Feasibility Study of PV/Wind/Micro-Hydro/Biomass Hybrid System for off-grid Electrification of Selected Rural Areas in Ethiopia

(Case Study: Eastern Gojam Zone, Sinan District)

By

Muluneh Minwuye

Advisor: Getachew Bekele(Phd)

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This is to certify that the thesis prepared by Muluneh Minwuye, entitled: Feasibility study of PV/Wind/Micro-Hydro/Biomass hybrid system for off-grid electrification of selected rural areas in Ethiopia and submitted in partial fulfillment of the requirements for the degree of Master of Science (Electrical Power Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been acknowledged.

All examiners' comments are duly incorporated.

Name: Muluneh Minwuye Derseh

Signature: ________________________

Place: Addis Ababa

Date of submission: _________________

This thesis has been submitted for examination with my approval as a university advisor.

Advisor's Name: Dr. Getachew Bekele

Signature_____________

Abstract

Out of the total population of Ethiopia about 85% live in rural areas and the accessibility of electric is estimated to be less than 1%. Lack of electricity in rural area has its own negative effect in human health and economic development. Since the area is dispersely populated and lacks of infrastructure, it is not easy to generate and distribute electrical energy from the main rivers to the people living in rural areas. To solve this problem, the main suggestive solution is implementing stand alone and hybrid power system. Micro hydro power together with solar PV, wind and biomass will enable electricity accessible to the rural areas.

In this thesis, the feasibility of micro-hydro/wind/solar PV and biomass hybrid power system is studied in the selected rural areas of Ethiopia. The selected villages are located in North west part of the country known as "Kidusyohanes","Kundab" and" Debre". The feasibility has been studied by collecting the necessary data and analyzing with the help of HOMER(Hybrid Optimization modeling for Electric Renewable) software. Data for micro-hydro power is collected from the field sought and Ethiopian Ministry of Water & Energy (MoWE). Solar and wind data are collected from National Meteorological Agency of Ethiopia and other data sources such as NASA and SWERA. For the biomass, the data is collected from Local Agricultural and Rural development office to use the dung for the source of bio energy. The electric load for the community is estimated and scheduled based on the socio economic activity of the people in the area. The peak primary load is found to be 212,237,155kw for kidusyohanes, Kundab and Debre respectively. The peak deferrable (water wheel pump and Irrigation pump) load is 4kw for kidusyohanes and Kundab, and 3.3kw for Debre. For the next 10 years, the load demand will increase to 279.8(23.74%), 307.2(21.8%) and 195.0(17.36%)kw for Kidusyohanes, Kundab and Debre respectively.

From the study the combination of Hydro/PV, Hydro/Biomass and PV is found with the least cost energy of \$0.246/kwh, \$0.218/kwh, \$0.285/kwh for kidusyohanes, Kundab & Debre respectively. For Kidusyohaness 34%, Kundab 49.6% and Debre 34.9% excess energy is found from the simulation result. For Debre the simulation result shows that the system is supported with 294KW PV/685 S4KS25P when the diesel is included and 285 kw PV/700 S4KS25P when the diesel is excluded. The COE is \$0.285 and \$0.279\$/kwh for system with & without diesel respectively.

Key words:-Feasibility, micro-hydro power, wind, solar, biomass, hybrid, load estimation and scheduling.

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Glory to God!

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Table of contents

List of Figures

List of Tables

List of Acronyms

EELPA	Ethiopian Electric Light and Power Authority
EEPCo	Ethiopian Electric Power Corporation
UEAP	Universal Electric Access Program
PV	photo voltaic
NASA	National Aeronautics and Space Administration
SWERA	Solar and wind energy resource assessment
MW	Mega watt
GW	Giga watt
TWh	Tera watt hour
KWh	Killo watt hour
HOMER	Hybrid Optimization modeling for Electric Renewable
REN	Renewable
APS	Autonomous Power Station
TERNA	Technical Expertise of Renewable Energy Applications
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
K	Kelvin
µm	micro meter
Gsc	The solar constant
MPP	maximum power point
V_{oc}	Open circuit voltage
I_{sc}	Short circuit current
I_{mp}	Maximum power current
V_{mp}	Maximum power voltage
W_p	Peak watts
R_p	Leakage resistance
R_s	Leries resistance
I_s	Ideal current source
V_{module}	Module voltage
Φ	Latitude
Β	Slope
Γ	Surface azimuth angle

Ω	Hour angle
Θ	Angle of incidence
θ_z	Zenith angle
α_s	Solar altitude angle
γ_s	Solar azimuth angle
ω_s	sun rise/sun set angle
δ	The angle between the sun and the equator (declination)
G_{on}	The extraterrestrial radiation, measured on the plane normal to the radiation
G_o	Extraterrestrial radiation on a horizontal surface
H_o	Daily extraterristerial radation on horizontalsurface
H	Monthily avarage daily radation
n_d	n^{th} day of the year
n	Sunshine hours
N	The maximum possible daily hours of bright sunshine
a	Regraassion constant
b	Regrassion consstant
rpm	Revolusion per minute
VAWT	Vertica axis wind urbine
HAWT	Horizontal Axis wind turbine
V_c	Cutt-in wind speed
V_R	Rated wind speed
V_F	cut-out wind speed
NMA	National metrological agency
IC	Internal Cumbastion engine
ROR	Run off River
N_s	Maximum efficiency speed of the turbine
Fps	Foot per second
PVC	Polyvinyl chloride
FRE	Fiber reinforced epoxy
DEM	Digital Elevation Model
C-Si	Crystalline silicon

CIS	Copper indium (di)selenide
CdTe	Cadmium telluride
CIGS	Copper indium gallium (di) selenide
ADL	Average deferrable load
COE	cost of Energy
NPC	Net present cost
OST	Optimal system type
CFL	compact floor sent light

CHAPTER ONE

1 Back Ground of the Study and Literature Review

1.1 Background

Electric Power was introduced to Ethiopian in the late 19th Century, during the regime of Minilik. The first generator was given to Minilik around the Year 1898 to light the palace. In addition to the use of generators ,Minilik got constructed the first Hydro Power Plant on Akaki River in the year 1912 in order to supply power to small factories. Then it extended to public places and major roads in the vicinity of the palace. The former authorized body, Ethiopian Electric Light and Power Authority (EELPA), was established in 1956. It has been reorganized as the Ethiopian Electric Power Corporation (EEPCo) in 1997 which is responsible for generation, transmission, distributions and sales of electricity nationwide [1].

The number of electrified towns and rural villages have highly increased in the last few years in accordance with the strategic plan and reached to a total number of 6,317 by July 7, 2012 which brought the electric energy access to 48.3%. The corporation has two electric energy supply systems that are the Interconnected System (ICS) and the Self Contained System (SCS). The main energy source of ICS is hydro power plants and also the SCS are mini-hydro and diesel power generators allocated in various areas of the country [1].

The ICS consists of 12 hydro, 11diesel standbys, one geothermal and two wind farm power plants with installed capacity of 1939.6MW, 112.3MW, 7.30MW and 81MW respectively which brought a total of 2140.2 MW. The SCS consists of three small hydro-powers and several diesel power plants. Generation in this system is mainly by diesel power plants having an aggregate capacity of 26.80 MW. The contribution from the small hydropower plants was only 6.15 MW of these Dembi small hydro power plants with 0.8 MW was out off operation since 2009. The total Generation capacity of EEPCo currently is about 2,167MW which is very low to demand of the country [1].The contribution of each source is listed in the following table.

Table 1-1: Installed capacity (MW) of ICS as of July 7, 2012

		Capacity(MW)					
		Hydro	Diesel	Geothermal	wind	Total	Initial year
1	Koka	43.2				43.2	1960
2	Awash II	32				32	1966
3	Awash III	32				32	1971
4	Fincha	134				134	1973/2003
5	Melka Wakena	153				153	1988
6	Tis abay	11.4				11.4	1964
7	Tis abay II	73				73	2001
8	Gilgel Gibe I	184				184	2004
9	Aluto Langano			7.3		7.3	1999
10	Kality		14			14	2004
11	Dire dawa		38			38	2004
12	Awash 7 Killo		35			35	2004
13	Tekeze	300				300	2009
14	Gilgel Gibe II	420				420	2010
15	Beles	460				460	2010
16	Amertinesh	97				97	2011
17	Ashegoda				30	30	2012
18	Adama				51	51	2012
	Sub total	1939.6	87	7.3	81	2114.9	
1	Alemaya		2.3			2.3	1958
2	Dire dawa(mu)		4.5			4.5	1965
3	Adigrat		2.5			2.5	1992,93,95
4	Axum		3.2			3.2	1975,92
5	Adwa		3			3	1998
6	Mekelle		5.7			5.7	1965
7	Shire		0.8			0.8	1975,91,93
8	Jimma		1.1			1.1	
9	1Nekempt		1.1			1.1	1984
10	Ghimbi		1.1			1.1	1962,84
11	Sub total	0	25.3	0	0	25.3	
	Ics sub total	1939.6	112.3	7.3	81	2140.2	

Table 1-2: Installed capacity (MW) of SCS as of July 7, 2012

		Capacity(MW)				
		Hydro	Diesel	Geothermal	Wind	Total
1	Yadot	0.35				0.35
2	Sor	5				5
3	Dembi	0.8				0.8
4	Isolated Diesel power plants		20.65			20.65
	SCS Sub Total	6.15	20.65			26.8
	EEPCo Total	1945.75	132.95	7.3	81	2167
	%	0.898	0.061	0.003	0.037	1

The electric energy generated from the main hydro power plants is transported by high voltage transmission lines rated 45, 66, 132, 230, and 400 kV. The total length of the existing transmission lines is about 11,796.32 km. The existing transmission lines status by voltage level is categorized as follows [1].

Table 1-3: Transmission network distance (km) by voltage level

Year	400KV	230KV	132KV	66KV	45KV	Total
2007/08	_	2175	3983.25	2234.6	475.93	8868.78
2008/09	_	2175	3983.25	2234.6	475.93	8868.78
2009/10	211.38	2235.02	4170.69	2234.6	430.15	9281.84
2010/11	686.701	3550.9	4033.21	2234.6	475.93	10981.34
2011/12	686.701	4222.976	4658.417	1973.136	255.09	11796.32

Power distribution in both ICS and SCS is effected at a primary voltage of 33, 19, 15 and 11 kV, consisting entirely of 3-phases, 3-wire feeders, and is stepped down to a utilization voltage of 380/220 V (3-phase, 4-wire) using 3-phase transformers to customer's level. The distribution system consists of 148,745.5 km of 33 kV, 19 kV, 15 kV and 11 kV; and 380/220 V lines; and 18,888 distribution transformers. The total distribution line status for the last five years was as stated below.

Table 1-4: Distribution line status

Year	2007/08	2008/09	2009/10	2010/11	2011/12
km	99110	120271	126038	138838	148,745

The total number of connected customers by the end of July 7, 2012 reached 1,900,000. This figure might have been higher than the billed customers at present.The current share of the country's energy is 89.8% hydro, 6.1% diesel, 3.7% winds and 0.3% geothermal.

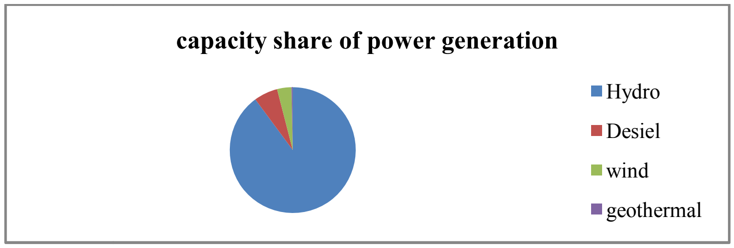


Figure 1-1**:** capacity Share of power generation

The country has launched the program called Universal Electric Accesses Program (UEAP). UEAP has been launched by the Government of Federal Democratic Republic of Ethiopia to meet the demand of agricultural sector (irrigation pumps), industrial and commercial sector, rural water supply installations, residential consumptions, and education and health sectors. This program has been working for the expansion of the existing grids to rural areas [1].

1.2 Statement of the Problem

The electricity supply in Ethiopia is extremely antiquated. With electricity consumption of 37kwh per capita per year, the country has one of the lowest consumption rates worldwide. Only approximately 15% of the population has access to the power grid. In the countryside, where around 85% of inhabitants live, this figure falls to only 1%. About 50% of the electricity is consumed in the capital, Addis Ababa [4, 5 and 43].

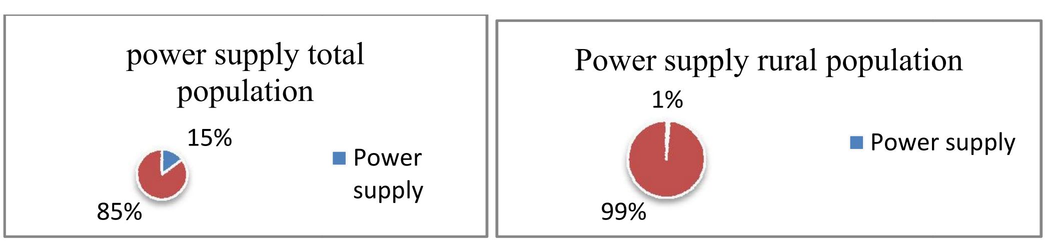


Figure 1-2: Power supply for total population and rural population

On account of the proximity to the equator the sun goes down at about 6:30 p.m. and from the early evening some form of lighting is required. As a rule this is provided by kerosene lamps. Approximately 40 liters of kerosene per lamp are burnt annually, producing around 80 Kg of CO2. A kerosene lamp, however, produces poor light and cause not only eye damage, but also emits harmful soot odour. Another source of power is dry cells which are used to operate radios and cassette recorders. When the batteries are flat they are simply thrown away because there is no recycling system [43]. They use diesel for grin milling, wood and cattle's dung for cooking purpose.

This activity is also the source of environmental pollution because of the burning of the wood and diesel. As the most rural community of Ethiopia, these villagers also lead their lives by crop production. But due to lack of electric power for water pumping for the irrigation purpose, the people cultivate their crops only in rainy seasons. Even the topographical nature is not suitable to use the rivers water for the irrigation purpose unless and other wise pumped using water pump. In some specific villages they use water for milling purpose. They used to charge their cell phone by going a long distance to the nearby town. The figure (fig.1.3) below shows the activities of people taken from the site.

Since most of the rural areas are located far away from the national grid, extending the grid may be very difficult and expensive. In addition, there is no infrastructure like roads and People in the rural areas are sparsely populated; such an extension of the grid to electrify rural areas is not economical. So, the suitable solutions for such problems are the implementation of standalone and hybrid electric power system at (near) the specific locations, using renewable energy resources like micro- hydropower, solar, wind and biomass .This method of electrification seems reasonable for the country, like Ethiopian, which has plenty of rivers and 13month sunshine .

1.3 Objective of the Study

General Objective: - The general objective of this thesis is to study the feasibility of PV/Wind/Micro-Hydro and biomass energy for the electrification of selected rural areas for the off-grid system in Ethiopia.

Specific objective:

- To assess wind, solar, micro-hydro and biomass (cattle's dung) energy resources in the areas (Kidusyohannes, Kundab and Debre) for the hybrid power generation system.
- To model the system for hybrid power generation inclusive of the resource mentioned.
- To analyze the system based on the available energy resources.
- To estimate the load based on the tangible (current) activities of the people in the area 24 hours.
- To model and simulate with the simulation software, HOMER (Hybrid Optimization and Modeling of Energy Renewable).
- To analyses the results and to see feasible solutions.

Figure 1-3: Different Activity of people in the area

1.4 Methodology

A). Site identifications:-The sites are found in North western parts of the country, Amahara regional state government, in sinan district. Among the villages in this district, three villages are selected and the system is modeled according to their resource. The following pictures show the sites from Google earth.

Figure1-4: location of sites, Kidusyohanes”(10° 30'24.74"N,37 ° 46' 15.52''), Kundab”(10° 27 ‘ 59“ N,37° 48’ 24”E) and Debre ”(10° 31’ 15.30” N , 37° 49’ 25.19”E)[20].

For Kidusyohanes and Kundab the hybrid system will contain all the resources considered (hydro, solar, wind and biomass) but for the Debre case only the wind, solar and biomass is considered due to lake of appropriate head for micro hydro. For case of reliability diesel generator may be included in the system of Debre.

B). Data collection:-The data required for the potential assessment of rivers (flow rate data) is collected from the Ethiopian ministry of water and energy. From this source for several years date is recorded and found in electronic media at the gauge station of the river. This datum is used by adapting to the specific site using ArcGIS software. Head of the river is measured using rope and location of the system is done from the field work by the author. For the case of biomass the data for dung production is found from local administrator body (Sinan District Agriculture and Rural Development office). For the case of solar radiation, Sunshine hour is found from the National Metrology agency of Ethiopia [3]. Based on this datum the radiation for the area is numerically calculated with the appropriate methodology. The result of these different sources is compared with the NASA and SWERA data and the worst case is considered. In the same way the wind speed data is collected from NASA and SWERA then by comparison the appropriate date is considered in to the system [12].

C). System analysis: Based on the datum collected, measured and calculated:-

- ✓ First the data which is found from different sources is analyzed and converted to suitable form.
- ✓ The load data for energy demand is calculated and estimated based on the people's socioeconomic activities and the possible load to be used.
- ✓ These load also scheduled again based the activity of the people in a 24 hour based and the possible load to be at a time.
- ✓ This load is forecasted for the next 10 years and the output of the simulation or the result is discussed based on this forecasted load.
- ✓ The system is modeled accordingly by using the soft ware, HOMER.
- ✓ The result is discussed based on output of the software from different perspective.
- ✓ Finally, the conclusion and recommendation is given.

1.5 Review of Related Literatures

In this sub section different literature which is related to this work are revised. The majority of the revised materials are the work which is done for Ethiopian Electrical power issue. The material includes Doctoral dissertation, thesis papers, journal papers, and world report papers.

A thesis paper entitled "Assessment of micro hydro potential of selected Ethiopian rivers" which is conducted at the North West part of the country by Tilahun A. [5] is studied the micro hydro power potential at the selected sites. He studied on the three different rivers named "Jedeb", "Temcha" and "Gilgel_Abay". He used HOMER software for system optimization and modeling and ArcGIS software for the treatment of hydro data. Finally he founds that the system is feasible for the local load considered with the excess energy of 50% as the tolerance for the increased demand in the future.

Doctoral thesis with the title called "Study in to the potential and feasibility of a standalone solar and wind hybrid electric energy supply system" by Bekele G. [4]. This dissertation is done with the help of HOMER software with the aim to investigate supplying electric energy from solar-wind hybrid resources to remotely located communities detached from the main grid line in Ethiopia. The study is done for 200 model families. From the result he founds that wind energy may be a viable option if integrated into other energy conversion systems such as PV, diesel generator and battery. In case of solar resource the result demonstrated the availability of extensive utilizable solar energy at each location. The feasibility is done in three different approaches. First the commonly available component is used for both the load side and supply side. In the second approach the best technologies available are compared and those with the highest efficiency are selected. A third approach followed is to see if cost is minimized by considering a self contained system, i.e., every household having its own supply system. The results obtained in the second approach have shown that the net present cost is less than 50 % of that for the first approach. The third approach is found to be of a higher cost.

