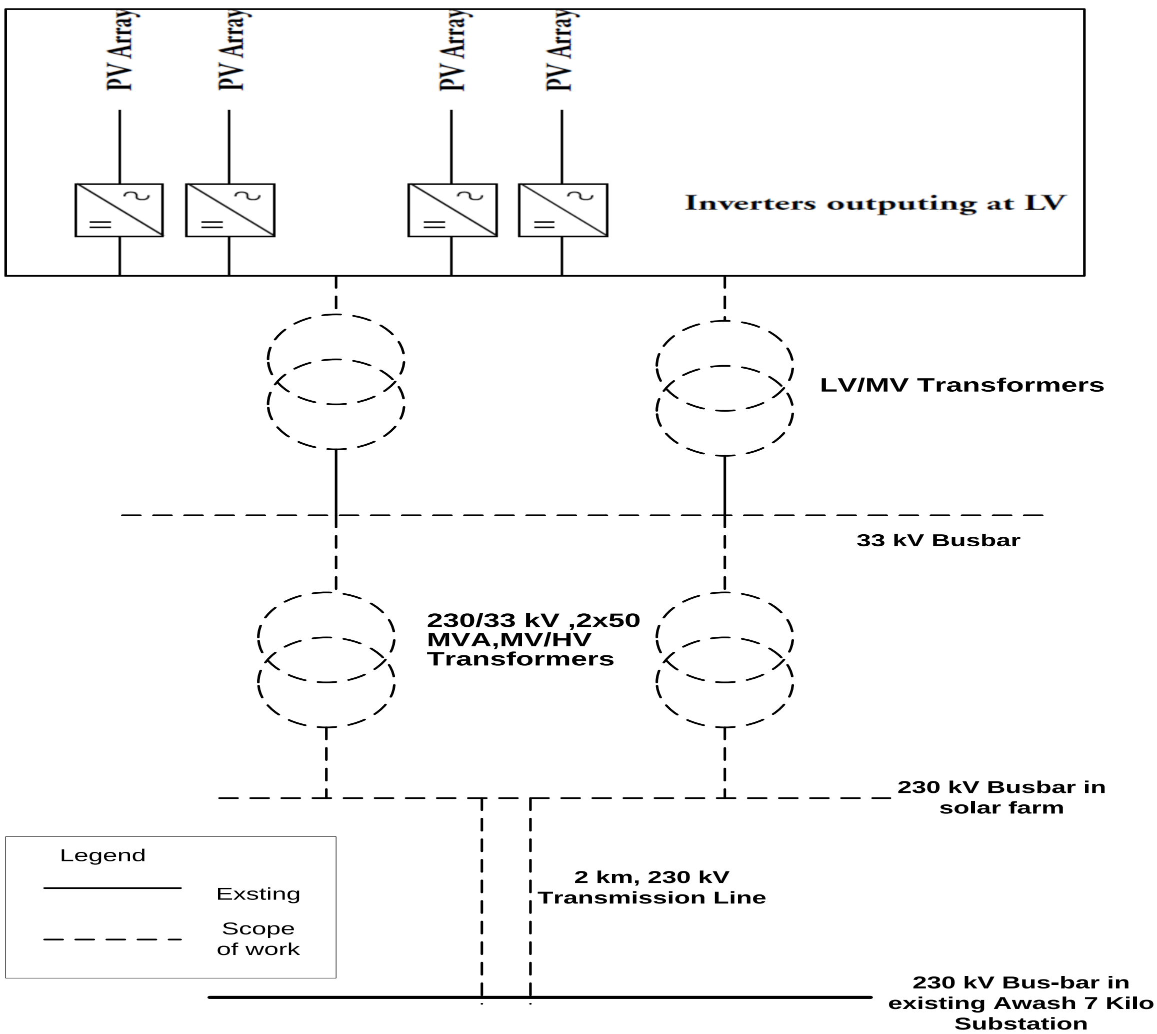
The objective of MW-scale project is to support the strategy to enhance the socio-economic development of Ethiopia by increasing the availability and reliability of electricity through the generation of environmentally sustainable energy from diverse renewable sources. The Solar Project is part of a number of renewable energy projects being implemented to achieve this goal. These projects collectively will lead to hybrid of hydro, wind, solar, and geothermal modules offering greater reliability than any one of them alone because the energy supply will not depend entirely on any one source. In Ethiopia, solar radiation is high and the amount of solar electric power generation is high. In all cases, solar, wind and hydro create a very well-rounded renewable energy portfolio, which also complement each other.