The "feasibility of small-scale hydro/PV/wind based hybrid electric supply system" is done by Tadess G.[3] for the district of "Dejen" in Ethiopia to electrify 10,500 families. The model is done by using HOMER software with six different sites. He founds many feasible hybrid system combinations having a cost of energy less than $0.156/kWh.

A paper is done by Bekele G., Boneya G.[28] with the title called "Design of a Photovoltaic-Wind Hybrid Power Generation System for Ethiopian Remote Area". In this paper the outers have done to address the problem of electricity access for the model community in remote area of the country. They used the HOMER software for modeling the system. The load for the community is estimated in hourly bases. As a result they found different combination of feasible solutions.

A thesis paper by Mengesha A. [17] with the title called “Techno-economic Assessment of Wind Energy to Supply the Demand of Electricity for a Residential Community in Ethiopia” is done. He used HOMER software to analyze the optimization process and to identify the potential wind area and optimize cost effective wind energy system. From 34 sites with wind speed data from NASA three sites are selected with average wind speed (>4m/s) for the work. The three selected regions are Moyale, Mehalemeda and Negele. From this site he found that Moyale site is found to be ideal place to implement wind energy system. The optimization process is done for 100 hypothetical households by calculating the appliance. He identified the most cost effective system is the (2-FL100 wind turbine, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

Concerning biomass energy a journal paper is done by Dawit D. [14] entitled “Assessment of Biomass Fuel Resource Potential and Utilization in Ethiopia”: Sourcing Strategies for Renewable Energies. This paper assessed biomass fuel resource potential of Ethiopia and also investigated strategies for its modern utilization. The paper discussed different sourcing strategies for modern utilization of biomass as biomass gasification/Biogas, Liquid biofuel (biodiesel and bio-ethanol), Hydrogen energy (bio electrification) and Cooking stove technologies.

A report with the title “The REN 21 Renewable 2013 Global Status Report” [44] provides useful insight into the global renewable energy market and policy arena. Global investment in renewable energy decreased in 2012, but investment expanded significantly in developing countries. Renewable energy is spreading to new regions and countries and becoming increasingly affordable in developing and developed countries alike.

The “feasibility of Micro-Hydro Installation” is done for Strangford lough wild flowers and conservation association by Mark T.[33]. This thesis is concerned with a feasibility study for a micro-hydro scheme on a conservation site in Newtownards, Northern Ireland. The conservation site has an existing 10m dam behind which is a 4 acre lake; water flows through an existing outflow pipe continuously throughout the year. The study confirmed that the concept of a micro-hydro scheme using the existing dam is sound, and that a peak sustainable power output of 54kW could be achieved using a high efficiency vertical axis turbine.

The study paper by Dalelo A. [2] with the title “Rural Electrification in Ethiopia opportunities and bottlenecks” is exploring the opportunities and bottlenecks to rural electrification through stand alone or self-contained system. The study indicates that the country has a huge potential for rural electrification through the stand-alone system. There are, however, formidable challenges like low purchasing power, unfavorable public attitude towards the private sector and unfair regulations that work against development and dissemination of renewable energy technologies.

A thesis paper presents the “feasibility of combined wind–Hydro power station in Greece” by Maria S. [10]. An excel worksheet was built to simulate the operation of the overall power station. As a result a combined wind/hydro power plant could be a reliable solution for a remote island. It could not be provided 100% autonomy and the cheapest solution but using renewable as the main energy sources and the APS (autonomous power station i.e. diesel generator) as the auxiliary source it would be a trustworthy solution with numerous of environmental and economical benefits.

Tamirat B. [35] studies “Comparative Analysis of Feasibility of Solar PV, Wind and Micro Hydro Power Generation for Rural Electrification in the Selected Sites of Ethiopia”. The comparative is done based on monthly payment for Dilamo village and Gode. At Gode only PV and wind is compared. For Dilamo micro-hydro is found to be low cost .The wind system comes second in place. For Gode wind power generation cost is a little bit smaller than that of solar PV system.

Thesis paper with the title “A Feasibility Study on Wind Energy Resource for Utility-Scale Application in Gambia” by Philip N. [32] is discussed. This thesis paper presents a preliminary investigation on the suitability of Greater Banjul Areas (GBA) wind resources for utility-scale power generation.

A journal paper By Gaoqiang Z. ea al [24] entitled “Analysis on the impact of large-scale wind power accessing the power grid on Inner Mongolia grid” is presents the impact of large scale wind power on power grid. For the large-scale wind power accessing the power grid in Inner Mongolia, a quantitative study has been done from two aspects which are ancillary facilities of wind power project accessing to power grid and the average price and cost of purchasing electricity for power Grid Corporation. As a result from the aspect of ancillary facilities of wind power project accessing to power grid, the grid construction cost will increasingly grow with large-scale wind power accessing the power grid. Large-scale wind powers accessing the power grid also increases the purchasing electricity cost for the grid.

A study paper by GTZ [27] with the title" Wind Energy Program TERNA Site Selection Report Ethiopia" is discussed the selection of sites for wind turbines. The company tries to identify 11 sites by erecting 10m tower (for 9 sites) and 30m tower (for two sites) equipped with Anemometer, wind vane and data logger. The measurement has been done for 6 months. The company found that the maximum wind speed at Ashegoda (N-0562882, E-1484021) 9.47 m/s and Minimum wind speed Nefas Mewcha(N-0441319, E-1296313) 3.51 m/s .

1.6 Organization of the Thesis

This thesis has six chapters .The first of which gives the background of the country energy status and method of the study, objective of the study and the problems which motivates for the paper to be done. This chapter also discusses related literatures which are done by different authors. The second chapter has coverage of solar, wind and biomass energy resource and energy potential assessment methods. In the third chapter hydropower is discussed and all the drainage area and all the aspects of hydropower are presented in this chapter. The fourth chapters discuss the optimization of the system model, the load estimation as well as the input data is summarized in this chapter. The fifth chapter discuses the outputs of the simulation result in each site separately. In the final chapter, chapter six, recommendation, conclusion and suggestion for future works are given.

CHAPTER TWO

2 Renewable Energy Resources

2.1 Solar PV System and Solar Energy Potential Assessment

2.1.1 Introduction

Almost all type of renewable energy comes from the sun directly or indirectly. Wind energy is found because of uneven heating of the surface of the earth and it is known that hydropower depends on the availability of the rain around the area and the rain is also depends on wind and sun directly. We can use the sun energy as photovoltaic for electric production and heater for heat production.

Most of the developing countries are suffering from what many call the energy crisis, which is characterized by depletion of locally available energy resources and dependence on imported fuel. In fact, the energy crisis is believed to be the second most serious problem in these countries next to the food crisis. What is more, the energy crisis is exacerbating the food crisis by increasing the rate of deforestation and thereby causing degradation of farmlands. Furthermore, dependence on imported fuel is weakening the capacity of the concerned countries to buy food whenever the need arises. All these situations apply to Ethiopia. Traditional fuels contributed 99.9% of the rural energy consumption, with fuel wood being by far the most important source (81.8%), followed by dung (9.4%), crop residues (8.4%) and small amount of charcoal . On the whole, over 95% of the domestic energy needs are met from biofuel thereby contributing to deforestation, loss of soil nutrients and organic matter. In any case, Ethiopia is one of the countries that rely extremely on the biomass (Table 2.1). From the table we can observe that 86% of the total and 97% of the household energy consumption depends entirely on the biomass. Furthermore, biomass is expected to retain its dominant position in the coming decades. In fact, its contribution in rural areas is estimated to increase from 66% in 1992 to 68% in 2014 [2, 5].

Table 2-1: Household energy consumption as a percentage of total biomass consumption in a number of selected African countries [2]

country	Biomass energy consumption(% of total energy consumption)	Household energy consumption(% of total biomass energy)
Burundi	94	78.5
Ethiopia	86	97
Kenya	70	93
Somalia	87	92
Sudan	84	90
Uganda	95	78.6

The three most important rural energy sources, in their order of importance, are fuel wood, dung and agro-residue; while the three most important end users are mitad-baking, other cooking and lighting. The implication of this is that, if rural households are provided with electricity, even for lighting, the gain in terms of environmental protection of rural areas is significant [2].

Total renewable power capacity worldwide exceeded 1,470 gig watts (GW) in 2012. Hydropower rise to an estimated 990 GW. Globally, wind power accounted for about 39% of renewable power capacity added in 2012, followed by hydropower and solar PV, each accounting for approximately 26%. Solar PV capacity reached the 100 GW to pass bio-power and become the third largest renewable technology in terms of capacity (but not generation), after hydro and wind. By the end of 2012, renewable comprised more than 26% of total global power generating capacity and supplied an estimated 21.7% of global electricity, with 16.5% of total electricity provided by hydropower. The United States, Brazil, Canada, and Germany remained the above for total renewable electric capacity by the end of 2012.The top countries for non-hydro renewable power capacity were China, the United States, and Germany, followed by Spain, Italy, and India [44].

Table2-2: Renewable electric power capacity top regions and countries (GW), 2012[44].

Technology	world total	EU-27	BRICS	China	United States	Germany	Spain	Italy	India
Bio power	83	31	24	8	15	7.6	1	3.8	4
Geothermal power	11.7	0.9	0.1	0	3.4	0	0	0.9	0
Ocean(tidal)power	0.5	0.2	~0	0	0	0	0	0	0
Solar PV	100	69	8.2	7	7.2	32	5.1	16	1.2
concentrating solar thermal power	2.5	2	~0	0	0.5	0	2	0	0
wind power	283	106	96	75	60	31	23	8.1	18.4
Total renewable power capacity(no hydro)	480	210	128	90	86	71	31	29	24
Hydro power	990	119	402	229	78	4.4	17	18	43
Total renewable power capacity	1470	330	530	319	164	76	48	47	67

BIRCS: An association of emerging national economies including Brazil, Russia, India, China, and South Africa.

EU-27: The use of "European Union" or "EU" throughout refers specifically to the EU-27.

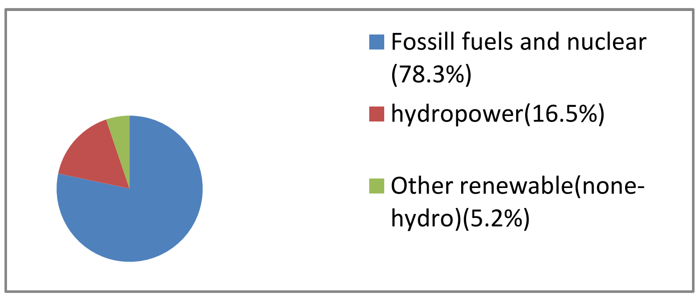


Figure 2-1: Estimated Renewable Energy share of Global electricity, end-2012 [44]

2.1.2 Over view of solar power

PV is starting to play a substantial role in electricity generation in some countries, meeting an estimated 5.6% of national electricity demand in Italy and about 5% in Germany in 2012, with far higher shares in both countries during sunny months. Italy and Germany both ended 2012 with more solar PV than wind capacity in operation, together accounting for almost half of the global total. Germany shares the largest solar PV energy in the world which is 32% which makes its total capacity share to 32.4GW and Italy follows second by accounting the share of 16% which is 16.4GW [44].

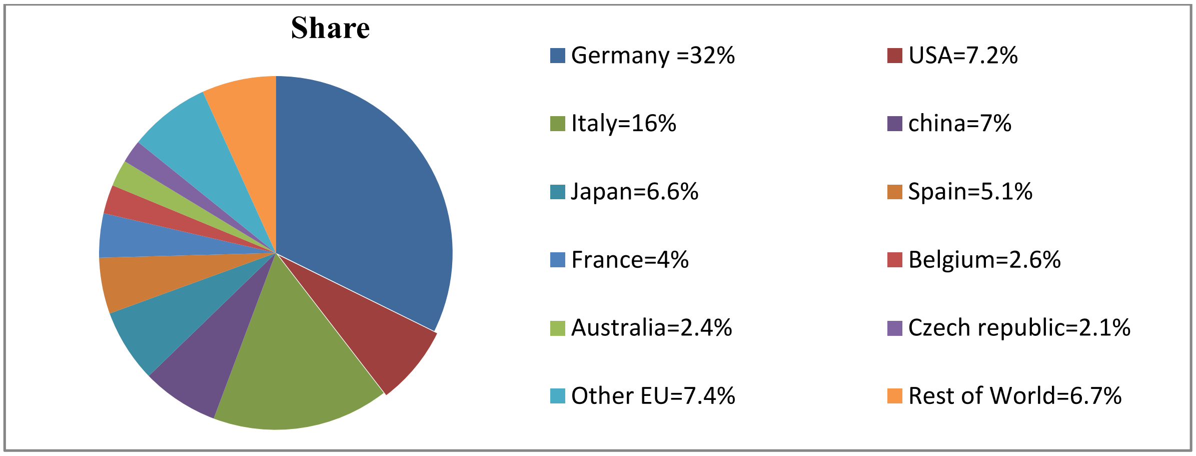


Figure 2-2: Solar PV global capacity, shares of top 10 countries, 2012 [44]

2.1.3 Solar Energy Resource in Ethiopia

Studies indicate that for Ethiopia as a whole, the yearly average daily radiation reaching the ground is 5.26 KWh/m2. This varies significantly during the year, ranging from a minimum of 4.55 KWh/m2 in July to a maximum of 5.55 KWh/m2 in February and March. On regional basis, the yearly average radiation ranges from values as low as 4.25 KWh/m2 in the areas of Itang in the Gambella regional state (western Ethiopia), to values as high as 6.25 KWh/m2 around Adigrat in the Tigray regional state (northern Ethiopia) [2]. An assessment study indicated in 2002, that the average daily solar radiation reaching the ground for Ethiopia as a whole is 5.2 kWh/m2 [43].

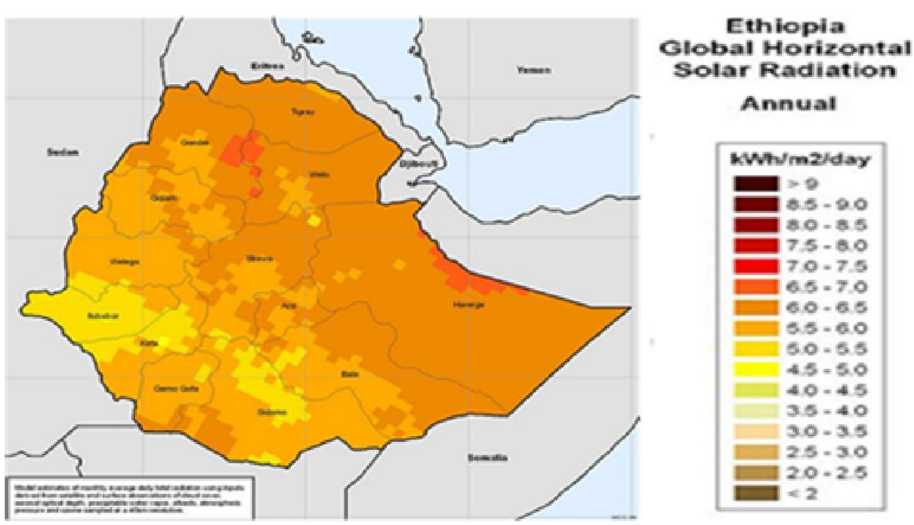


Figure 2-3: Global Horizontal solar radiation annually for Ethiopia [38]

The strength of the solar radiation in Ethiopia is expected to be the highest category of the world. Therefore the radiation can qualify to be the sole resource of energy for the country. So sun energy can bring an important contribution to a sustainable and decentralize energy mix for Ethiopia. But many solar energy technologies are still rather expensive - especially for a poor country like Ethiopia. Hence the use of photovoltaic systems is only worth to generate electricity for island net systems which cannot join the main grid. In contrast to the expensive PV systems, solar thermal system is already affordable today [43].

2.1.4 Source of Solar Energy

Solar energy is the energy which is found from the. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^{9}m and is, on the average 1.5×10^{11}m from the earth. As seen from the earth the sun rotates its axis once about every four weeks. However it does not rotate as a solid body and the equator takes about 27 days and the Polar Regions take about 30 days for each rotation [2, 6].

The Sun’s spectral distribution is the range and intensity of the wavelengths in its emitted radiation. This is a very important matter because different types of solar cell respond differently to the various wavelengths in sunlight. It is well known that the Suns spectrum is similar to that of a perfect emitter, known as a black body, at a temperature of about 6000 K. The smooth curve in Figure 2.4(b) shows that such black body radiation spreads over wavelengths between about 0.2 and 2.0 μm, with a peak around 0.5 μm. The range of wavelengths visible to the human eye is about 0.4 μm (violet) to 0.8 μm (red). Shorter wavelengths are classed as ultraviolet (UV), longer ones as infrared (IR). The figure shows two more curves, labeled AM0 and AM1.5, representing actual solar spectral distributions arriving at Earth. To explain these we need to consider the path length or Air Mass (AM) of sunlight through the atmosphere. AM0 refers to sunlight just outside the atmosphere (path length zero) and is therefore relevant to PV used on Earth satellites. In the case of terrestrial PV, the path length is the same as the thickness of the atmosphere (AM1) when the Sun is directly overhead. But if it is not overhead the path length increases.

When solar cells are installed at or near ground level, they generally receive indirect as well as direct solar radiation as shown in Figure 2.4(a). The diffuse component represents light scattered by clouds and dust particles in the atmosphere; the albedo component represents light reflected from the ground or objects such as trees and buildings. The electrical output from the cells depends on the combined effect of all components – direct, diffuse, and albedo [9].

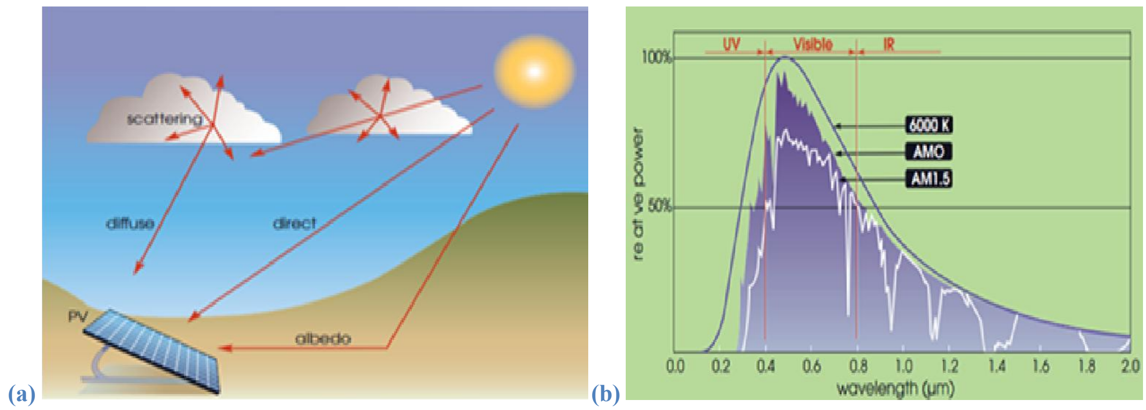


Figure 2-4: (a) Solar radiation from the sun to PV through atmosphere; (b) spectral distributions of solar energy [9]

2.1.5 The Solar Constant and Angels

The solar constant, Gsc, is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth sun distance outside of the atmosphere [2].