This project will have a tremendous impact in elevating the energy mix the country is utilizing, enabling it to achieve a more stable and reliable energy generation. Solar energy is the best source of power for Ethiopia—where there is presently no fossil fuel or nuclear energy—because it is the most efficient, cleanest and the most ecologically acceptable source. Once we implement the project, the energy generated from our solar farms will have almost no other variable costs. Coming directly from the sun, it will be naturally shielded from market price fluctuations, and will not produce any waste or pollution. It will be the most reliable of all renewable energy sources in meeting the electricity needs of the country and the continent. We do, however, recognize that the nature of solar power is “intermittent” and can only be fully utilized with large-scale energy storage system.

Overall objective of this project is to enhance socio economic development of Ethiopia by increasing availability, reliability of electricity and environmentally sound energy from hybrid renewable energy sources. This project which could lead to hybrid, hydro, wind and solar modules are, offer greater reliability than any one of them alone because the energy supply does not depend entirely on any one source. For example, on a cloudy stormy day when solar thermal generation is low there's likely enough wind energy available to make up for the loss in solar electricity hybrid, during winter time solar radiation is high and the amount of solar electric production is high and during summer time likely enough rainfall available which is expected to a lot of electric energy extracted from hydro power plant. Hybrid solar, wind and hydro are complementary of each other. Thus, this action will improve the reliability of power supply and diversify power generation sources for increased energy security.

4.Scope of the study

The scope of this present study is to assess the technical, financial and economic feasibility of integrating Utility-Scale Photovoltaic Power Plants to the main grid. The study will investigate the economic and financial viability of the project. Project Single Line Diagram for each one of the proposed Solar PV Stations is indicated in Figure 1 below



Single Line Diagram of HV grid interconnection point for Proposed Solar Farm.

Figure 1:Single Line Diagram of HV Grid Interconnection Point

For connection to the 230kV transmission grid, it is necessary to adhere to National Electricity Rules and the connection must meet EEU's Grid requirements.

The solar PV project size is proposed to be 100MWp power for each site. This higher rating is used for grid connection designs.

The proposed plant will be connected to the 230kV transmission system through an 33kV/230kV substation. This involves an 33kV/230 kV power transformer, underground cables at 33 kV and overhead lines at 230kV with at least 2 x 50MVA rated capacity. The network connection is designed to carry rated power on a 24-hour basis.

For connection to the 230kV transmission grid, it is necessary to adhere to the National Electricity Rules and the connection must meet EEP's Grid requirements.

5. The location Selected project Solar PV Sites Location

Semera, Hurso and Awash 7 Kilo are located in eastern part of Ethiopia at the Latitude 11°47′32″N and longitude 41°0′31″E , the Latitude 9° 36' 0"N and longitude 41° 38' 4"E and the Latitude 9° 1' 0"N and longitude 40° 11' 0"E, respectively. Site selection of these solar farm was carried out based on:

- **Solar resource**– Global Horizontal Irradiation, annual and inter-annual variation, impact of shading.
- **Local climate** – flooding, high winds, snow and extreme temperatures.
- **Available area** – area required for different module technologies, access requirements, pitch angle and minimizing inter-row shading.
- **Land use** – this will impact land cost and environmental sensitivity. The impact of other land users on the site should also be considered.
- **Topography**– flat or slightly south facing slopes are preferable for projects in the northern hemisphere.
- **Geotechnical**– including consideration of groundwater, resistivity, load bearing properties, soil pH levels and seismic risk.
- **Geopolitical** – sensitive military zones should be avoided.
- **Accessibility** – proximity to existing roads, extent of new roads required.
- **Grid connection** – cost, timescales, capacity, proximity and availability.
- **Module soiling** – including local weather, environmental, human and wildlife factors.
- **Water availability** – a reliable supply is required for module cleaning.

Considering transmission line loss and costs, all the proposed sites of PV power stations shall are not be far away from access the power grid or load center. Location of the project area is shown Figure 2 below.

Figure 2:Figure 2 Project Location Map Three selected Solar PV Station

All proposed solar farm sites have flat topography and are free from any obstruction. Based on the generally flat topography of the surrounding area no significant horizontal shading is expected. All infrastructure facilities include existing 230 kV line in the project areas.

The land required for each proposed solar farm is 80 hectare. There no evidence of past or current cultivation on the site. Furthermore no settlement could be found on the proposed solar

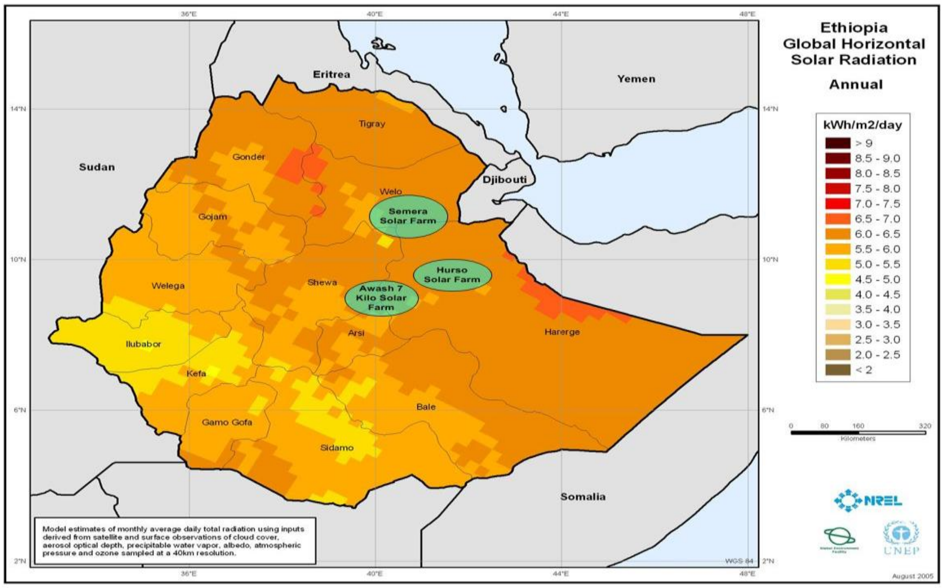


Figure 3: solar maps Annual Daily Solar Radiation of Ethiopia (Including project area) (Source: SWERA)

In order to capture as much solar energy as possible, the photovoltaic cell must be oriented towards the sun. If the photovoltaic cells have a fixed position, their orientation with respect to the south (northern hemisphere), and tilt angle, with respect to the horizontal plane, should be optimized. For regions nearer to the equator, this tilt angle will be smaller, for regions nearer to the poles it will be larger. A deviation of the tilt angle from the optimum angle, will lead to less power to be capture by the photovoltaic system.

6. Hurso, Semera and Awash 7 Kilo Solar Resources Assessments

The light of the sun, which reaches the surface of the earth, consists mainly of two components: direct sunlight and indirect or diffuse sunlight, which is the light that has been scattered by dust and water particles in the atmosphere. Photovoltaic cells not only use the direct component of the light, but also produce electricity when the sky is overcast. On average, the total solar energy received over the year is used to estimate the solar energy potentials of a region as opposed to the measure of instantaneous irradiance.

The daily radiation of eastern part of Ethiopia is very high although there are zonal and seasonal variations. Solar radiation potential in Awash 7 Kilo, Hurso and Semera are estimated to range from 6.4 to 7.2 KWh/M2. As majority of the population in the region live in dispersed area solar energy resources could be the most appropriate electricity resources.

The utility scale solar PV project is planned to be located in eastern parts Ethiopia. Eastern Ethiopia is one of the areas with the richest solar energy resources available in the country. The Global Horizontal Irradiance (GHI) of the selected solar farms varies between 2370.6 to 2440 kwh/m2 and the number of annual sunshine hours lies between 2870 and 3241. The areas belong to the richest solar irradiation in Ethiopia. According to the resource assessment, the average irradiance of the selected solar farm will be in the range of 2271.5-2650 kWh/m2. The data indicate riches solar energy resource is available, and the planned solar farms are viable option for grid connected solar PV power plants in Ethiopia.

7. Utility-scale Photovoltaic Power Plants Energy Systems

Typical components for Utility-scale photovoltaic power plants are:

Solar PV modules – These convert solar radiation directly into electricity through the photovoltaic effect in a silent and clean process that requires no moving parts. The photovoltaic effect is a semiconductor effect whereby solar radiation falling onto the semiconductor PV cells generates electron movement. The output from a solar PV cell is direct current (DC) electricity. A PV power plant contains many cells connected together in modules and many modules connected together in strings to produce the required DC power output.

Module mounting (or tracking) systems – These allow PV modules to be securely attached to the ground at a fixed tilt angle, or on sun-tracking frames.

Inverters – These are required to convert the DC electricity to alternating current (AC) for connection to the utility grid. Many modules in series strings and parallel strings are connected to the inverters.

Step-up transformers – The output from the inverters generally requires a further step-up in voltage to reach the AC grid voltage level. The step up transformer takes the output from the inverters to the required grid voltage 33 kV the grid connection point and requirements.

The grid connection interface – This is where the electricity is exported into the grid network. The substation will also have the required grid interface switchgear such as circuit breakers and disconnects for protection and isolation of the PV power plant as well as generation and supply metering equipment. The substation and metering point are often external to the PV power plant boundary and are typically located on the network operator’s property.

- **Controllers (MPPT):** Maintain the solar module at the maximum power point output.
- **Wires:** Electrically connect equipment together.