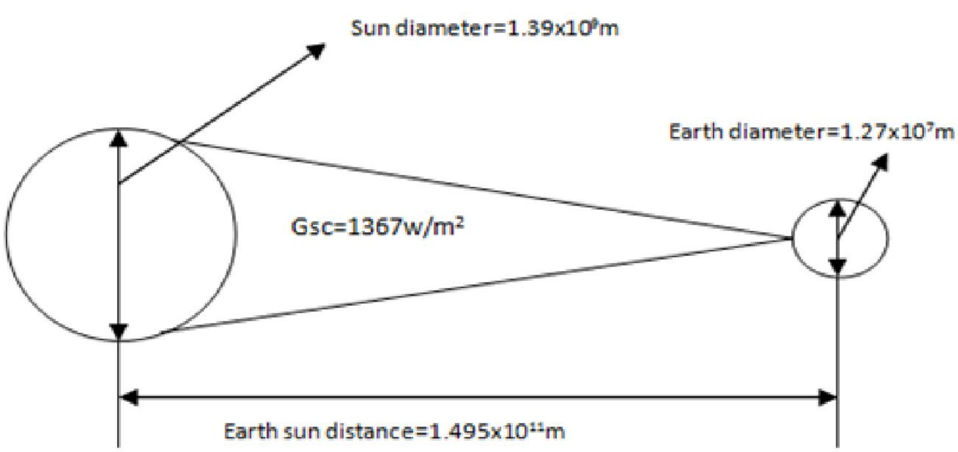


Figure 2-5: Sun-Earth Relationship [2]

2.1.6 Energy Production in Photovoltaic Systems

2.1.6.1 Characteristics of Diode

With positive and negative bias voltage in the circuit of diode and the current I_0 (dark saturation current), Id (diode current); the diode current growing rapidly above about 0.6 V. Figure 2.6 shows the diode characteristics.

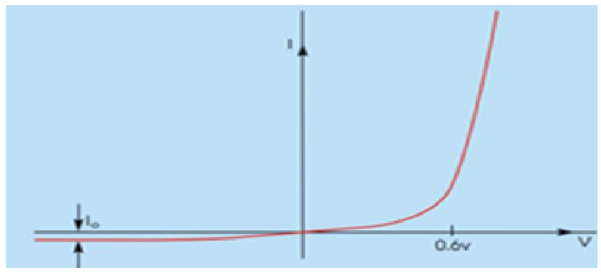


Figure 2-6: The voltage- current characteristic of a silicon diode [9, 22]

Mathematically the curve is expressed as:

$$I_d = I_0 \left[\exp\left(\frac{qV}{KT}\right) - 1\right] \text{---} \quad (2.1)$$

Where: q is the charge on an electron

: K is Boltzmann's constant, and T is the absolute temperature. [9].

2.1.6.2 Photons in Action

A stream of photons containing minute packets or quanta of energy shines on the cell. Various possible fates await them, some productive, others fruitless. The productive photons will generate minority carriers that take centre stage in solar cell. The basic reason may be simply stated: a potential barrier that inhibits transfer of majority carriers across a p-n junction positively encourages the transfer of minority carriers. Whereas majority carriers experience 'a hill to climb', minority carriers see 'a hill to roll down'. With luck they are swept down this hill, collected at the cell terminals, and produce an output current proportional to the intensity of the incident light [9].

2.1.6.3 Power Generating

The minority carrier which is created by the solar photons speeds towards the solar cell's output terminals under the magical influence of the p-n junction. The figure 2.7 (a) below consists of a diode representing the action of the p-n junction together with a current generator representing the light generated current I_L.

In dark conditions I_L is zero and the cell is quiescent. If an external voltage source is connected the cell behaves just like a semiconductor diode with the characteristic shown in part (b) of the figure. In sunlight the generator produces a current I_L proportional to the level of insolation. It is effectively superimposed on the normal diode characteristic, and we may write:

$I = I_d - I_L$ -- (2.2)

Substituting for the diode current using Equation (2.1) gives:

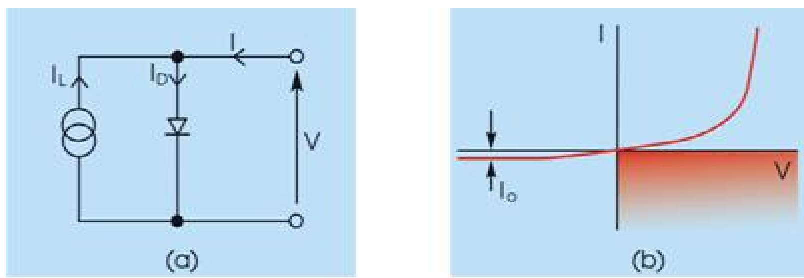


Figure 2-7: (a) The equivalent circuit of a solar cell; (b) its I-V characteristics [9]

$$I = I_0 \left[\exp\left(\frac{qV}{KT}\right) - 1\right] - I_L \quad (2.3)$$

This equation confirms that the diode I–V characteristic is shifted down into the fourth quadrant by an amount equal to the light - generated current IL as shown in fig 2.8(a). so For convenience the I–V characteristics of a solar cell are normally ‘ flipped over ’ to the first quadrant. In general the cell’s power output equals the product of its voltage and current. No power is produced on open circuit (maximum voltage, zero current) or short circuit (maximum current, zero voltage). The full rated power is obtained by operating the cell slightly below maximum voltage and current at its maximum power point (MPP). The I_V characteristics suggest another important aspect of the solar cell it is helpful to think of it as a current source rather than a voltage source like a battery. At a given insolation level the solar cell provides a more or less fixed current over a wide range of voltage. The maximum voltage of the cell, its open circuit voltage Voc, is given by the intercept on the voltage axis and lays in the range 0.5 V – 0.6 V. The maximum current from the cell, its short circuit current Isc, is given by the intercept on the current axis and is proportional to the strength of the sunlight. It represents the full flow of minority carriers generated by the sunlight and successfully ‘collected’ after crossing the p-n junction [9].

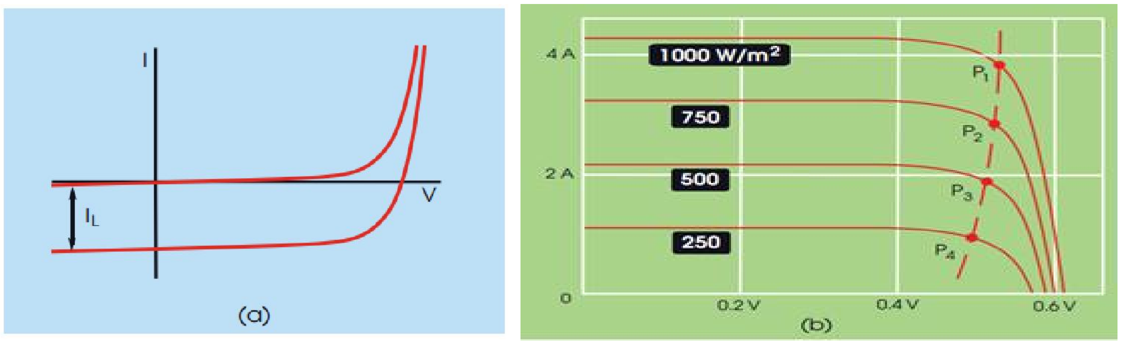


Figure 2-8: (a) The light generated current shifts the cell’s characteristics into the fourth quadrant; (b) A family of I-V curves for a 2wp solar cell [9]

The above parameters are further illustrated by Figure 2.9. The blue curve shows a typical I-V characteristic at 1000 W/m 2 insolation, labeled with the short circuit current, open circuit voltage, and maximum power point. The red curve shows how power output varies with voltage; the maximum value is $P_{mp} = I_{mp} \times V_{mp}$. Since the current holds up well over most of the voltage range, it follows that the cell’s output power is roughly proportional to voltage up to the MPP. This emphasizes once again the importance of operating the cell close to the MPP, if its power output potential is to be realized.

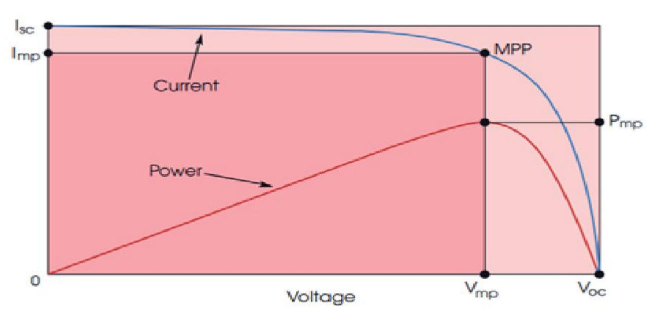


Figure 2-9: current and power at standard isolation [9]

2.1.6.4 Equivalent Circuit of Photovoltaic Cell

When solar cell is exposed to sunlight photons are absorbed and hole-electron pairs may be formed. If these mobile charge carriers reach the vicinity of the p-n junction, the electric field in the depletion region will push the holes into the *p*-side and push the electrons into the *n*-side, as shown in fig 2.10. The *p*-side accumulates holes and the *n*-side accumulates electrons, which creates a voltage that can be used to deliver current to a load. If electrical contacts are attached to the top and bottom of the cell, electrons will flow out of the *n*-side into the connecting wire, through the load and back to the *p*-side. Since wire cannot conduct holes, it is only the electrons that actually move around the circuit.

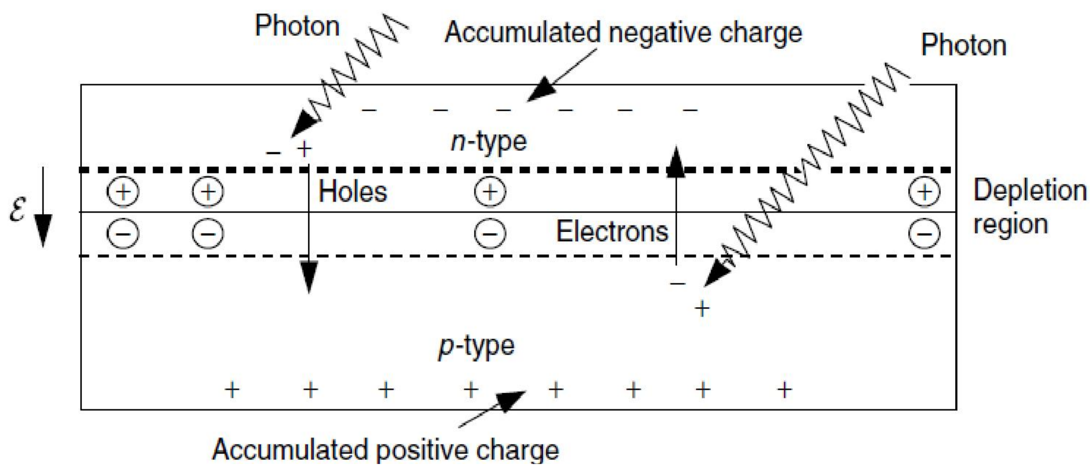


Figure 2-10: Formation of equivalent cell of photon [22]

Figure 2.10 shows a PV equivalent circuit that includes some parallel leakage resistance Rp. The ideal current source I_S, series resistance Rs. R_S might be contact resistance associated with the bond between the cell and its wire leads, and some might be due to the resistance of the semiconductor itself [22].

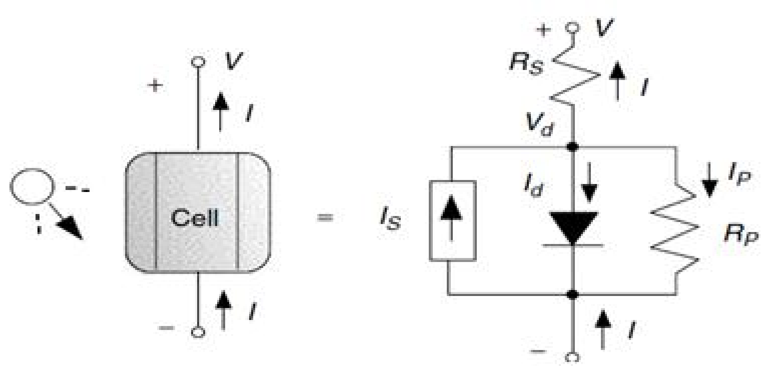


Figure 2-11: Equivalent circuit of a solar cell [22, 26]

Using Kirchhoff's current low at the node of the diode

$I_s = I + I_d + I_p$ -- (2.4)

$I= I_s - I_d- I_p$

The value of V_d is found from spread sheet and voltage across each cell is found by:

$V = V_d - IR_s$-- (2.5)

$I= I_s - I_0\{\exp [\frac{q(v+I.Rs)}{KT}]-1\}-(\frac{V+I.Rs}{Rp})$ ------------------------------- (2.6)

Where:

I=the load current (A)

I_p=current through the parallel resistance (A)

I_d=the diode current (A)

I_s=current produced by the cell (A)

I_o=reverse saturation current of the diode (A)

V=output voltage (V)

q=charge on an electron(C)

K=Boltzmann's constant

T=working temperature of the cell (K)

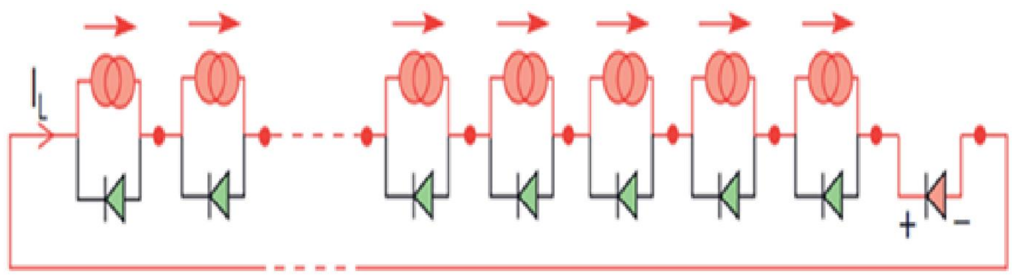
2.1.6.5 Connecting of Cells, Modules and Power Output From the PV Cell

Since an individual cell produces only about 0.5 V, it is a rare application for which just a single cell is of any use. Instead, the basic building block for PV applications is a module consisting of a number of prewired cells in series .Multiple modules, in turn, can be wired in series to increase voltage and in parallel to increase current, the product of which is power. The combination of modules series and in parallel referred to as an array.

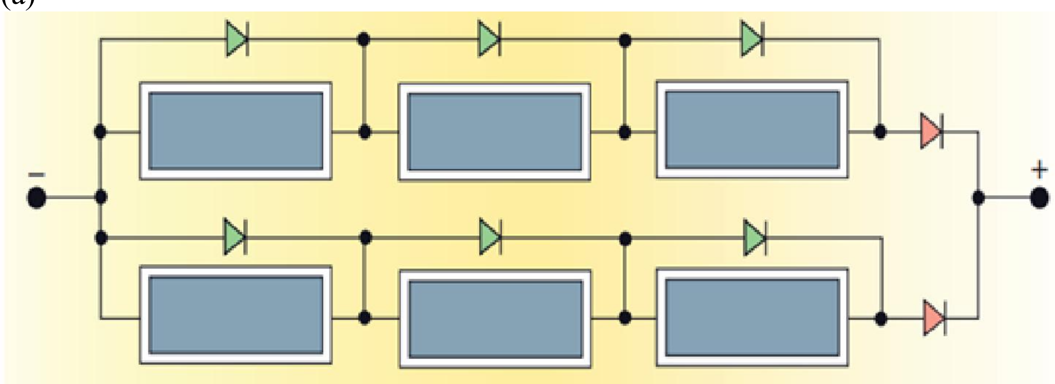
There are also bypass diodes, one in parallel with each module, to provide a current path around the module if it fails or becomes bad. In addition there are two diodes referred to as blocking diodes, one in series with each string, to ensure that current only flows out of the modules. They are generally used in battery charging systems to prevent the batteries from discharging back through the modules at night. The module voltage V can be easily found by multiplying the number of cells in the module *n*.

$V_{module} = n(V_d - IR_S)$--(2.7)

$P_{(watts)} = V_{module}\, I$ --(2.8)



(a)



(b)

Figure 2-12:(a) connection of cells; (b) modules to form an array [9, 22]

2.1.7 Solar Radiation Estimations

To design and analyze solar systems, we need to know how much sunlight is available. The sun light which is received on the surface of the earth is depending on different factors. The position of the sun in the sky, the slop and orientation of collector surface, the surrounding area (whether it is reflector or absorber), the shading and obstructing object are the most common factor. As shown in Fig. 2.13, the angle formed between the plane of the equator and a line drawn from the center of the sun to the center of the earth is called the solar declination, *δ*. It varies between the extremes of ± 23.45◦. Where n is the number of the day of the year starting 1 at January 1.

$\delta = 23.45 \sin\left(360\frac{284+n}{365}\right)$

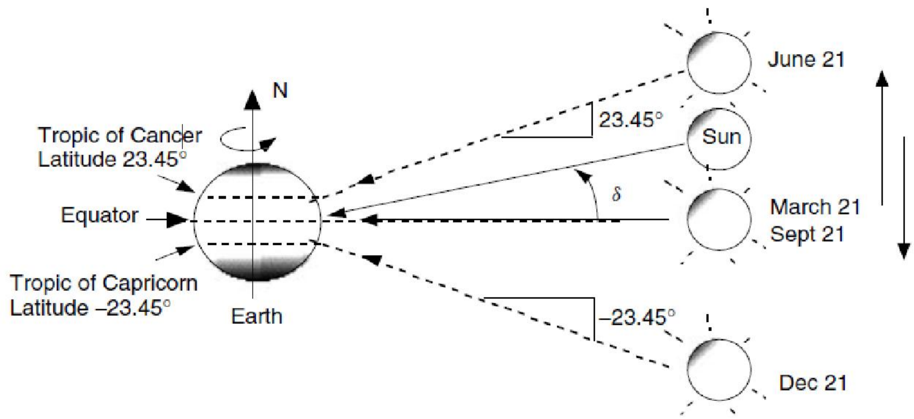


Figure 2-13: The angle between the sun and the equator (declination) δ [22].

The geometric relationships between a plane of any particular orientation relative to the earth at any time (weather plane is fixed or moving relative to the earth) and the incoming beam solar radiation, that is, the position of the sun relative to that plane can be described in terms of several angles. Some of the angles are indicated in the figure below [2].