Figure 9 gives an overview of a megawatt scale grid-connected solar PV power plant.

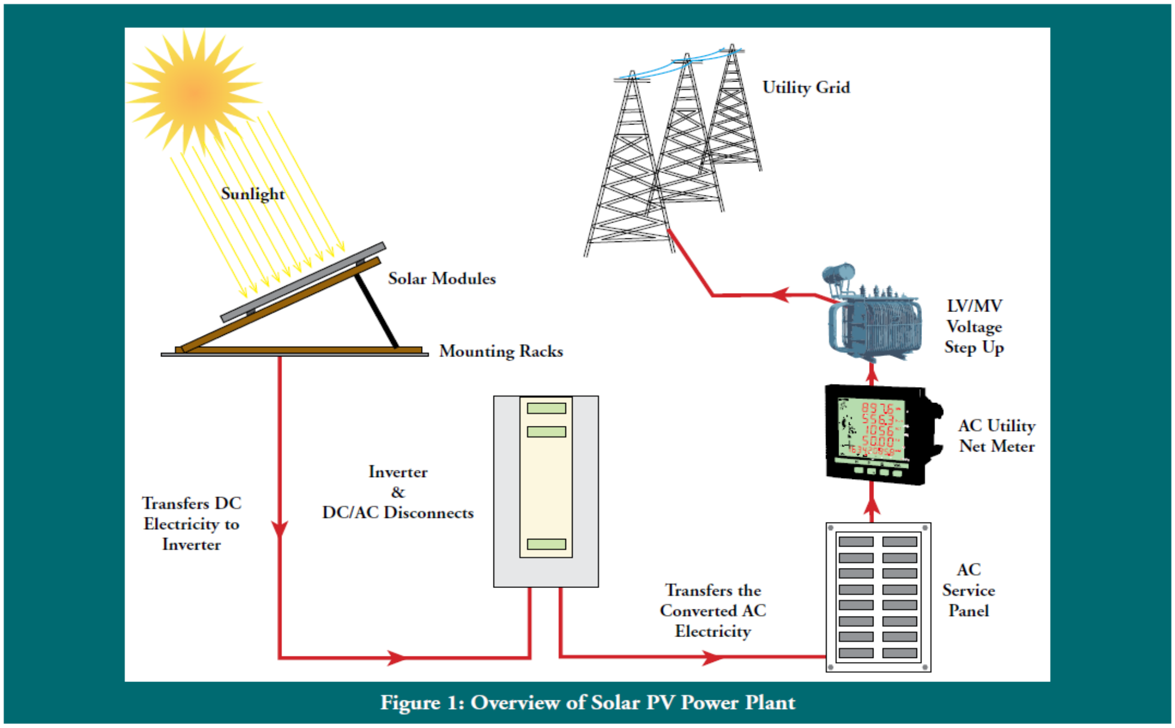


Figure 1: Overview of Solar PV Power Plant

Figure 4: Overview of a megawatt scale grid-connected solar PV power plant

7.1 SOLAR PV SYSTEM DESIGN

The design of a PV plant involves a series of compromises aimed at achieving the lowest possible Levelized cost of electricity. Choosing the correct technology (especially modules and inverters) is of central importance. Selecting a module requires assessment of a complex range of variables. At the very least, this assessment would include cost, power output, benefits / drawbacks of technology type, quality, spectral response, performance in low light, nominal power tolerance levels, degradation rate and warranty terms.

The factors to consider when selecting inverters include compatibility with module technology, compliance with grid code and other applicable regulations, inverter-based layout, reliability, system availability, serviceability, modularity, telemetry requirements, inverter locations, quality and cost.

In designing the site layout, the following aspects are considerers:

- Choosing row spacing to reduce inter-row shading and associated shading losses.
- Choosing the layout to minimize cable runs and associated electrical losses.
- Allowing sufficient distance between rows to allow access for maintenance purposes.
- Choosing a tilt angle that optimizes the annual energy yield according to the latitude of the site and the annual distribution of solar resource.

- Orientating the modules to face a direction that yields the maximum annual revenue from power production. In the northern hemisphere, this will usually be true south.

The electrical design of a PV project can be split into the DC and AC systems.

The DC system comprises the following:

- Array(s) of PV modules.
- Inverters.
- DC cabling (module, string and main cable).
- DC connectors (plugs and sockets).
- Junction boxes/combiners.
- Disconnects/switches.
- Protection devices.
- Earthing.