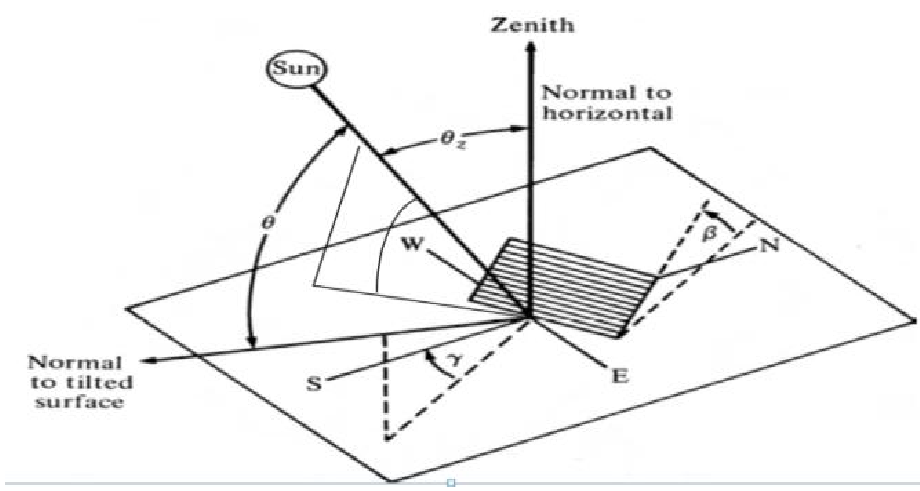


Figure 2-14: The position of the sun relative to the plane [2]

Where:

- Φ: Latitude, the angular location north or south of the equator, north positive; $-90^0 \leq \Phi \leq 90^0$
- B: slope, the angle between the plane of the surface in question and the horizontal; $0^0 \leq \beta \leq 180^0$. ($\beta > 90^0$ means that the surface has a down word facing component)

- γ: surface azimuth angle, the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, west positive;$-180^0 \leq \gamma \leq 180^0$.
- Ω: hour angle, the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, morning negative afternoon positive.
- θ: Angle of incidence, the angle between the beam radiation on a surface and the normal to that surface.

Additional angels to define the position of the sun in the sky are

- θ_z: Zenith angle , the angle between the vertical and the line to the sun, i.e., the angle of incidence of beam radiation on a horizontal surface.
- α_s : solar altitude angle, the angle between the horizontal and the line to the sun ,i.e., the complement of zenith angle.
- γ_s : solar azimuth angle, the angular displacement from south of the projection of the beam radiation on the horizontal plane. Displacement east of south is negative and west of south is positive.

From the above listed angles we can get numerical expression to get the radiation to interest. The angle of incidence θ, can be expressed interims of the other angels [2].

$$\cos\theta=\sin\delta \sin\Phi \cos\beta - \sin\delta \cos\Phi \sin\beta \cos\gamma+\cos\delta \cos\Phi \cos\beta \cos\omega+\cos\delta \sin\Phi \sin\beta \cos\gamma \cos\omega +\cos\delta \sin\beta \sin\gamma \sin\omega$$

$$\sin\alpha_s=\sin\Phi\sin\delta+\cos\Phi\cos\omega\cos\delta$$

$$\cos\theta_z=\sin(90^0-\theta_z)= \sin\alpha_s$$

$$\sin\gamma_s= \sin\omega \cos\delta / \sin\alpha_s$$

$$\omega=15^0(12-t_{loc})$$

where t_{loc}=local solar time in hours.

$$\omega_s=\cos^{-1}(\tan\Phi\tan\delta)$$

Where: ω_s sun rise/sun set angle

Considering the two sources of variation in extraterrestrial radiation we can write the following equation, i.e., variation in the radiation emitted by the sun and the sun earth distance variation.

$G_{on=}G_{sc}\left[1+0.033\cos\frac{360\,n}{365}\right]$ -- (2.9)

Where:

G_{on} the extraterrestrial radiation, measured on the plane normal to the radiation on the n^{th} day of the year.

The extraterrestrial radiation on a horizontal surface is given by
$G_o=G_{on}\cos\theta_z$

$\cos\theta_{z=}\cos\delta\cos\omega+\sin\delta\sin\Phi$

$G_o = G_{sc}(1+0.033\cos\frac{360n}{365})*(\cos\Phi\cos\delta\cos\omega+\sin\delta\sin\Phi)$ ------------------(2.10)

To get daily extraterristerial radation on horizontalsurface ,H_o we integrat eqn. 2.10 from sun rise to sun set angles and we get

$H_o = \frac{24*3600*Gsc}{\pi}\left(1+0.033\cos\frac{360nd}{365}\right)*(\cos\Phi\cos\delta\sin\omega_s+\frac{\pi\omega s}{180}\sin\delta\sin\Phi)$ ----(2.11)
Where:

ωs = sun set hour angle

n_d =The n^{th} day of the year

Radiation data are the best source of information for estimating avarage incident radiation. Lacking these or data from nearby location of simillar climate,it is possible to use empirical relashin ships to estimate radiation from hours of sunshine or cloudness.The original Angstrom-type regration equation related monthily avarage daily radiation,H, to extraterristerial radation ,$H_{o,}$for the location [2].

$H=H_o(a+b\frac{n}{N})$ --(2.12)

Where:

a and b are constants depending on the location. The maximum possible daily hours of bright sunshinegiven(N) is given by equation:

$N = \frac{2}{15}\cos{-1}\ (\tan\delta\tan\Phi)$

n= sunshine hours

The values of constants “a” and “b” depends on the location i.e., the surrounding area and has the average value a=0.33 and b=0.43[3, 28] and the value of Φ is 10.533^0 [20].

2.1.7.1 Methods of Solar Radiation Estimation

Need for estimation: Before installing a solar energy system, it is necessary to predict both the demand and the likely solar energy available, together with their variability. Ideally, the data required to predict the solar input are several years of measurements of irradiance on the proposed collector plane. These are very rarely available, so the required (statistical) measures have to be estimated from meteorological data available either (i) from the site, or (ii) (more likely) from some ‘nearby’ site having similar irradiance, or (iii) (most likely) from an official solar atlas or database [26].

2.1.7.2 Sunshine Hours as a Measure of Insolation

All major meteorological stations measure daily the hours of bright sunshine, n. Records of this quantity are available for several decades. It is traditionally measured by a Campbell–Stokes recorder, which comprises a specially marked card placed behind a magnifying glass. When the sun is ‘bright’ a hole is burnt in the card. The observer measures n from the total burnt length on each day’s card. Sunshine hours are also measured by electronic devices. Many attempts have been made to correlate insolation with sunshine hours, usually by an expression of the form eqn. 2.12 [26].

2.1.7.3 Satellite Estimates

Geostationary meteorological satellites can produce maps of estimated global insolation across a continent, without using sunshine-hour data as an intermediary. In essence, instruments on the satellite measure separately the radiation coming in from the Sun and that reflected from the Earth; the difference is that reaching the Earth’s surface. Many of the data are available from websites, best found with a web search engine [26].

The sunshine duration data for the nearby station from the selected area is found for Debere markose [3].This data is converted to the sunshine radiation form by the appropriate empirical formula. This value will be compared with the data which is found from NASA and SWERA. All other values are calculated using the formula. By using this formula the angle is calculated as: $\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right)$

Table 2-3: The declination angle and average days of menthes [16]

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
Days of the month	31	28	31	30	31	30	31	31	30	31	30	31
m	-	31	59	90	120	151	181	212	243	273	304	334
Average days for months(i)	17	16	16	15	15	11	17	16	15	15	14	10
n day of year(i+m)	17	47	75	105	135	162	198	228	258	288	318	344
$\delta(^0)$	-20.9	-13.0	-2.4	9.4	18.8	23.1	21.2	13.5	2.2	-9.6	-18.9	-23.0

using eqn.2.12 and the value of a=0.33 and b=0.43 the following result is found for comparison.

Table 2-4: Solar radiation from different sources

months	$\omega_s(^0)$	N	n(sunshine hours)	Ho kwh/m^2/d	n/N	H (calcuated) kwh/m^2/d	NASA kwh/m2/d	SWERA KWh/m^2/d
JAN	94.07	12.54	9.9	8.7	0.79	*5.83*	*6.32*	*1.82*
FEB	92.46	12.33	10.1	9.6	0.82	*6.55*	*6.74*	*1.62*
MAR	90.45	12.06	8.4	10.4	0.7	*6.56*	*6.68*	*1.29*
APR	88.24	11.77	8	10.9	0.68	*6.78*	*6.62*	*1.62*
MAY	86.37	11.52	8.1	11	0.7	*6.94*	*6.19*	*1.37*
JUN	85.45	11.93	7.3	11	0.61	*6.52*	*5.48*	*0.61*
JUL	85.86	11.45	5.8	10.9	0.51	*5.99*	*4.96*	*0.67*
AUG	87.44	11.66	4.9	11	0.42	*5.62*	*5.07*	*0.83*
SEP	89.59	11.95	7.9	10.7	0.66	*6.57*	*5.63*	*1.19*
OCT	91.8	12.24	9.1	9.9	0.74	*6.42*	*5.93*	*1.56*
NOV	93.65	12.49	9.5	9.8	0.76	*6.44*	*6.14*	*1.85*
DEC	94.53	12.6	9.7	8.5	0.77	*5.62*	*6.14*	*1.48*
AV						*6.24*	*5.99*	*1.33*

As it is observed from the table 2.2 and Figure 2.15 the value which is found from SWERA is very low in comparison from the calculated and NASA value. The solar radiation value from NASA and calculated is almost similar. For this purpose the value of solar radiation which is found from the calculated value is used as the input for the software.

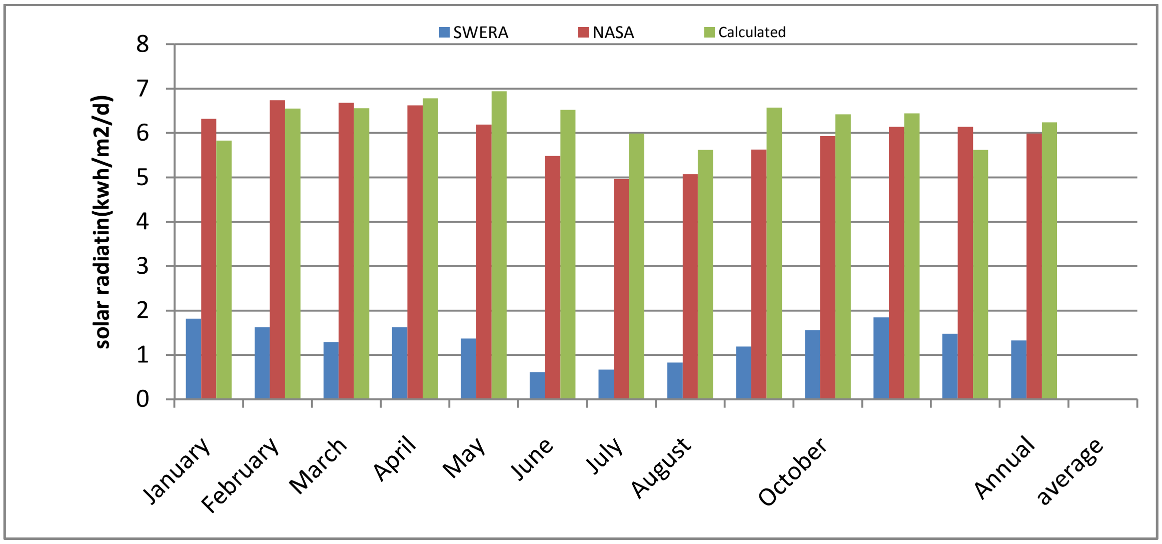


Figure 2-15: Solar radiation from different sources

2.2 Wind Power System and Wind Resource Assessment

2.2.1 Over view of Wind power

Wind results from expansion and convection of air as solar radiation is absorbed on Earth i.e. wind energy is created because of the difference in temperature of the earth, the wind is solar power in mechanical form. On a global scale these thermal effects combine with dynamic effects from the Earth's rotation to produce prevailing wind patterns. In addition to this general or synoptic behavior of the atmosphere there is important local variation caused by geographical and environmental factors. Wind speeds increase with height, and the horizontal components are significantly greater than the vertical components [26].

During 2012, almost 45 GW of wind power capacity began operation, increasing global wind capacity 19% to almost 283 GW. The top 10 countries accounted for more than 85% of year-end global capacity. From the end of 2007 through 2012, annual growth rates of cumulative wind power capacity averaged 25%. Africa and the Middle East saw little development, but Tunisia almost doubled its capacity, adding 50 MW; Ethiopia joined the list of countries with commercial-scale wind farms, installing 52 MW; and construction began on several South African projects totaling more than 0.5 GW [44].

Table 2-5: wind power Global capacity, Top 10 countries, 2012[44].

country	china	United stats	Germany	Spain	India	United Kingdom	Italy	France	Canada	Portugal	World Total
share GW	60.8/ 75.3	60	31.3	22.8	18.4	8.4	8.1	7.6	6.2	4.5	283

Note! For china left hand side is officially added to the grid but right hand side is total installed capacity

2.2.1.1 Wind Power Resource in Ethiopia

Ethiopia also has exploitable reserve of 1,350GW wind energy with an average speed of 3.5–5.5m/s, 6 hours/day. Small towns, villages, farms and other scattered loads in remote areas provide ideal situation in which electricity generation from wind is convenient compared to conventional diesel generation or grid connection [42]. The available information identifies two basic zones with homogenous periodicity separated by the rift valley. In the first of these, covering most of the highland plateaus, there are two well-defined wind speed maximal occurring, respectively, between March and May and between September and November, according to location. In the second zone, covering most of the Ogaden and the eastern lowlands, average wind velocity reaches maximum values between May and August [2].

Figure 2-16:Adama1 wind farm 51MW and Ashegoda wind farm 120MW (left to right respectively [1]

The country has installed 51MW Wind power which is known as Adama1 and began production in 2011.Ashegoda wind farm is also inaugurated with a capacity of 120MW in 2013 [1]. So, the country still installs 171 MW wind farm. Figure 2.16 depicts this fact from the areas.

2.2.2 Energy Harvesting From Wind

Wind power is the conversion of wind energy into electricity. This is achieved using wind turbines, which convert the kinetic energy of wind in to electrical energy as follows: Wind turns propeller-like blades around a rotor. The rotor, which is made up of the blades and hub, causes a low-speed shaft to turn at approximately 30-60 rotations per minute (rpm). The low-speed shaft connects to a 2 or 3 stage speed-increasing gearbox that connects it to a high-speed shaft and increases the rpm to approximately 1000-1800 rpm. This is the rotational speed most generators require to produce electricity. The high-speed shaft drives a generator. The generator produces electricity. The process of converting wind power to electricity is clean, environmentally sound and, as long as the sun keeps shining and winds are created, completely renewable [22].

2.2.3 Types of Wind Turbine

One way to classify wind turbines is in terms of the axis around which the turbine blades rotate.

a).Horizontal axis wind turbines (HAWT)
b).Vertical axis wind turbine which is with blades that spins around a vertical axis (VAWT).

The principal advantage of vertical axis machines that they don't need any kind of yaw control to keep them facing into the wind. A second advantage is that the heavy machinery contained in the nacelle (the housing around the generator, gear box, and other mechanical components) can be located down on the ground, where it can be serviced easily. Since the heavy equipment is not perched on top of a tower, the tower itself need not be structurally as strong as that for a HAWT. There are several disadvantages of vertical axis turbines, the principal one being that the blades are relatively close to the ground where wind speeds are lower and there is a wind shadowing effect of the tower. The horizontal axis wind turbine must be strong in order to carry the nacelle.

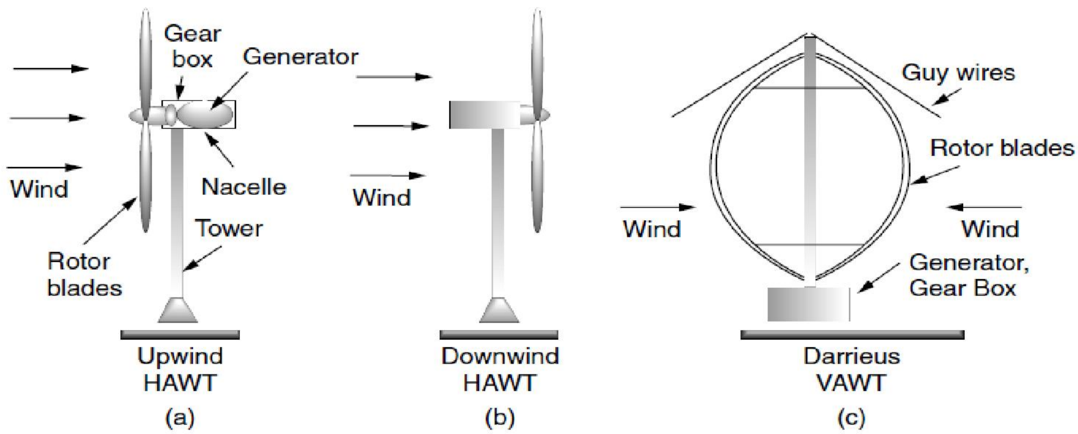


Figure 2-17: HAWT :(a) upwind machines; (b) downwind machines; (VAWT) (c) [22]

2.2.4 Internal Parts of Wind Turbine

A wind turbine has different components. The inter operation of these components enable the turbine fully functional .The following figure shows the components mainly (internal components) of wind turbine.

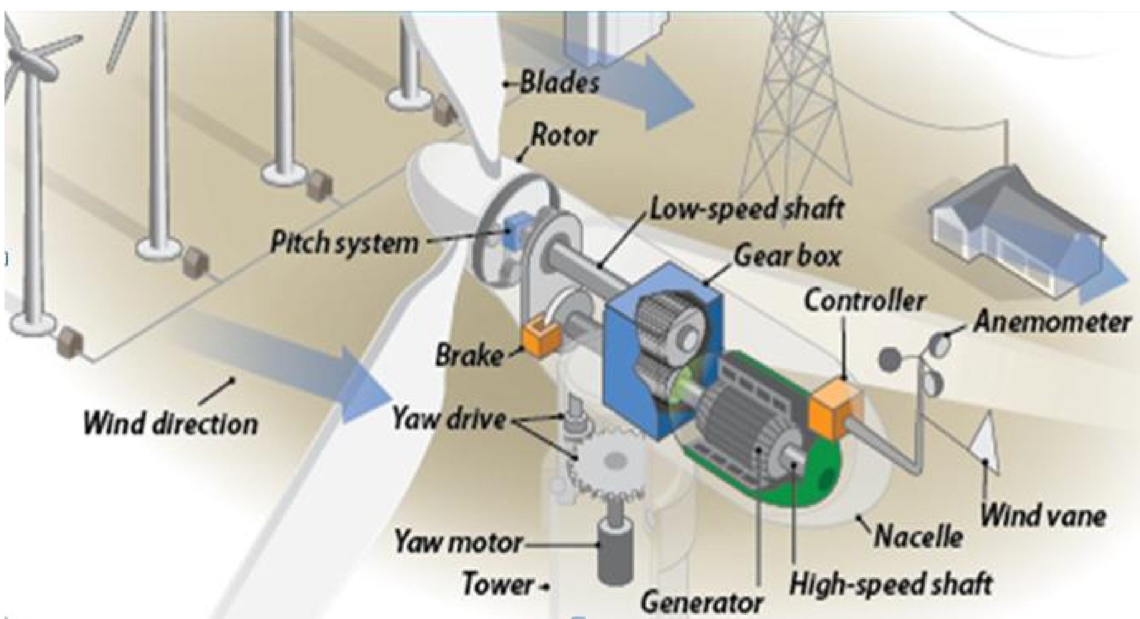


Figure 2-18: Parts and functions of wind turbine [15]

Anemometer:-Measures the wind speed and transmits wind speed data to the controller.