The AC system includes:

- AC cabling.
- Switchgear.
- Transformers.
- Substation.
- Earthing and surge protection

8 The Average Annual Energy Output at Three Selected Sites

Typically, the procedure for predicting the energy yield of a PV plant using time-step (hourly or sub-hourly) simulation software will consist of the following steps:

1. Sourcing modeled or measured environmental data such as irradiance, wind speed and temperature from land-based meteorological stations or satellite imagery (or a combination of both). This results in a time series of "typical" irradiation on a horizontal plane at the site location along with typical environmental conditions.
2. Calculating the irradiation incident on the tilted collector plane for a given time step.
3. Modeling the performance of the plant with respect to varying irradiance and temperature to calculate the energy yield prediction in each time step.
4. Applying losses using detailed knowledge of the inverters, PV module characteristics, the site layout, DC and AC wiring, module degradation, downtime and soiling characteristics.
5. Applying statistical analysis of resource data and assessing the uncertainty in input values to derive appropriate levels of uncertainty in the final energy yield prediction.

The "optimal system" determined by PVsys depends on the input assumptions. Key assumptions are summarized in the **table 4** below energy calculation in proposed sites levelized energy determination and cost estimate for the project.

Table 1:Key Assumptions and Input Data for Analysis

Variable	Value
O and M cost of PV	$0.0037/kWh
Discount Rate	10%
Life time of the project	25 year
Tracing System type	No Tracking
Annual Output Degradation	0.5%/year

The energy yield prediction provides the basis for calculating project revenue. The aim is to predict the average annual energy output for the lifetime of the proposed power plant (along with the confidence levels). The level of accuracy required will depend on the stage of development of the project. To estimate accurately the energy produced from a PV power plant, information is needed on the solar resource and temperature conditions of the site. Also required are the layout and technical specifications of the plant components

The total averages annual energy output Hurso, Awash 7Kilo and Semera will be 540,000,000 kWh.

The generation yearly in average generation of 25 years is shown in Table 5,6 and 7

System Performance Analysis & Simulation the proposed solar farm is presented below Average annual energy production 25 years lifetime for Hurso Solar Farm in MWh. The annual energy production calculated based on P90 figures.

Table 2:Average annual energy production 25 years lifetime for Hurso Solar Farm in MWh

Table 5: Fixed System: Inclination=10°, Orientation=-0° Hurso Solar Farm			
1	182,000.00	14	170,518.47
2	181,090.00	15	169,665.88
3	180,184.55	16	168,817.55
4	179,283.63	17	167,973.46
5	178,387.21	18	167,133.60

6	177,495.27	19	166,297.93
7	176,607.80	20	165,466.44
8	175,724.76	21	164,639.11
9	174,846.13	22	163,815.91
10	173,971.90	23	162,996.83
11	173,102.04	24	162,181.85
12	172,236.53	25	161,370.94
13	171,375.35		
Total Energy Production in 25 years lifetime			**4,287,183.16**

Table 3:Average annual energy production 25 years lifetime for Semera Solar Farm in MWh

Average annual energy production 25 years lifetime for Semera Solar Farm in MWh

Fixed System: Inclination=11°, Azimuth=-0° Semera Solar Farm			
1	175,000.00	14	163,960.07
2	174,125.00	15	163,140.27
3	173,254.38	16	162,324.57
4	172,388.10	17	161,512.95
5	171,526.16	18	160,705.38
6	170,668.53	19	159,901.86
7	169,815.19	20	159,102.35
8	168,966.11	21	158,306.83
9	168,121.28	22	157,515.30
10	167,280.68	23	156,727.72
11	166,444.27	24	155,944.08
12	165,612.05	25	155,164.36
13	164,783.99		
Total Energy Production in 25 years lifetime			**4,122,291.50**

Table 4:Average annual energy production 25 years lifetime for Awash 7 Kilo Solar Farm in MWh

Fixed System: Inclination=10°, Orientation=-0° Awash 7 Kilo Solar Farm			
1	183,800.00	14	172,204.92
2	182,881.00	15	171,343.90
3	181,966.60	16	170,487.18
4	181,056.76	17	169,634.74
5	180,151.48	18	168,786.57
6	179,250.72	19	167,942.63
7	178,354.47	20	167,102.92
8	177,462.69	21	166,267.41
9	176,575.38	22	165,436.07
10	175,692.50	23	164,608.89
11	174,814.04	24	163,785.84
12	173,939.97	25	162,966.92
13	173,070.27		
Total Energy Production in 25 years lifetime			**4,329,583.87**

Annual energy production based on different types of Annual Exceedance Probability (AEP) is presented in table below:

Table 5:Energy calculation based on different level of Annual Exceedance Probability (AEP)

	Hurso Solar Farm	Semera Solar Farm	Awash 7 Kilo
Installed Capacity	**100MWp**	**100MWp**	**100MWp**
Annual Energy Production (GWh)			
Exceedance Probability (%) (P90)	**182**	**175**	**184**
Exceedance Probability (%) (P75)	**202**	**194**	**204**
Exceedance Probability (%) (P50)	**226**	**218**	**229**

9. Optimization results from PV System

9.1 PV system overall scheme

PVsyst is a PC **software** package utilized for the study, to estimate sizing, simulation and data analysis of complete PV systems. According to simulation of PV software "PVSYST", when dip angle is 15º, azimuth is 0º and the annual power output will be maximum. The optimization results for three selected sited summarized in Annex-I .

In this section, results of first year production simulation for the 100MWp Power Plant is showed for each project.

For these simulations Yingli modules and Gamesa inverters have been used. Final selection of any other equipment from different manufacturers listed in vendor list (See Annexure 3) will involve slight modifications in the simulation results and in the economical proposal.

The meteorological data used for the simulation have been provided by Meteonorm software for the different locations.

The results obtained with these PVSyst simulations consider losses generated in the MV ring and transformers but not in the evacuation infrastructures (33kV Switchyard + power line).

Table 6:PVSyst Simulations Summary

	Indicative Net Energy Export Estimate (MWh/Yr)	Indicative Specific production	Indicative Performance Ratio (PR)
100 MWp Awash 7 Kilo PV Power Plant	183,800.00	1,826 kWh/kWp/yr	80.2%
100 MWp Hurso PV Power Plant	182,000.00	1,809 kWh/kWp/yr	77.7%
100 MWp Awash 7 Kilo PV Power Plant	175,000.00	1,736 kWh/kWp/yr	77%

10. Economic and Financial Analysis

10.1 GENERAL

The main purpose of the present feasibility study is to assess the technical, financial and economical viable option of Utility Scale Photovoltaic Power Plants at three selected sites of Semera, Hurso and Awash 7 Kilo. Renewable energy project:

•With zero emission of greenhouse gas and pollutants

•That replaces equal energy generated by from diesel generating generators set after put in to operation and

•Which That return will replaces the greenhouse gas emission resulted resulting from the using use of fire coal and heavy oil.

The good environmental and social benefit of realized from the project conforms to the spirit of the Kyoto protocol, and it is qualified for declaration of the clean development mechanism. CDM project can use Certified Emission reduction (CERs) revenue as the additional revenue for project financing as well as enhance the market competitiveness of the project. Hence Construction prices of grid- connected solar PV has declined with the Kyoto protocol of clean development mechanism.

10.2 METHODOLOGY

The basic methodology applied is the discounted cash flow analysis. in this feasibility study a discount rate of 10% has been used ,which represents the opportunity cost of capital presently adopted in Ethiopia. Furthermore, a sensitivity analysis has been carried out with different discount rate.

10.3 PERIOD OF ANALYSIS

The economic study has been carried out on a period of 25 years of operation. Considering that the project is supposed to start generation mid 2016 after two year of construction, the period of analysis covers the time interval up to year 2041.

10.4 LEVELIZED COST

The analysis aims evaluating the levelized cost of Utility-Scale Photovoltaic Power Plants. The basic methodology applied is the discounted cash flow analysis. In finance, (DCF) analysis is a method of valuing a project, or a company, using the concepts of the time value of money. All future cash flows are estimated and discounted to give their present value- the sum of all future cash flows, both incoming and outgoing, is the net present value (NPV), which is taken as the value or price of the cash flows in question. Present value may also be expressed as a number of years' purchase of the future undiscounted annual cash flows expected to arise. Using DCF analysis to compute the NPV takes as input cash flows and a discount rate and gives as output a price.

Levelized Energy Cost (LEC, also known as Levelised Cost of Energy, LCOE is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance .Levelized Energy Cost is very useful in calculating the economic life time costs of generation plant.

It can be defined in a single formula as:

$$\mathrm{LEC} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where

- LEC= design lifetime levelized electricity generation cost
- I_t= Investment expenditures in the year t
- M_t= Operations and maintenance expenditures in the year t
- F_t= expenditures in the year t
- E_t= Electricity generation in the year t
- r= Discount rate
- n= Life of the system

10.4.1 DISCOUNT RATE

Discount rate is a rate of interest used to convert benefit and costs occurring at different times to a common time. Bank practice is to use a rate of 10 or 12 percent to calculate the net present value of a project, or to compare with the internal rate of return. In this financial proposal uses a 10 % discount rate for base case.

10.4.2 Levelized Cost of Energy Key Assumptions

The levelized cost of energy calculated based on the following assumption.