Blades:-Lifts and rotates when wind is blown over them, causing the rotor to spin. Most turbines have either two or three blades.

Brake:-Stops the rotor mechanically, electrically, or hydraulically, in emergencies.

Controller:-Starts up the machine at Rated wind speeds and shuts off the machine at cut off wind speed. Turbines do not operate at wind speeds above about cut off speed because they may be damaged by the high winds.

Gear box:-Connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator:-Produces 50/60-cycle AC electricity; it is usually an off-the-shelf induction generator.

High-speed shaft:-Drives the generator.

Low-speed shaft:-Turns the low-speed shaft at about 30-60 rpm.

Nacelle:-Sits atop the tower and contains the gear box, low and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.

Pitch:-Turns (or pitches) blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor:-Blades and hub together form the rotor.

Tower:-Made from tubular steel, concrete, or steel lattice and it Supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction:-Determines the design of the turbine. Upwind turbines face into the wind while downwind turbines face away.

Wind vane:-Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw Motor: - Powers the yaw drive.

Yaw Drive: - Orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines don't require a yaw drive because the wind manually blows the rotor away from it.

2.2.5 Wind Power Probability Density Functions

The type of information displayed in the discrete wind speed histogram is very often presented as a continuous function, called a probability density function. The defining features that the area under the curve is equal to unity, and the area under the curve between any two wind speeds equals the probability that the wind is between those two speeds expressed mathematically.

f (v) = wind speed probability density function

Probability ($v1 \leq v \leq v2$) $=\int_{v1}^{v2} f\ (v)\ dv$

Probability ($0 \leq v \leq \infty$) $=\int_{0}^{\infty} f\ (v)\ dv = 1$

The average wind speed can be found using a probability density function in much the same manner as it was found for the discrete approach to wind analysis [22].

$V_{avg} =\int_{0}^{\infty} v\ f\ (v)\ dv$

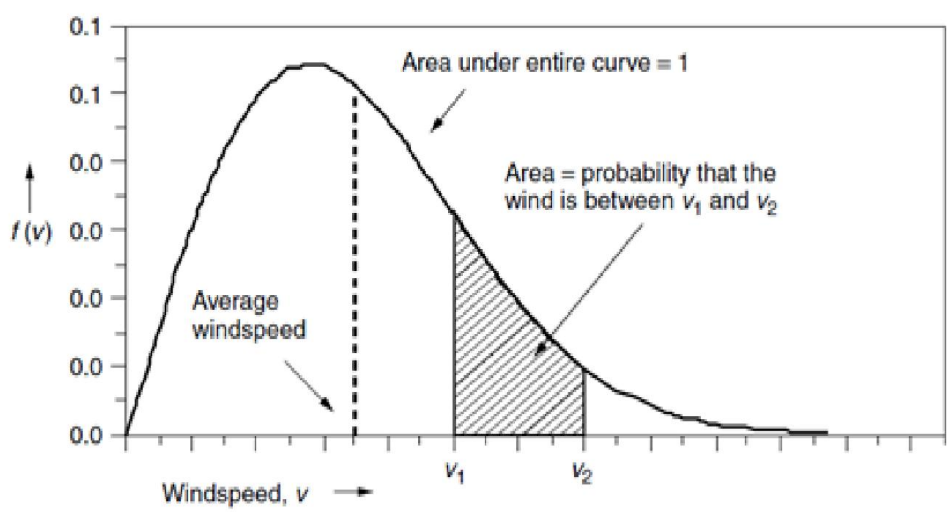


Figure 2-19: A wind speed probability density function [22]

2.2.6 Weibull and Rayleigh Assumption

A very general expression that is often used as the starting point for characterizing the statistics of wind speeds is called the Weibull probability density function [22].

$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}$ exp [-$(\frac{v}{c})$ ^{k}] Weibull probability density function

Where k is called the shape parameter and c is called the scale parameter. When the shape parameter k is equal to 2, the probability density function is given its own name, the Rayleigh probability density function:

f$(v) = \frac{2v}{c2}$ exp[-$(\frac{v}{c})$ ^{2}] Rayleigh probability density function.

There is, in fact, a direct relationship between scaling factor c and average wind speed v.

$$v_{ave} = \int_0^\infty v\, f(v) dv = \int_0^\infty \frac{2v2}{c2}\ exp\left[-\left(\frac{v}{c}\right)2\right] = \frac{\sqrt{v}}{2}\ c \cong 0.886c$$

Using the eqn. 3.1, the wind speed is changed to the designed height [3, 4, and 22].

$$\frac{V}{V0} = \frac{\ln\left(\frac{H}{Z}\right)}{\ln\left(\frac{H0}{Z}\right)} \text{ --- } (3.1)$$

Where:

- Ho →Reference height (m)
- H →Height where wind speed is to be determined (m)
- Z →Measure of surface roughness, is called roughness length
- V →Wind speed at height of H (m/s)
- Vo →Wind speed at the reference height, Ho (m/s)

  The value of z is determined according to the terrain property.

2.2.7 Energy Output from Wind Turbine

Wind turbine cannot extract all of the energy from the upcoming wind. This is because if it extracts all the energy from the upcoming wind, the wind must stop behind the turbine which is impossible. This conclusion, that the maximum theoretical efficiency of a rotor is 59.3%, is called the Betz efficiency or, sometimes, Betz law. The overall energy extraction depends on a number of factors, including the characteristics of the machine (rotor, gearbox, generator, tower, controls), the terrain (topography, surface roughness, obstructions), and, of course, the wind regime (velocity, timing, predictability) [6, 23].

$P=0.5926\, \eta \frac{1}{2} \rho A v^3$

P_A= 16/27 ½ ρv3A Available power density. This is the theoretical maximum amount of power that can be extracted from the wind

P_D =16/27 ½ ρv^3 A η Power delivered .This is the power that the wind turbine delivers to its load.

$\eta = \frac{PD}{PA}$ In a well-designed wind turbine, the efficiency can reach 0.7

Where:

1/2ρv3 is the power in the wind, 16/17*1/2ρv3is the available power density from the wind, A is the swept area of the wind turbine and η is the efficiency of the wind turbine.

2.2.8 Idealized Wind Turbine Power Curve

The power curve shows the relationship between wind speed and generator electrical output. The cut-in wind speed V_c is the minimum needed speed to generate net power. As velocity increases above the cut-in wind speed, the power delivered by the generator tends to rise as the cube of wind speed. When winds reach the rated wind speed V_R, the generator is delivering as much power as it is designed for [22].At some point the wind is so strong that there is real danger to the wind turbine. At this wind speed V_F, called the cutout wind speed the machine must be shut down.

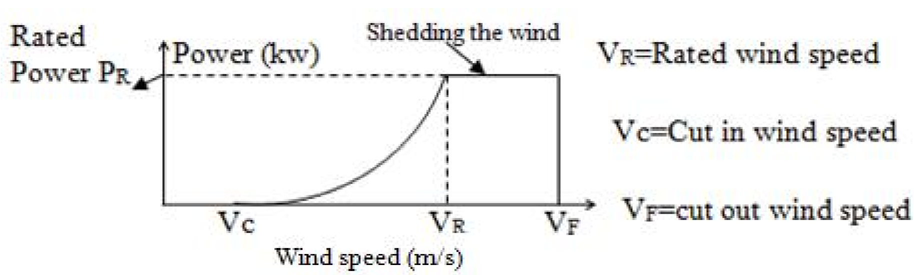


Figure 2-20: Idealized power curve [22]

2.2.9 Control Methods

Above V_R, there must be some way to shed some of the wind's power or else the generator may be damaged. Three approaches are common on large machines: an active pitch-control system, a passive stall-control design, and a combination of the two. Passive Yaw control is also applicable for small kilo watt turbine.

Pitch control:-This is an electronic system monitors the generator output power; if it exceeds specifications, the pitch of the turbine blades is adjusted to shed some of the wind. Physically, a hydraulic system slowly rotates the blades about their axes, turning them a few degrees at a time to reduce or increase their efficiency as conditions dictate. The strategy is to reduce the blade's angle of attack when winds are high [22].

Stall control: - For stall-controlled machines, the blades are carefully designed to automatically reduce efficiency when winds are excessive. Nothing rotates as it does in the pitch-controlled scheme and there are no moving parts, so this is referred to as passive control. The aerodynamic design of the blades, especially their twist as a function of distance from the hub, must be very carefully done so that a gradual reduction in lift occurs as the blades rotate faster [22].

Combined control:-For large turbine >1MW this method is applied. The blades rotate just as they do in the active, pitch-control approach. The difference is, however, that when winds exceed the rated wind speed, instead of reducing the angle of attack of the blades, it is increased to induce stall.

Passive Yaw control:-For Small, kilowatt-size wind turbine Passive yaw controls that cause the axis of the turbine to move more and more off the wind as wind speeds increase are common. This can be accomplished by mounting the turbine slightly to the side of the tower so that high winds push the entire machine around the tower [22].

2.2.10 Wind Potential Assessment

If measured data for the site is not available the nearby station measured data is used. In this case the nearby station is Debre Markose which is convincible to use the data. The annual average wind speed is calculated to be 3.5 m/s at 10m height [3]. From NASA the annual average wind speeds of the location to be 3.1 m/s at the same 10 m height [12]. From Ethiopian National Metrology agency (NMA) 10 m extrapolation of the wind speed data obtained from the data logger measurement at 2m is 2.4 m/s [3].

Table 2-6: Monthly average wind speed from NASA

	Jan.	Feb.	Ma	Ap.	Ma	Ju	Jul	Au	Se	Oc	No	Dec	Av
10m	3.4	3.3	3	3.1	3.1	3.7	3.5	2.8	2.5	2.5	3	3.3	3.1
25m	4.26	4.15	3.77	4.08	4	4.63	4.4	3.52	3.14	3.14	3.77	4.15	3.999

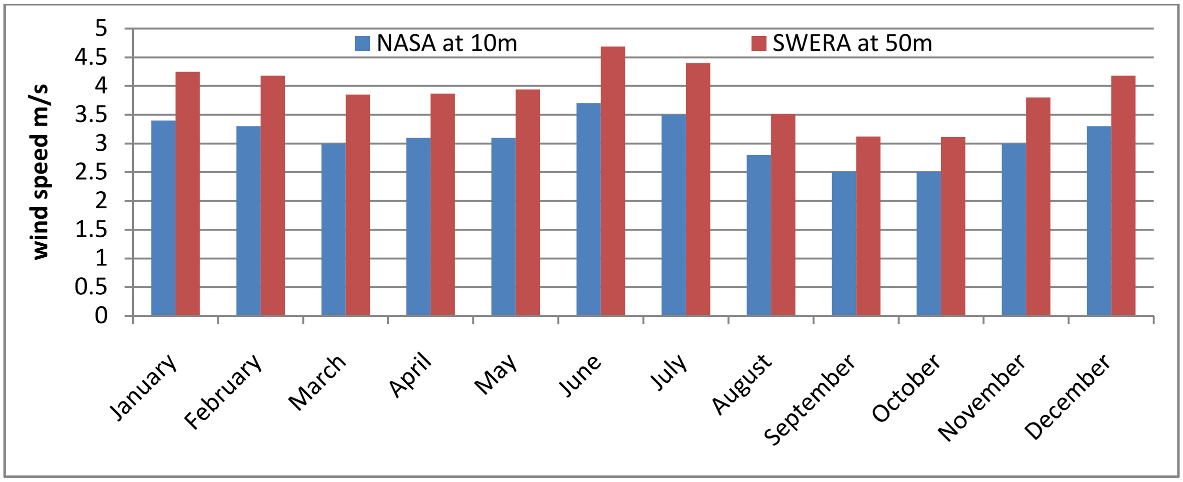


Figure 2-21: Annual average wind speed data from different sources

For this purpose the data from NASA is used it is because between the two real measured data. Using eqn. 3.1 with the value of $Z_{o,}$ 0.01[11] the wind speed is changed to the designed height i.e. at 25m as seen from table 2.6.

2.3 Biomass Energy System and Biomass Resource Assessment

2.3.1 Over view of Biomass power

Biomass is a collective term used for all materials that are biogenic in origin i.e., derived from the product of photosynthesis. The origin of biomass is mainly divided in to two i.e. animal derived and plant derived. Biomass in the form of fuel wood was perhaps the first energy source used by human beings and was the main fuel till the industrial revolution, after which fossil fuels like coal and oil replaced biomass as the main fuels. Biomass is still an important fuel in developing countries. Biomass energy offers several advantages in the form of energy security; socio-economic development and environment .A variety of physical, thermo-chemical, chemical and biochemical processes are used for converting biomass into energy [8].

By the end of 2012, global bio-power capacity was approaching 83 GW. Around 350 TWh of electricity was generated worldwide in 2012, a 5% increase over the previous year. Averaging national bio-power generation outputs over the period 2010–12, the United States had a substantial lead, with Germany second, followed closely by Brazil and China, both of which are gaining ground rapidly. The main types of commercial bio-power systems are medium- to large-scale direct-fired (similar to most coal- and gas-fired power plants), co-fired, gasifiers, and smaller-scale, modular systems. Together, they produce around 1.4% of the world's electricity generation (compared with coal at 41%).Almost 90% of bio-power is generated with solid biomass fuels. Landfill gas, biogas, synthesis gas (also known as syngas), and liquid bio-fuels are also commonly used for bio-power generation and make up the remaining 10%. In the United States, 100 bio-power projects (543 MW) came on line in 2012, bringing total capacity to 15 GW about 18% of the global total [44].

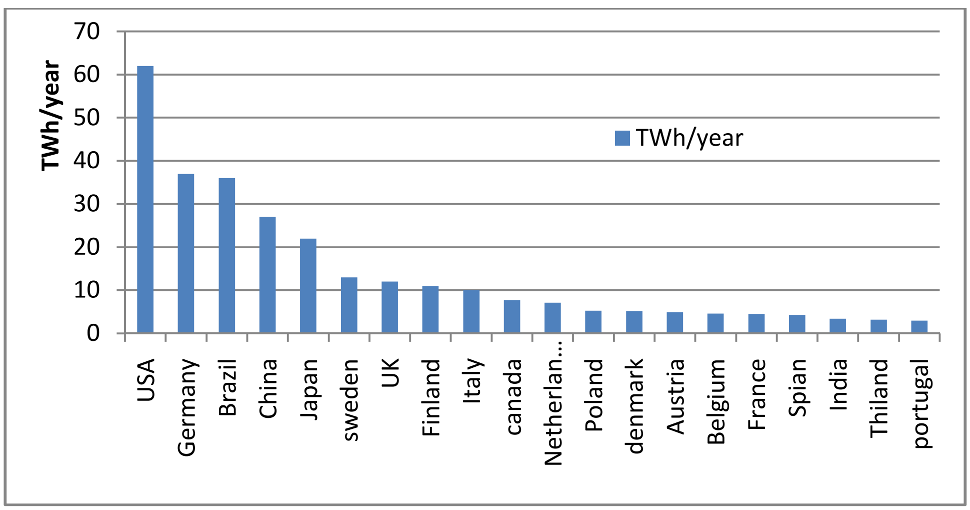


Figure 2-22: Bio-power generation of top 20 countries, annual average 2012 [44]

2.3.2 Bio-power Resource in Ethiopia

Wood, agricultural residues, animal waste and human wastes are considered as major biomass resources. The total energy that can be derived annually from these resources is estimated to be about 101,656.77 Tcal. Out of this, the share of the woody biomass is estimated to be 79%, followed by animal waste 11 percent, crop residue 8 percent and human waste 2 percent. The contribution of dung and crop residues for the total energy consumption of rural households is around 18% of the total rural energy consumption. The total dung that can be produced annually from the current livestock and poultry population is about 27,835,022.62 tones. From this, about 111,284.42 Tcal of energy can be derived annually [2].

According to Ministry of Water and Energy the Electric Energy Potential of the country is listed in the following table [42].

Table 2-7: The exploitable reserve and exploited energy sources [42]

Resource	Unit	Exploitable Reserve	Exploited	
			Amount	Percent
Hydropower	MW	45,000	~2100	<5%
Solar/day	KWh/m2	4_6		<1%
Wind: power :speed	GW m/s	1350 >7	171MW	<1%
Geothermal	MW	7000	7.3	<1%
Wood	Million tons	1120	560	50%
Agricultural waste	Million tons	15-20	~6	30%
Natural gas	Billion m^3	113	_	0%
coal	Million tons	>3000	_	0%
oil Shale	Million tons	253	_	0%

2.3.3 Systems of Energy Production from Biomass

Biomass conversion refers to the process of converting biomass into energy that will in turn be used to generate electricity and/or heat. The principal categories of biomass conversion technologies for power and heat production are direct-fired and gasification systems. Within the direct-fired category, specific technologies include stoker boilers, fluidized bed boilers, and co-firing. Within the gasification category; specific technologies include fixed bed gasifiers and fluidized bed gasifiers. Anaerobic digesters are also considered a biomass conversion technology [41].

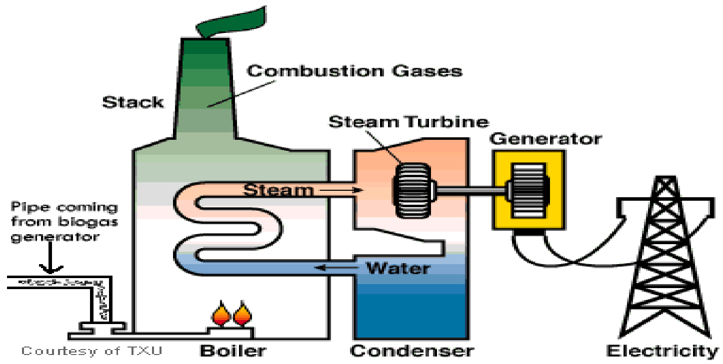


Figure 2-23**:** Direct fired biomass power generation [16]

Direct-firing:-Most bio-power plants use direct-fired systems as figure 2.23 shows. They burn bio-energy feed stocks directly to produce steam. This steam drives a turbine, which turns a generator that converts the power into electricity. In some biomass industries, the spent steam from the power plant is also used for manufacturing processes or to heat buildings (combined heat and power systems).

Co firing:-An alternative approach to building small, inefficient plants dedicated to biomass power production is to burn biomass along with coal in slightly modified, conventional steam-cycle power plants. Called co-firing, this method is an economical way to utilize biomass fuels in relatively efficient plants. And, since biomass burns cleaner than coal, overall emissions, especially sulfur dioxide emissions, are correspondingly reduced in co-fired facilities [22].

Gasification:-Gasification systems use high temperatures and an oxygen-starved environment to convert biomass into synthesis gas, a mixture of hydrogen and carbon monoxide. The synthesis gas, or "syngas," can then be chemically converted into other fuels or products, burned in a conventional boiler, or used instead of natural gas in a gas turbine. By gasifying the fuel first and then cleaning the gas before combustion, it would be possible to use biomass with gas turbines [22].

2.3.4 Biomass Gasifiers

The Biomass Gasifier unit is essentially a chemical reactor, where thermo-chemical processes, such as, Drying of biomass fuel, Pyrolysis, Combustion and Reduction take place. Most of the biomass materials, such as, wood, charcoal, rice-husk, coconut shell, etc. can be easily converted into the gaseous fuel known as producer gas, which comprises of carbon monoxide(CO), hydrogen(H_2), carbon dioxide(CO_2), methane(CH_4) and nitrogen(N_2). Such fuel gas has a good calorific value of 1000-1200 kcal/nm^3, and it can directly be burnt with high efficiency and good degree of control without emitting any smoke. The producer gas flame temperature can be as high as 1100°C. Each kilogram of air-dry biomass with 10% moisture content yields about 2.5 nm3 of producer gas. In energy terms, the conversion efficiency of the gasification process is in the range of 80-90% [8, 41].

2.3.5 Gasification of Biomass

The biomass gasification process basically converts almost all the forms of biomass or solid fuels, such as, agricultural residues, corn-wastes, rice-husks, woods, wood-wastes, etc. into a combustible gas mixture which is normally called producer gas. The producer gas is comprised of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. This process of conversion is typically used for various biomass materials, and it partially limits the combustion of such biomass during the process. The partial combustion occurs when the intake of air (oxygen) supply is controlled and its less than adequate quantity is fed into the system for the combustion of biomass. The gasifier essentially acts as a reactor where various complex physical and chemical processes take place. Biomass gets dried, heated, pyrolysed, partially oxidized and reduced in this reactor during the process as it passes through the gasifier, which ultimately yields the producer (inflammable) gas as a usable product [41].There are four distinct processes take place in a gasifier, the main reactions which take place in a gasifier are, drying, pyrolysis, combustion & redaction.

2.3.5.1 Drying of Biomass Fuel

Biomass fuels usually contain up to 35% moisture. When the biomass is heated to around 100^{o}C, the moisture gets converted into steam.

2.3.5.2 Pyrolysis

After drying as the biomass is heated it undergoes pyrolysis. Pyrolysis is the thermal decomposition of biomass fuels in the absence of oxygen. In the first step, the raw biomass fuel is heated, causing it to undergo a process called pyrolysis in which the volatile components of the biomass are vaporized. As the fuel is heated, moisture is first driven off; then at a temperature of about 400◦C the biomass begins to break down, yielding a product gas. The solid byproducts of pyrolysis are char (fixed carbon) and ash. In the second step, char heated to about 700◦C reacts with oxygen, steam, and hydrogen to provide additional syngas. The heat needed to drive both steps comes from the combustion of some of the char [8, 41].

2.3.5.3 Combustion

Oxidation: Air is introduced in a gasifier in the oxidation zone. The oxidation takes place at about 700-1400 ^{o}C, in which the solid carbonized fuel reacts with oxygen in the air producing carbon dioxide and releasing heat.

$$C+O_2= CO_2+ 406\ kJ/g.mol$$

Reduction: At higher temperatures and under reducing conditions several reactions take place which results in formation of CO, H2and CH4 [8].

$$CO_2+ C = 2CO -172.6\ kJ/g.mol$$

$$C+H_2O = CO + H_2-131.4\ kJ/g.mol$$

$$CO_2+H_2= CO +H_2O -41.2\ kJ/g.mol$$

$$C+2H_2= CH_4+75\ kJ/g.mol$$ [8].

Typical composition of producer gas is presented in Table2.8.

Table 2-8: composition of producer gas [8]

Component	Composition (%)
Carbon monoxide	18-22
Hydrogen	13-19
Methane	1-5
Heavier Hydrocarbons	0.2-0.4
Carbon dioxide	9-12
Nitrogen	45-55
Vapour	4

2.3.6 Classification of Biomass Gasifiers

Classification of biomass gasifier based on the density factor (ratio of dense biomass phase to total reactor volume) is a simple and effective method of classification. The gasifier can be classified into:

a). Dense-phase gasifier
b). Lean-phase gasifier

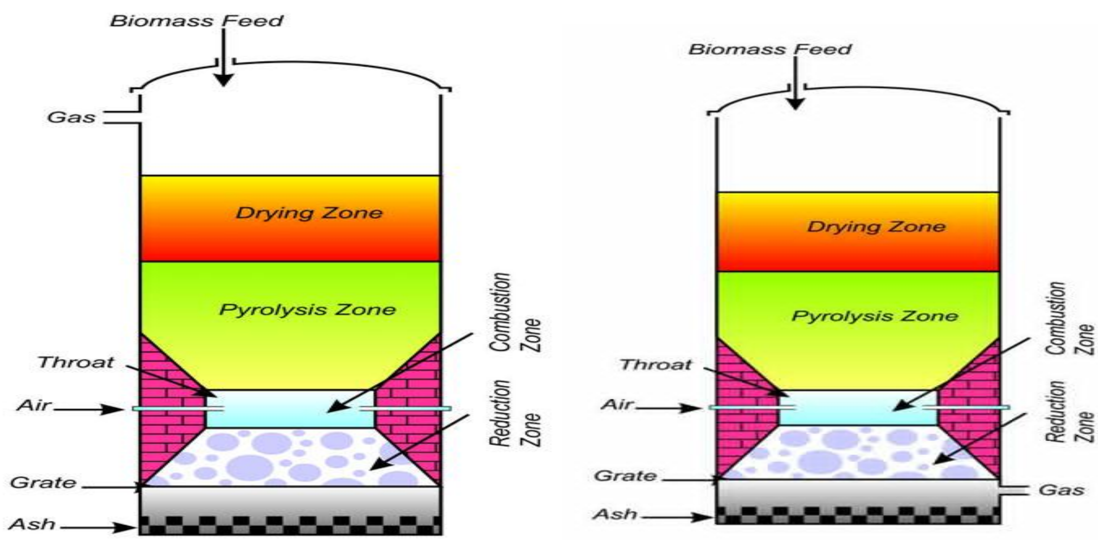
In lean phase gasifier e.g. fluidized bed, the biomass occupies very little reactor volume i.e. 0.05 -0.2. Most of the gasifier employed for decentralized applications in developing countries are dense phase reactors, mostly fixed bed reactors, they have typical density factor of 0.3 -.0.8 [8].There are two main types of fixed bed gasifier. These are Updraft or counter-current gasifier and Downdraft or co-current gasifier [8, 41].

2.3.6.1 Updraft Biomass Gasifier

In Updraft Gasifier System, air (oxygen) supply is fed into the chamber at the bottom, and this air flow acts as counter-current to the movement of biomass material. After going through the process, the producer (inflammable) fuel gas rises upward and is finally collected and drawn off at the upper part of this Gasifier. It contains clearly allocated zones for the partial combustion, reduction and pyrolysis process of the biomass. Updraft Gasifier achieves higher efficiency as the hot air passes through biomass material bed and leaves the Gasifier at lower temperature. The heat given off during the process of gasification is used for preheating and drying the fed biomass. Updraft Gasifier is best suited for the applications where moderate amount of dust in the fuel gas is acceptable and a higher flame temperature is required [8, 41]. The resulting producer gas is reach in hydrocarbons (tars) and has higher heating value. It is more suitable for burning in furnaces for thermal applications. Due to higher concentration of impurities (tar) it requires a more elaborate gas cleaning system if the gas has to be used in an IC engine [8].

2.3.6.2 Downdraft Biomass Gasifier

In Downdraft Gasifier System, the controlled intake of air (oxygen) is fed into the chamber containing downward movement of biomass material. After going through the process, the producer (inflammable) fuel gas is finally collected and drawn off at the bottom of this Gasifier. It is an efficient technique which has the capacity to process the biomass containing the moderate moisture (up to 30%). About 5 to 10 minutes time is needed to ignite the combustion and bring the plant to an operative temperature. Downdraft Gasifier is best suitable for the applications where the temperature control is critical, and the cleaner fuel gas is required. These Gasifiers can be used in those applications where moderate temperature is required up to 600^{o}C [8, 41].



(A) (B)

Figure 2-24:- Updraft biomass gasifier A; Downdraft Biomass Gasifier B [41]

2.3.7 Operation of Gasifier

The operating conditions play an important role in obtaining clean producer gas from a gasifier. In case of gasifier using woody biomass, fuel size is an important operating parameter. Fuel size affects the fuel movement within the gasifier as well as it has an impact on rate of reaction. Large wood pieces provide a smaller surface area per unit volume of the reactor; hence the pyrolysis reaction is less intense. Larger particles can also give rise to bridging which hampers fuel movement inside the gasifier. It is recommended to use fuel of one-fourth or one-fifth of the smallest dimension of reactor cross-section. Fuel moisture is another important parameter. High moisture content fuel reduces the calorific value of the producer gas and a value lower than 20 % is desirable. Adequate provision of biomass storage to store air-dried biomass is essential for a biomass gasifier system. The storage should be sufficient to take care of biomass requirements during the rainy season. A high fuel-bed temperature (above 800^{o}C) is preferred to achieve a low tar gas [8].

Power gasifier:-Typical specific fuel wood consumption values for power gasifier having dual-fuel engines and 100% producer gas engines are given in table 4.3. Using these values it is possible to calculate the quantity of fuel wood required for a power gasifier.

Table 2-9: Typical specific fuel wood consumption for power gasifier [8].

Power gasifier	Specific fuel wood Consumption	Reference[8]
3.7 kWe dual-fuel engine	1.2 -1.4 kg/kWh	Mukunda, Dasappa, Paul et al.
100 kWe dual fuel engine	0.9-1.0 kg/kWh	Mukunda, Dasappa, Paul et al.
120 kWe 100% producer gas Engine	1.0 -1.2 kg/kWh	Sridhar, Sridhar, Dasappa et al.

2.3.8 Conversion to Electricity

In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity. Appropriate electric generators are available in virtually all countries and in all sizes. The technology is well known and maintenance is simple. In most cases, even universally available 3-phase electric motors can be converted into generators. Technologically far more challenging is the first stage of the generator set: the combustion engine using the biogas as fuel. In theory, biogas can be used as fuel in nearly all types of combustion engines, such as gas engines (Otto motor), diesel engines, gas turbines and Stirling motors etc. In most commercially run biogas power plants today, internal combustion motors have become the standard technology either as gas or diesel motors [8, 13].

2.3.9 Appropriate Combustion Engines

In general, diesel engines operate on biogas only in dual fuel mode. To facilitate the ignition of the biogas, a small amount of ignition gas often diesel fuel is injected together with the biogas. Almost every diesel engine can be converted into a pilot injection gas engine. The advantage of these motors running in dual fuel mode is that they can also use gas of low heating value. However, in such cases, they consume a considerable amount of diesel. Up to engine sizes of around 200kW, pilot injection engines seem to have an advantage over gas motors due to their slightly higher efficiency (3-4% higher) and lower investment costs. By contrast, gas motors with spark ignition (Otto system) can operate solely on biogas. In practice, a small amount of petrol (gasoline) is often used to start the engine. This technology is used for very small generator sets (~ 0.5-10 kW) as well as for large power plants.

Today, experience of the use of combustion motors to produce electricity from biogas is extensive; this can be regarded as a proven standard technology. Internal combustion motors have high requirements in terms of fuel quality. Harmful components especially hydrogen sulphide (H2S) in the gas can shorten the lifetime of a motor considerably and cause serious damage. This must be addressed in two ways:

- Producing clean producer gas
- Use of appropriate and robust motors and components

In theory, most engines originally intended for cars, trucks, ships or stationary use can run on biogas as fuel and are available almost everywhere within a power range between 10 and 500 kW. This holds true especially in the case of dual fuel use. Robust engines with a certain sulphur resistance are mostly free of non-ferrous metal, as these materials are highly prone to damage through sulphur rich biogas [13].

2.3.10 Appropriate Gas Quality

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

- The methane content should be as high as possible as this is the main combustible part of the gas;
- The water vapour and CO2 content should be as low as possible, mainly because they lead to a low calorific value of the gas;
- The sulphur content in particular, mainly in form of H_2S, must be low, as it is converted to corrosion causing acids by condensation and combustion. The water vapour content can be reduced by condensation in the gas storage or on the way to the engine.

The reduction of the hydrogen sulphide (H_2S) content in the biogas can be addressed via a range of technical methods.

• The injection of a small amount of oxygen (air) into the headspace of the storage fermented leads to oxidation of H_2S by microorganisms and hence the elimination of a considerable part of the sulphur from the gaseous phase. This is the most frequently used method for desulphurization. It is cheap and can eliminate up to 95% of the sulphur content in the biogas. However, the right proportioning of air still seems to be a challenge [13].

2.3.11 Biomass Resource Assessment in the Area

Biomass can be found from different resources. The following are the common sources of biomass. Biomass energy can be extracted from different sources. The following figures are some of the sources of biomass.

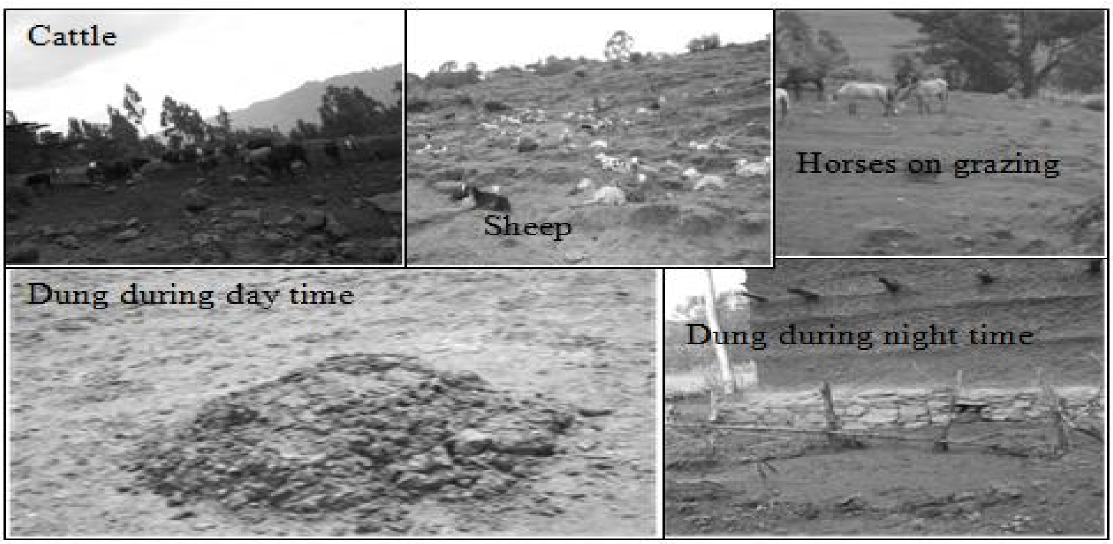


Figure 2-25: Sources of biomass taken from the site

2.3.11.1 Estimation of Animal Dung

Potential supply of animal dung for a country or a province can be calculated by knowing the population of the particular animal and relevant dung productivity factor.

Potential animal dung (kg/day on dry basis) = number of animal x dung productivity (kg/head/day on dry basis) [8, 31].

The production of dung differs from country to country or even region to region in a country. This is because of differences in animal size and weight as well as feed intake.

Table 2-10: Animal Dung production in different regions [8]

country	Animal	Dung production (dry basis)	Volatile solid
North America	Dairy cattle Non-dairy cattle	5.68 2.55	5.23 2.35
Western Europe	Dairy cattle Non-dairy cattle	5.52 2.88	5.08 2.65
Eastern Europe	Dairy cattle Non-dairy cattle	4.49 2.91	4.13 2.68
Oceania	Dairy cattle Non-dairy cattle	3.77 3.29	3.47 3.03
Latin America	Dairy cattle Non-dairy cattle	3.16 2.70	2.91 2.48
Africa and Middle East	Dairy cattle Non-dairy cattle	2.01 1.68	1.85 1.54
Asia	Dairy cattle Non-dairy cattle	3.07 2.49	2.82 2.29
Indian Subcontinent	Dairy cattle Non-dairy cattle Buffalo	2.87 1.50 2.65	2.64 1.38 2.43
Other livestock Developing countries	Swine Sheep Goat Camel Horse Mule/Ass Poultry		0.34 0.32 0.35 2.49 1.72 0.94 0.02

The surplus dung available for biogas production may be significantly lower than the potential calculated above. There are two important factors influencing the availability of surplus dung available for biogas production, these are [8].

Collection efficiency factor: - All the dung is not collected. One of the main reasons is that cattle in many regions are not stall fed and are left in the fields to feed. In such cases the collection of dung becomes difficult. Also in several areas, the cattle are not kept in covered shed and dung during the rainy season gets washed away and is not collected. Thus we have to define a collection efficiency factor (ranging from 0 to 1)

Dung has several alternate uses it is dried and used as fuel, it is mixed with clay to plaster walls and floor of the house or it is used as a fertilizer, but for this analysis purpose this alternate use is not considered.

According to the Ethiopian Energy Authority, dairy cattle produce 2.01 kg manure per head per day and nondairy cattle produce 2.27 kg/head/day[8].Based on data collected from 1987-93 the EEA calculates that 22% of all manure produced is used for fuel [8]. In another literature, higher utilization rate is taken i.e 38% [32].But currently the Ethiopian water and energy minister estimates that the average cattle holdings per head is 4kg and this data is used for the estimation of the cows dung. The cost of dung for fuel is estimated to be 306 Ethiopian birr per ton which is equivalent to $17 based on the current exchange rate .The production of biogas from cattle's dung is 0.3m^3 /kg [8].

All feed materials consist of solid material and water. Fresh cattle dung, for example, consists of about 80% water and 20% total solids (TS). The TS in turn consist of Volatile Solids (VS) which is the organic matter which can be digested and Fixed Solids (FS) which are essentially mineral matter which cannot be digested. In case of fresh cattle dung, TS consist of 70% VS and 30% FS. In the plant, 2 kg of feedstock produces about 500 g of methane, and the reaction is completed with 24 hours [8].

Table 2-11: Number of animals estimated to give dung in the area

Name of Villages	No of cattle	No of sheep	No of horses
Deber	308	452	98
Kundab	1473	855	165
Kidusyohannes	174	270	107

For cattle's dung collection efficiency 38% and 4kg/head.
For horses dung collection efficiency 38% and 1.72kg/head.
For sheep's dung collection efficiency 38% and 0.32kg/head.

Kidusyohanes:-For all the cases the dung productivity is considered constant i.e.4kg/had,1.72kg/head and 0.32kg/head for cattle, horse and sheep respectively for each day. For this village the productivity of dung from cattle is 0.265ton/day,0.1765ton/day from horse and 0.013ton/day from sheep. The total dung production is about 0.454ton/day.

Kundab:-For this village the productivity of dung from cattle is 2.239ton/day, 0.5588ton/day from horse and 0.0201ton/day from sheep. The total dung production is about 2.8179ton/day.