- Low case economic discount rate is 8%.
- Base case economic discount rate is 10%.
- High case economic discount rate is 12%.
- investment cost of Hurso , Awash 7 kilo and Semera Solar Power Plant is 620 MUSD
- Capacity factor is 21%
- Economic life time of the project is 25 year.
- Construction period is two year.
- Annual energy production of all solar power plant is 540 GWH
- Annual operating and maintenance cost is 0.0037 USD per KWH.
- Degradation factor 0.5%/year
- 100% loan facility
- Interest rate is 0.5% of loan amount.
- Grace period is three years
- Repayment period is 22 year

10.5 Levelized Cost Result

The levelized costs indicate how much it costs to generate one kWh via the Utility Scale Photovoltaic Power Plants at three selected sites of Semera, Hurso and Awash 7 killo considers investment costs discounted over the lifetime of solar-PV system. The base case levelized costs of Photovoltaic Power Plants at 10 % discount rate with CDM revenue is **6.64 USc/KWh** and **6.93 USc/KWh** without CDM revenue. Furthermore, a levelized cost sensitivity analysis has been carried out with 8% and 12% discount rate. The summary result of Levelized Cost is presented in table below USc/kWh.

Table 7:Levelized Cost of Utility Scale Photovoltaic Power Plants

Table-7 - Levelized Cost of Utility Scale Photovoltaic Power Plants

Discount rate	Levelized Cost (USc /KWh)	
	Semera, Hurso and awash 7 Kilo Solar PV with CDM revenue	**Semera, Hurso and awash 7 Kilo Solar PV without CDM Revenue**
8%	**6.61**	**6.90**
10%	**6.64**	**6.93**
12%	**6.68**	**6.98**

But the LCOE is calculated based on the 4% one-time-only loan fee will be added into the loan and will be paid the first year of the projects. However, LCOE indicated table above will be even lower when it consider the 4% one-time-only loan fee will be paid over the 20 or 25 years maturity period.

10.6 ECONOMIC ANALYSIS

The economic analysis serves to assess the economic viability of Utility Scale Photovoltaic Power Plants at the three selected sites of Semera, Hurso and Awash 7 killo. For this purpose, the economic costs of the Project are compared to its economic benefits. Both costs and benefits are set up as cash flows over the economic lifetime of solar-PV system, including the construction period and the operation period. Assuming that solar-PV system is commissioned in mid 2015 and that it has an economic lifetime of 25 years, the evaluation covers the period up to 2041 European calendar.

All costs and benefits are expressed in USD to make them comparable to the costs considered in the recent studies for solar-PV system. A discount rate of 10% is used for the base case economic evaluation. The key assumptions made for the economic analysis are summarized in Table below.

Table 8:Key Assumptions for economic Analysis

Table -8 Key Assumptions for economic Analysis

Item	**Value**

Economic discount rate - Base	10%
Economic discount rate - Low, High	8%, 12%
Construction period	2 year
Economic lifetime	25 year
Standard conversion Value	0.9
Installed Power Capacity	300MWp
Annual Energy	540 GWH
Degradation factor	0.5%/year
Operating and maintenance cot	0.0037 USD/KWH

10.6.1 Economic Analysis Results

The economic analysis indicated in table below shows that Utility Scale Photovoltaic Power Plants at the three selected sites lead to the following results. At base case discount rate Semera, Hurso and Awash 7 kilo Photovoltaic Power Plants economic Net Present Value has a profit of **68** million USD, Benefit to Cost Ratio for Semera, Hurso and Awash 7 kilo Photovoltaic Power Plant are **1.284**, and economic internal rate of return for Semera, Hurso and Awash 7 killo Photovoltaic Power Plants is **44.9%**. The base case financial indicators show that Semera, Hurso and Awash 7 kilo Photovoltaic Power Plant are above the minimum economic decision criteria.

Furthermore, economical sensitivity analysis has been carried out with 8% and 12% discount rate.

The summary result for the economic analysis is shown in table below.

Table 9:Semera, Hurso and Awash 7 Kilo Economic Analysis Summary

Table – Semera, Hurso and Awash 7 Kilo Economic Analysis Summary

Economical Analysis result	At 8% Discount rate	At 10% Discount rate	At 12% Discount rate
Economical Net Present Value (NPV) in MUSD	84	68	55
Benefit Cost Ratio (B/C)	1.284	1.278	1.27
Economical Internal Rate of Return (EIRR)		44.9%	

10.8 Financial Analysis

The financial analysis serves to assess the financial viability of option Semera, Hurso and Awash 7 kilo Photovoltaic Power Plants. Electricity price calculation with the consideration of the lower electricity price level in Ethiopia and the focus of shareholders and lender on profitability, repayment capacity and cash flow situation of the project, combined with the influence of CDM revenue on project earnings.