Debre:-For this village the productivity of dung from cattle is 0.468ton/day, 0.2953ton/day from horse and 0.01197ton/day. The total dung production is about 0.7068ton/day.

To see the contribution of the dung as a power source, the dung which is found from these different villages is feed in to the software for each system.

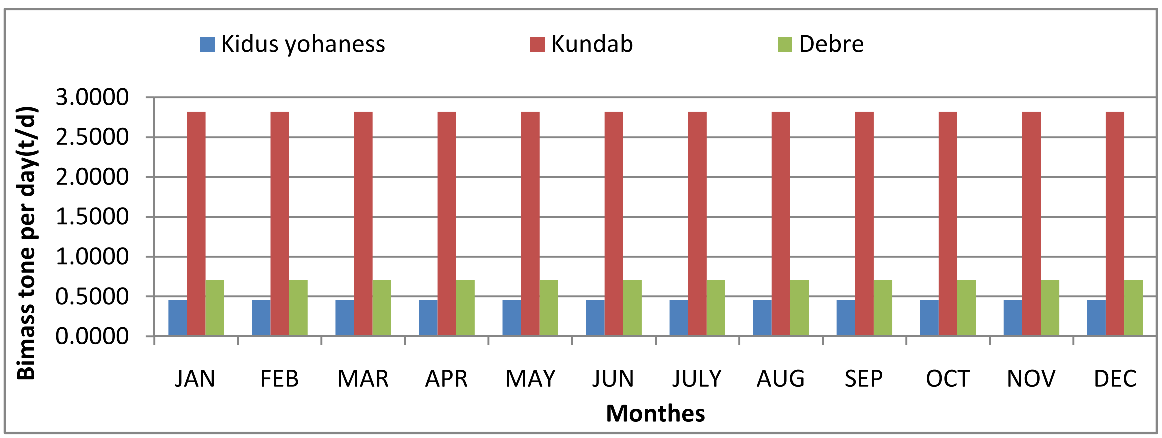


Figure 2-26: Available Biomass resource tones per day

CHAPTER THREE

3 Hydro Power System and Hydropower Potential Assessment

3.1 Introduction

Hydropower is the power derived from the natural movement or flow of masses of water. Most commonly, this power is harnessed by taking advantage of the fall of water from one level to another, thus exploiting the effect of gravity. The energy of the falling water is converted to mechanical energy by the use of a turbine. Micro hydropower turbines come in many shapes and sizes from waterwheels, to pumps used as turbines (where water is forced through the pump in the opposite direction), to squirrel cage turbines, called cross flow turbines. Once the turbine is used to convert water energy to mechanical energy, the mechanical energy in turn can be used to perform work or converted to some other form of energy, such as electrical energy (called hydroelectric energy). The energy-producing potential at any given hydropower site depends on the energy of the water, which in turn depends on the distance the water falls, called the head, and on the amount of water flowing.

The actual amount of mechanical or hydroelectric energy produced at such a site also depends on the efficiency at which the turbine or turbine-generator unit can convert the water energy to the other forms of energy. Sites with modern micro-hydro electric units will have efficiencies ranging from 40 to 75%. In other words, 40 to 75% of the energy producing potential is actually converted into useful energy [45].

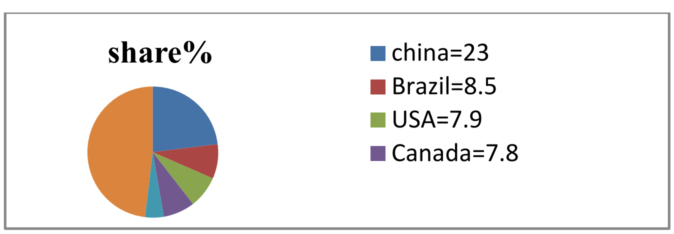


Figure 3-1: Hydropower Global capacity, shares of top five countries, 2012 [44]

Global installed capacity of hydro power is estimated 990 GW. The top countries for hydro capacity are China, Brazil, the United States, Canada, and Russia, which together account for 52% of total installed capacity [44].

3.1.1 Hydropower Resource in Ethiopia

Ethiopia is often described as the water tower of northeastern Africa. It was estimated that the country has a hydropower potential of 45,000 MW [42]. Not more 1945.75 MW so far has used. Thus leave more than 89.7% of the potential unused [1]. Almost all of the power stations operating at present are big plants and meant to feed the national grid. The development of mini- and micro hydro, which is more suited to rural electrification, is not practiced yet. The average annual potential (exploitable with small slope plants without reservoir) is estimated to be about 20 TWh/year. The electric energy generated from small slope plants, being smaller in capacity and geographically dispersed, is of great importance for rural electrification [2].

3.2 Micro Hydropower Resource of Ethiopia

The development of mini- and micro-hydro, which is more suited to rural electrification, is not practiced yet. The average annual potential (exploitable with small slope plants without reservoir) is estimated to be about 20 TWh/year [2]. From the economically feasible potential; only 10% would be suitable for small scale power generation including Pico and Micro hydropower. The recent baseline survey done for energy access projects reveals that the total theoretical potential for micro hydro development is100 MW or about 1000 projects of a typical capacity of 100kW [35]. The following table (Table 3.1) shows the regional distribution of micro-hydro potential of the country. The Central and Southwestern highlands of the country have an annual water surplus which provides the basis for run-of-river hydro development on small scale [5, 35].

Table 3-1: Summary of technical micro hydro potential in Ethiopia per region

Region	Approximate Micro Hydro Potential (Technical MW)
Oromia	35
Amahara	33
Benishangul-Gumuz	12
Gambella	2
SNNP	18

3.3 Description about Hydropower Generation

The energy associated with water manifests itself in three ways: as potential energy, pressure energy, and kinetic energy. The energy in a hydroelectric system starts out as potential energy by virtue of its height above some reference levels in this case, the height above the powerhouse. Water under pressure in the penstock is able to do work when released, so there is energy associated with that pressure as well. Finally, as water flows there is the kinetic energy that is associated with any mass that is moving. Figure 3.2 suggests the transformations between these forms of energy as water flows from the fore bay, through the penstock, and out of a nozzle [22].

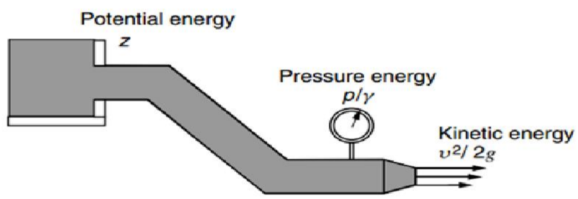


Figure 3-2: Transformations of energy from potential, to pressure, to kinetic.

It is convenient to express each of these three forms of energy on a per unit of weight basis, in which case energy is referred to as head and has dimensions of length, with units such as "feet of head" or "meters of head." The total energy is the sum of the potential, pressure, and kinetic head and is given by

$$\text{Energy head} = z + \frac{p}{\gamma} + \frac{v2}{2g}$$

Where z is the elevation above a reference height (m), p is the pressure (N/m2), γ is the specific weight (N/m3), v is the average velocity (m/s), and g is gravitational acceleration (9.81 m/s2) [22].

The overall efficiency η comprises efficiencies of penstock, turbine, gearing, generator, transformers and losses in the transmission and distribution lines. Usual values of these single efficiencies are given in the following Figure 3.3.

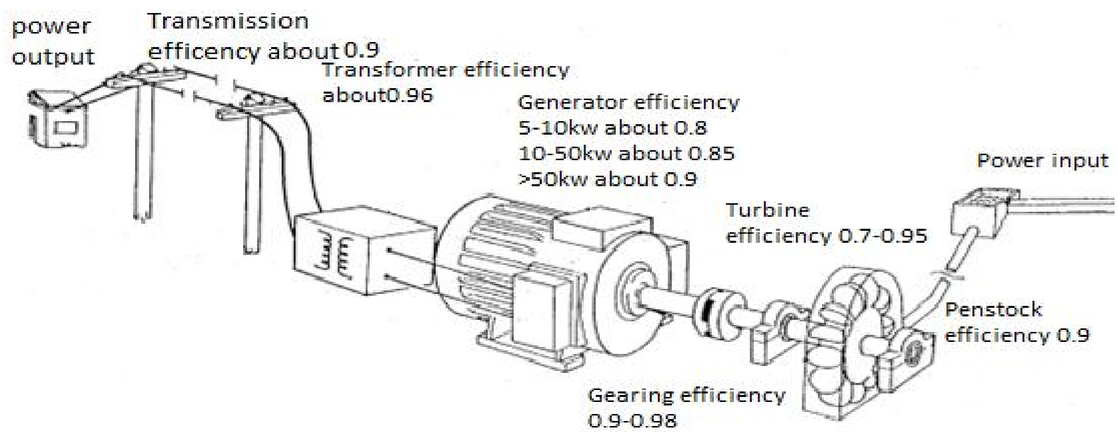


Figure 3-3: values of the efficiencies of different parts of hydro system [40]

3.4 Types of Hydropower Schemes

3.4.1 Run of River

Run of river hydropower systems use the natural downward flow of rivers and micro turbine generators to capture the kinetic energy carried by water. The simplest micro-hydro plants are run-of-the-river systems, which mean that they don't include a dam. As such, they don't cause nearly the ecosystem disruption of their dams and reservoir counterparts. A portion of the river is diverted into a pipeline, called a penstock that delivers water under pressure to a hydraulic turbine/generator located in a powerhouse located at some elevation below the intake. Depending on how the system has been designed, the powerhouse may contain a battery bank to help provide for peak demands that exceed the average generator output Figure 5.3 shows the description [22].

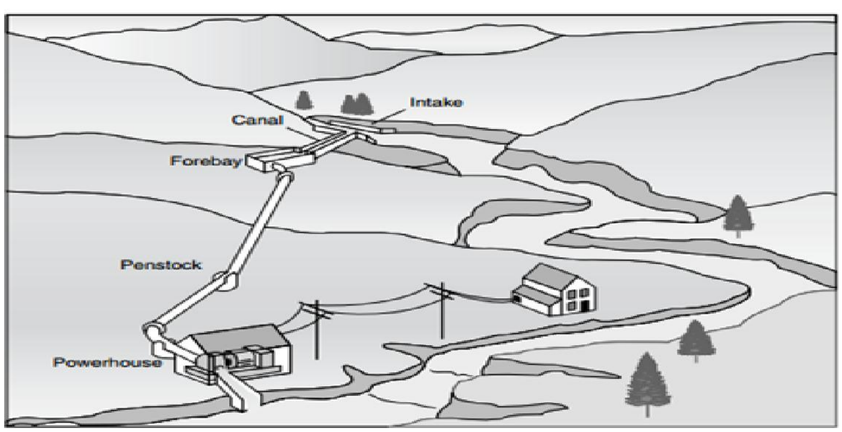


Figure 3-4: micro-hydropower scheme [22]

3.4.2 Impoundment

The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.

Figure 3-5: Tekeze-300MW-impodument type hydropower in Ethiopia [27]

In large hydropower systems the construction of large dams is necessary to store water and to provide sufficient head for the turbine. In addition of maintaining a sufficient head for the turbine, the dam/reservoir had the advantage that the stored water is used during dry seasons. And also these water storage schemes enable the power station to generate at times of peak power demand, and then allow the water level to rise again during off peak time. Schemes with large dams are better suited to larger, gently graded rivers [5].

3.4.3 Pumped Storage

Figure 3-6: Typical pumped storage hydropower plant [34]

Pumped storage plants utilize a reversible pumping turbine to store hydro energy during off-peak electricity hours by pumping water from a lower reservoir to an upper reservoir. This stored energy is then used to generate electricity during peak hours, when electricity is costly to produce, by distributing water from the upper to the lower reservoir [5].

3.5 Micro Hydropower Generation

The principle of micro-hydropower generation system is the same as large hydropower generation the difference is only the size of the generated power and the presence of the dame is mostly in large hydropower.

3.5.1 Classification of Hydropower Plants

Water can be harnessed on a large or a small scale the list below outlines the categories used to define the power output from hydropower. Micro-hydro power is the small-scale harnessing of energy from falling water [29].

- Large- hydro More than 100 MW and usually feeding into a large electricity grid
- Medium-hydro 15 - 100 MW - usually feeding a grid
- Small-hydro 1 - 15 MW - usually feeding into a grid
- Mini-hydro above 100 kW, but below 1 MW; either stand alone schemes or more often feeding into the grid
- Micro-hydro from 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid.
- Pico-hydro from a few hundred watts up to 5kW.

3.5.2 Micro Hydropower Plants in Ethiopia

Ethiopia depends largely on large hydro power plant. But the country has small scale hydro power potential. EELPA, the former national utility, used to install and operate a number of small hydropower stations in the micro and mini range. These were used to supply towns as self contained system up to 1990s when demand exceeded their capacity especially during the dry season. The interconnected system (ICS) was brought to these towns and the importance of the micro hydro systems was drastically reduced. As many of these micro/mini hydro systems date back to the 1950s and 1960s, they became unreliable and extremely costly to operate. Today, only one of these micro hydro plants is in regular operation. The following table provides an overview of the existing EEPCO hydro plants in the micro range (≤500kW) and their current status [5, 35].

Table 3-2: The existing micro hydropower plants and current status in Ethiopia

	Name, location	Head(m)	Types of the scheme	Installed capacity (KW)	Year of commissioning	Current status
1	Yadot,Bale Zone	23	ROR	350	1991	Operational
2	Welega,Woliso town	16	ROR	162	1965	Not operational
3	Sotosomere, Jimma	30	ROR	147	1954 new set1969	Not operational (ceased in 1986)
4	Hulka, Ambo town	40	ROR	150	1954	Not operational (Ceased in1994)
5	Deneba, Buno Bedele	14	ROR	123	1967	Not operational (ceased in1990)
6	Gelenmite, DembiDollo town	42	ROR	195	1966	Not operational
7	Chemoga, Debre Markos Town	55	ROR	195	1962	Not operational
8	Debre Berhan		ROR	130	1955	Not operational (ceased in 1991)
9	Jibo,Harhar Zone		ROR	420	-	Not operational (ceasedbefore 1994)
	Total capacity		ROR	1872		
	Operational		ROR	350		
	Note operational		ROR	1522		

3.6 Classification and Types of Turbine

3.6.1 Turbines

Hydraulic turbines are classified as impulse turbines or reaction turbines according to the process by which, the water head and flow are converted to mechanical power. In impulse turbines, the head is converted to velocity in a stationary nozzle directed toward the turbine wheel, called a runner. The water jet from the nozzle is directed against curved buckets on the runner, which deflect the jet and reduce its velocity. The force resulting from this deflection is applied to the turbine runner, creating the turbine torque and power.

In reaction turbines, part of the available head may be converted to velocity within stationary parts of the casing, and the remainder or all of the head is converted to velocity within the turbine runner. The forces resulting from the velocity change act on the turbine runner, creating torque and power. Several of the more common types of hydraulic turbines and their areas of application are described below [45].

The choice of turbine will depend mainly on the pressure head available and the design flow for the proposed hydropower installation. Turbines are broadly divided into three groups; high, medium and low head [29].

Table 3-3: Classification of turbine based on the head

	Head pressure		
Turbine Runner	High	Medium	Low
Impulse	-Pelton -Turgo -Multi-jet pelton	-Cross flow -Turgo -Multi-jet pelton	-Cross flow
Reaction		-Francis Pump-as-turbine(PAT)	-Propeller -Kaplan

3.6.1.1 Impulse Turbines

Impulse turbines are most suited for sites with relatively high head and low flow. This is because the high head and corresponding high water velocity concentrates the available water power into a small flow area. The concentrated power is most efficiently converted by directing one or more water jets against buckets on the runner. The runner deflects the jet and reduces its velocity. An advantage of impulse turbines over the reaction turbines is that since the head is converted to velocity in the stationary nozzles, there is no pressure drop across the runner. Consequently, no close-clearance seals are needed between the runner and the turbine housing. This makes the impulse turbines simpler to manufacture and maintain, and more tolerant of less-than-clean water conditions. Impulse turbines are manufactured in three basic types: Pelton Wheel, Turgo, and Cross flow.

A). Pelton Wheel Turbine: - The best known impulse-type turbine is called the Pelton wheel turbine. This turbine has buckets on the runner that split the flow from the nozzle into two streams that are discharged from the sides of the runner. After the flow is diverted and split, the water drains from the turbine casing at a low velocity. An inherent limitation on the flow rate that a Pelton Wheel can handle is the size of water jet that can be efficiently diverted by the runner buckets. Several jets can be employed around the periphery of the runner to increase power. Under optimum conditions, a Pelton turbine can achieve up to 90% efficiency, due to the simple flow path through this type of turbine.

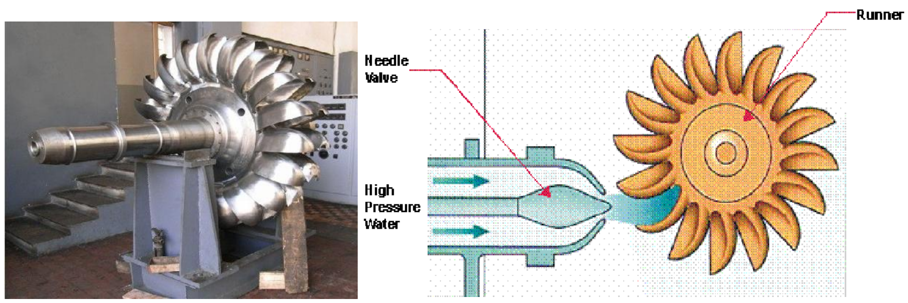


Figure 3-7: Pelton hydro turbine [37]

B). Cross flow Turbine:-The cross flow (sometimes referred to as Banki) impulse turbine was invented to accommodate larger water flows and lower heads than the Peloton Wheel turbine. The cross flow turbine uses an elongated, rectangular section nozzle directed against curved vanes on a cylindrically shaped runner. The water jet is slowed down in two stages, encountering the runner vanes twice as it passes through the horizontal runner. The elongated design of the runner and inlet nozzle increases the turbine flow capacity, which permits accommodation to lower heads [37].

Figure 3-8: Cross flow turbine [37]

C).Turgo Impulse Turbine:-The Turgo impulse turbine is an impulse turbine that can accommodate more water flow than a Pelton turbine. More and larger nozzles can be placed around the circumference of the runner due to the flow orientation away from the nozzles. An additional advantage of the Turgo turbine is that for the same head and runner diameter, the speed is about twice that of the Pelton turbine. The Turgo can achieve efficiencies of 92%, and maintains high efficiencies with flows as low as 25% of design [37].

Figure 3-9: Pelton Hydro Power Turbine Generator, Multi type Turgo Turbine Unit [37]

3.6.1.2 Reaction Turbines

Turbines in which part or all of the head is converted to velocity within the runner are referred to as reaction turbines.

A). Francis Turbines: - The Francis turbine has seen wide acceptance and is used in a full range of head and flow characteristics. Being a reaction turbine, the Francis uses both pressure and velocity to operate. Water is introduced radialy perpendicular to the shaft at the entrance of the runner and turns 90 degrees within the runner to discharge axially parallel to the shaft. The flow is generally controlled by wicket gates. The gates control flow and, alter the angle of that flow into the runner. For reasons relating to specialized design, and thus cost, Francis units have not been widely used in micro hydropower installations in recent years.