The electricity tariff is calculated based on levelized cost of energy production with 15% profit margin which is 7.97 USc per KWh. The cash flows associated with the Project are set-up over the lifetime of the project. The evaluation covers two years construction period and 25 years of operation up to 2041. All costs and benefits are to be considered in the Financial Analysis.

10.8.1 Financial Analysis Results (Quantifiable Benefits)

The financial analysis indicated in table below shows that Utility Scale Photovoltaic Power Plants at the three selected sites lead to the following result. At base case discount rate Semera, Hurso and Awash 7 kilo Photovoltaic Power Plants financial Net Present Value has a profit of **40.67 MUSD**, Benefit to Cost Ratio for Semera, Hurso and Awash 7 kilo Photovoltaic Power Plants is **1.15**, and financial internal rate of return for Semera, Hurso and Awash 7 killo Photovoltaic Power Plants is **33.26%**. The base case financial indicators show that Semera, Hurso and Awash 7 kilo Photovoltaic Power Plant are above the minimum financial decision criteria at 7.97 sales price.

Furthermore, financial sensitivity analysis has been carried out with 8% and 12% discount rate. the summary result for the analysis is shown in table below

Table 10:Semera ,Hurso and Awash 7 Killo Financial Sensitivity Analysis Summary

Table Semera ,Hurso and Awash 7 Killo Financial Sensitivity Analysis Summary

Financial Analysis result	**At 8% Discount rate**	**At 10% Discount rate**	**At 12% Discount rate**
Financial Net Present Value (NPV) in MUSD	50.93	40.67	32.63
Benefit Cost Ratio (B/C)	1.16	1.15	1.14
Financial Internal Rate of Return (FIRR)	33%		

10.9 Environmental Benefits

Solar power is a renewable energy source, which means it replenishes itself naturally and is at no risk for depletion. Using solar energy instead of fossil fuels to generate electricity offsets greenhouse gases, prevents carbon dioxide contamination and reduces air pollution because solar power does not produce greenhouse gases, such as carbon dioxide.

11. Conclusion and Recommendation

11.1 Conclusions

The prime purpose of this Utility-Scale Photovoltaic Power Plants project to realize the vision that renewable energy needs to play an increasingly significant role in the national energy mix. Wind, sun, and water are three infinite resources of pure energy that are ready to be harvested to meet the demand for clean power.

The Proposed solar farms is excellent sites for a large-scale PV systems. The sites have large areas of relatively flat ground and are free of obstructions that might add to the cost of construction or cause shading of the system. Additionally, road access and cap stability would facilitate construction of an array on the site. Furthermore, the eastern part Ethiopia has the highest available solar resource in the country, which makes it a suitable location for solar energy systems. On the proposed solar farms, the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 6.24 kWh/m^2/day.

The three selected solar farms are a suitable locations to implement utility-scale PV systems with a higher-than-average solar resource and readily available land area.. Additionally, PV system would create a significant distributed generation facilities for the area capable of providing a combined 300MWp or more of renewable energy to the national grid system. Furthermore, installing a PV system on one or more of these sites, contribute to loss reduction, offset energy costs, and create additional revenue for EEP.

The supply deficits being currently experienced can be averted, If the Utility-Scale Photovoltaic Power Plants can be installed as soon as possible. The Utility-Scale Photovoltaic Power Plants has an annual generation capacity three solar farms will be 540 GWh.

- This project will enhance the socio economic development of Ethiopia by increasing availability, reliability of electricity and environmentally sound energy from hybrid renewable energy sources
- Solar PV represents a true zero carbon emission generation option
- Solar PV offers significantly lower capital and operating costs than thermal technology;
- A high level of government financial assistance (that varies between jurisdictions) could be expected
- Typically, the key factors behind the relatively high cost of solar energy generation are associated with the high capital cost of the plant itself, the high proportion of infrastructure and land and the relatively low productivity (measured by the 30% capacity factor). Larger plant size would significantly improve the economics by spreading the infrastructure costs over a larger productive plant, and capturing economies of scale of the production plant itself;

The financial projection has estimated that a total of **620 MUSD** is required for implementation of the project for the selected sites of Semera ,Hurso and Awash 7 Kilo.

Taking together all the decision criteria Utility-Scale Photovoltaic Power Plants for the selected three solar farms is financially viable at 7.97 USc per KWh selling price. In addition economic analysis has shown that the Utility-Scale Photovoltaic Power Plants Project is economically attractive project .Therefore, this project is helps socio economic development of Ethiopia by increasing availability, reliability of electricity and environmentally sound energy from hybrid renewable energy sources

Based on the findings of this study, utility-scale PV systems are both technically and economically feasible.

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