Figure 3-10: Horizontal Francis Hydro Turbine Generator [37]

B). Propeller Turbines: - Propeller turbines are reaction turbines, and most are axial flow, meaning that the water flow path is parallel to the turbine shaft. As with the Francis runners, this reaction turbine is full of water from the start of the penstock to the end of the draft tube. The runner rotates and power is extracted by the blade displacing water as the column of water moves through the turbine. Units designed for higher heads will have more blades while these used on lower heads, will have fewer blades. Blades on low head units will be set at a greater angle from the flow direction, while blades on high head designs will be set at a reduced angle. Generally, as flow drops off, efficiency falls rapidly. There are several types of turbines in the micro hydropower range that use a simple fixed pitch propeller type runner. Fixed pitch units perform well at the design conditions, but suffer at other flow points. They are thus suitable for sites that offer constant flow conditions [37].

3.7 Turbine Design

This part will show how the turbine is designed and it helps to select the appropriate size of the turbine. The intention is not to design the turbine rather to select appropriate turbine.The crossflow water turbine is widely considered by many to be the most efficient and apropret type of turbine forapplications in micro-hydro and Pico-hydro projects [39]. Theoretical power is found by the following equation

$$P = \eta x g x Q \text{ x } H_{eff} \text{ x } \boldsymbol{\rho} \text{--} (5.1)$$

Where:

- g= in m/s^2 (it is generally considered to be 9.8m/s2 gravitational acceleration)
- $\boldsymbol{\rho}$ =is density of water in kg/m3 (standard accepted value is 1000kg/m3)
- H_{eff} =is the effective head in meters
- Q= is the volume flow rate in m3/s, the power obtained will be in watts.
- η=the efficiency of the system ($0< \eta<1$)

A). Determining the Length and Diameter of Turbine

After obtaining the values of head and flow, the value of the length of the turbine (L) and the value of the diameter (D) of the turbine is found by using the following formula [18].

$$LD = 2.627\frac{Q}{\sqrt{H}} \text{---} (5.2)$$

From this formula we can obtain the product of L and D as a constant value. Now, give some values to D and find the corresponding values of L. Tabulate these valus in a table. Choose any value of L that you feel is convenient to use and does not make the construction too hard or cumbersome. All parameters like blade spacing, jet thickness, maximum efficiency speed and diameter will change as accordingly as the change choice of L. The input values must be in meters only.

B).The Maximum Efficiency Speed of the Turbine

The maximum efficiency speed N_s can be calculated using the following formula [18].

$$N_s=\frac{39.81\sqrt{H}}{D} \text{-- (5.3)}$$

N_s obtained here will be in rpm (Revolutions per Minute). Here the rotational speed of the turbine depends on the type of system used. In systems where a speed increaser is not used, the speed of the turbine will be the same as the rotational speed of the generator to which the turbine is coupled. However it may not be true that the turbine is directly coupled to the generator, in which case a speed increaser of either gear train or belt type may be used with selected gear (speed) ratio, the selection of which depends on the turbine type used. With this and the rotational speed of the generator selected, the value of N_s can be found.

C). Determining the Blade Spacing

Blade spacing is the distance between the tips of two adjacent blades on the outer periphe ry. This quantity is usually denoted by t and it is calculated by [18].

$$\mathbf{t=\frac{KD}{\sin\beta}} \text{-- (5.4)}$$

Here k is a constant whose value is 0.087 and $\boldsymbol{\beta}$ is 30°, so sin$\boldsymbol{\beta}$ will be 0.5. Thus, simplif ying, we obtain, t=0.147D.

D). Area and Thickness of Jet

The area of jet can easily be determined. This also enables us to calculate the optimum thi ckness of the jet, which is the same as nozzle width, s. Use this formula,

$\mathbf{S=0.22\frac{Q}{L\sqrt{H}}}$--- (5.5)

E). Radial Rim Width

The radial rim width is the difference between the outer radius and inner radius.

This zone starts from the outer radius and ends at the inner one. This space contains the blades. This is denoted by a.

a=0.17D-- (5.6)

The outer radius is denoted by r_1, which is equal to D/2. Also, the inner radius r_2 is given by $\mathbf{r_{2}= 0.66r_{1}=0.33D.}$

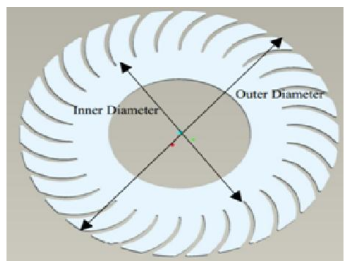


Figure 3-11: The outer and inner radius of a turbine

F). Radius of Blade Curvature

All the blades are actually arcs of a circle. To determine the radius of curvature of the blades use: $\boldsymbol{\rho}$ =0.163D.

Some otherdesign parameters have been derived after intense theoretical study and are now the standard accepted values. The most notable among these is the angle of attack of the nozzleα. First of all, a point on the turbine is selected where the jet is to be admitted. Atangent to this point is drawn and the jet is angled at an angle of 16°.α is universally accepted as 16 degrees i.e. $\alpha = 16^{o}$.

3.8 Designing Penstock

The penstock is a pipe that carries water from the intake to the turbine. Most micro-hydropower systems will include some type of penstock. Depending on the site characteristics, the penstock length may range from a few feet for manmade structures to several hundred feet for some run-of-the- stream sites. The exception is the manmade structure with an open flume [45].

Selecting Pipe Diameter: - The first requirement for sizing a penstock is to select the proper pipe diameter, using the design flow. A satisfactory penstock diameter depends on three factors. Energy (head) losses due to friction between the water flow in the pipe, the inside pipe wall Pressure limitations of the pipe as a function of wall thickness and Cost of the pipe and installation. A velocity of 4 fps is recommended for the initial penstock design [45]. The energy losses associated with friction can be expressed directly as feet of head loss.

Design flow rate: - The design flow rate is the flow rate for which the hydro turbine is designed. This is also typically the flow rate at which the turbine operates at its maximum efficiency, although HOMER assumes the turbine efficiency is constant [11]. The design flow rate for site kidusyohanes is found to be 0.354557m3/s and the diameter of the pipe is 0.3556m as illustrated in appendix C .As seen from the appendix C the head lose is found to be 0.36ft/100ft and the velocity is 3.7fps.For the case of hydro at Kundab the design flow rate is 0.494437m^3/s and also the diameter is 0.508m. Head lose through the pipe is 0.28ft/100ft and the velocity is found to be 3.8fps from Pipe diameter selection graphs [45].

3.9 Selecting Pipe Material

Material Selection: - The most common penstock materials include PVC (polyvinyl chloride), Steel, Polyethylene, FRE (fiber reinforced epoxy) and Tran site (asbestos cement). To select the material we can consider the following factors i.e. Cost, Availability and Physical properties (friction, strength, chemistry) Joining methods and installation limitations.

The selection of pipe material and pipe wall thickness depends on the pressure that the pipe will experience. There are two types of pressure to be considered the first is Static pressure, which is the pressure at the bottom of the pipe when the pipe is filled and the water is not flowing. The second is Pressure waves, which are caused when the amount of water flowing is suddenly changed, as by opening or closing a valve.

Static pressure depends on the head in the penstock. Pressure waves depend on how fast the flow changes in the penstock. To aid in determining the design pressure rating of the penstock and selecting the suitable pipe material, Table C-1 appendix C lists the wall thickness (t_w), pressure rating (P_R) and surge allowance factor (S_A) for several sizes of commonly available pipe materials. The procedure for determining penstock pressure rating (design pressure rating) is as follows:

1 foot of head =0.433 psi (pounds per square inch)), the static pressure can be determined by using Equation.

1m=3.2808ft

H_{grose}=11m=36.0888ft (Kundab)

H_{grose}=23m=75.4584ft (Kidusyohanes)

- Static pressure S can be calculated

S=0.433*h psi

S1=36.0888 *0.433= 15.626psi

S2=75.4584*0.433=32.67psi

- 14 in (Diameter of pipe for site kidusyohanes)

Steel: t_w = 0.25 P_R = 490 S_A = 50

PE (polyethylene) :t_w = 0.82 P_R =100 S_A = 9

A-C (transit asbestos cement): t_w =0.74 P_R =100 S_A = 38

FRP (fiber reinforced epoxy): t_w= 0.26 P_R= 225 S_A=15

- 20in (Diameter of the pipe for the site kundab)

Steel: t_w = 0.25 P_R = 340 S_A = 47

PE (polyethylene) : t_w = 1.12 P_R =100 S_A = 9

A-C (transited-asbestos cement): t_w =1.06 P_R =100 S_A = 37

For each pipe material selected, the penstock design pressure (Pd) can be determined using the following formula:

P_d= S+ (S_A*V) V is 3.7fps for 14in and 3.8fps for 20in

- For 14in (kidusyohanes)

S1=15.626psi

Steel: P_d =15.626 + 50*3.7 = 200.62 psi & P_R = 490

PE: P_d =15.626 + 9*3.7 = 48.926 psi & P_R = 100

A-C: P_d=15.626 + 38*3.7 = 156.226psi & P_R = 100

FRP: P_d=15.626+ 15*3.7 = 71.126psi & P_R = 225

Since the P_R is larger than the Pd for steel, PE and F_{RP} these materials can be used. AC, with a PR smaller than the Pd, cannot be used.

- For 20inc (kundab)

S2=32.67psi

Steel: P_d =32.67 +49*3.7 = 213.97psi & P_R =340

PE: P_d =32.67+ 9*3.7 = 65.97 psi & P_R = 100

A-C: P_d =32.67+ 37*3.7 = 169.57psi& P_R= 100

Since the P_R is larger than the Pd for steel and PE these materials can be used. AC, with a P_R smaller than the Pd, cannot be used.

3.10 Calculating Penstock System Head Loss

The next step is to calculate the total penstock head loss. The total losses are a function of both turbulence and friction. Turbulence is caused by the intake structure and by bends and obstructions in the pipe. Turbulence factors can best be considered by adding equivalent pipe length to the overall length of the penstock to get the adjusted length (La). This can be done by the following steps:

- Multiply the number of 90 degree bends by 30 feet
- Multiply the number of 45 degree bends by 15 feet
- Add 15 feet for the entrance at the intake
- Add 100 feet for the turbine isolation valve
- Sum all the additions and add to the total penstock length.

By considering 0 each 90 and 45 degree bends 15feet for Intake structure and 100feet turbine isolation valve. The adjusted length is found to be:

La_1= 15+100+ 14*3.2808ft =151.1ft=46m

La_2 =15+100+23*3.2808ft= 190.46ft=58.1m

Friction losses are a function of pipe size, length, and material. The friction effect is accounted for with the pipe material correction factors shown in Table 5.4. To obtain the head loss due to turbulence and friction, multiply the adjusted penstock length (La) determined above by the material correction factor from Table 5.4

Table 3-4: The pipe material correction factor

Pipe Material	Factor(fc)
Steel	1.16
PVC	0.77
PE	0.77
AC	0.87
FRP	0.77

Multiply this number by the H_f factor previously determined from the graph shown in the appendix C and divides the result by 100. This final number is the energy loss, in feet of head, for the flow, penstock length, and material selected. For this system the steel type material is selected.

H= (La*Fc*Hf)/100

where:

H= head loss in feet

f_c= friction loss correction factor

La= adjusted length of penstock in feet

H_f= head loss factor

Hf = 0.36(site one) from the graph

Hf=0.28(site two) from the graph

Steel:-fc = 1.16

For steel pipe

H_1= (1.16 x 151.1 x 0.36)/100= 0.631feet

H_2= (1.16*0.28*190.46)/100=0.619feet

This loss must be subtracted from the site's available head. Since it is a friction loss, it will not be available to produce power. So the net head H_{net} is:

H_{net1} =23-0.63=22.37m

H_{net2}=11-0.619=10.381m

3.11 Turbine Selection

Turbine selection is based mostly on the available water head, and less so on the available flow rate. The type and size of a turbine for a hydropower system is different for one project than the other depending on many factors. Therefore using these factors as criteria, the type and size of turbine for a particular hydropower system can be determined.

Using Flow, Head and Power as a criteria:-The selection of type, geometry and dimensions of the turbine for a particular micro hydro site depends on the site characteristics; the dominant factors being the head available and the power required. Selection also depends on the speed at which it is desired to run the generator or other devices loading the generator. Some turbines like the cross-flow and the Kaplan work efficiently with a large range of flow variation while others like the propeller turbines work only for a narrow range of flow variation with their efficiency falling rapidly with a little variation in flow. The selection of type of turbine for a hydropower site is assisted by the following tables, charts and graphs taking all the above variables in to consideration [5].

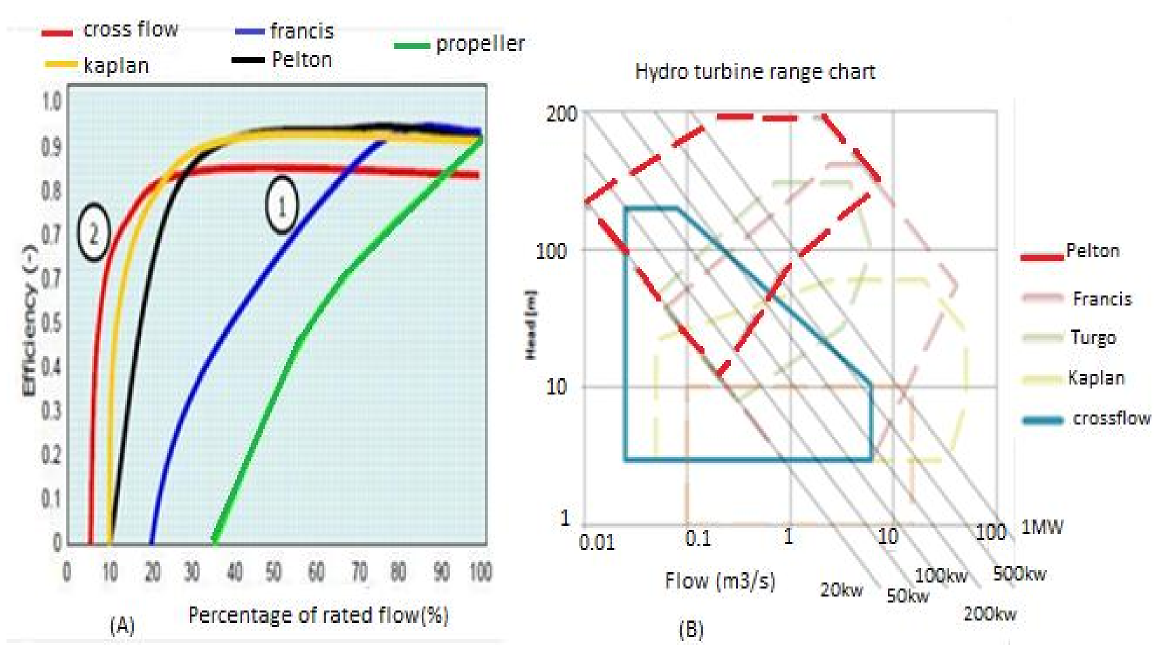


Figure 3-12: (A) The efficiency; (B) Range chart of hydro turbine [5]

3.12 Determining Head and Flow Rate

3.12.1 Measuring Head and Flow Rate

The head is measured by the author using the rope and the gross head of site at kidusyohanes is 23m and for site at Kundab is 11m.Under Ministry of water and energy of Ethiopia there are gauge stations to measure flow rate of major rivers. For this case the selected sites are far from the gauge station and the flow at these sites is not known. So, with some hydrological estimation techniques the gauge flow rate, which is found from ministry of water and energy, must be changed to the site. The flow rate at which no gauge can be estimated using one of the three methods Empirical, Statistical and Rainfall-Runoff modeling. But the simple empirical estimation is adopted instead of the more complex statistical and Rainfall-Runoff modeling [3, 5, and 30]. For the case of uncertainty the sensitivity variables is used as an input; this is to fill the gap that considers only the one year flow rate data.

$$Q_{site}=K[\frac{Asite}{Agauge}]Q_{gauge}$$

Where:

$Q_{site=}$The flow rate at the design site (m^3/s)

$Q_{gauge=}$ The flow rate at the gauged station (m^3 /s)

$A_{site=}$The catchment area of the site (m^2)(A_{site1}=76km^2,A_{site2}=96km^2)

Agauge =The catchment area the gauge (m^2)364km^2

K is the scaling factor. For simplicity K can be taken as the ratio of average annual rainfall of the site and the gauged area and the value is considered one [3].

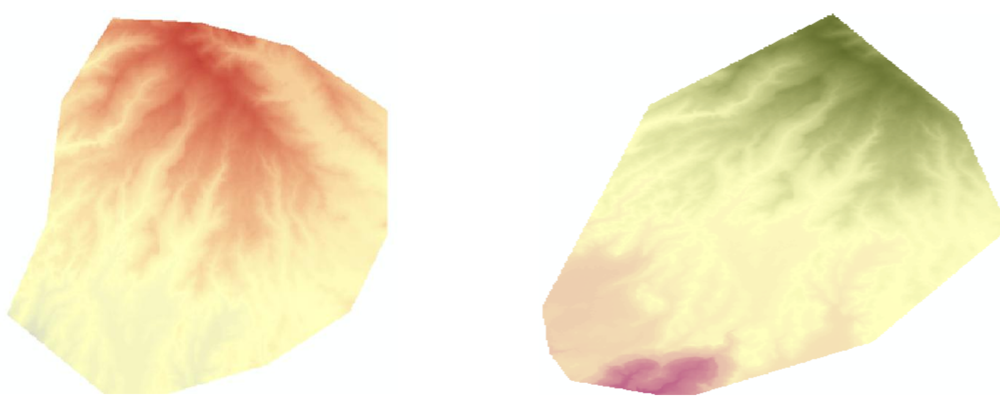
The catchment area of plant site is determined by using ArcGIS 9.3 Desktop [7] .This software is used for stream line identification and catchment area extraction, together with DEM (Digital Elevation Model) data found from ASTER GDEM (Advanced Space-borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model).

3.12.2 Determination of Catchment Area using ArcGIS 9.3 Desktop

Understanding drainage systems: - From the documentation of ArkGIS 9.3 ,a drainage basin is an area that drains water and other substances to a common outlet. Other common terms for a drainage basin are watershed, basin, catchment, or contributing area.

This area is normally defined as the total area flowing to a given outlet, or pour point. A pour point is the point at which water flows out of an area. This is usually the lowest point along the boundary of the drainage basin. The boundary between two basins is referred to as a drainage divide or watershed boundary**.**

Exploring Digital Elevation Models (DEM):-The most common digital data of the shape of the earth's surface is cell-based digital elevation models (DEMs). This data is used as input to quantify the characteristics of the land surface. A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.



(a) (b)

Figure 3-13: DEM (Digital Elevation Model):(a) for kidusyohanes;(b) for Kundab [19]

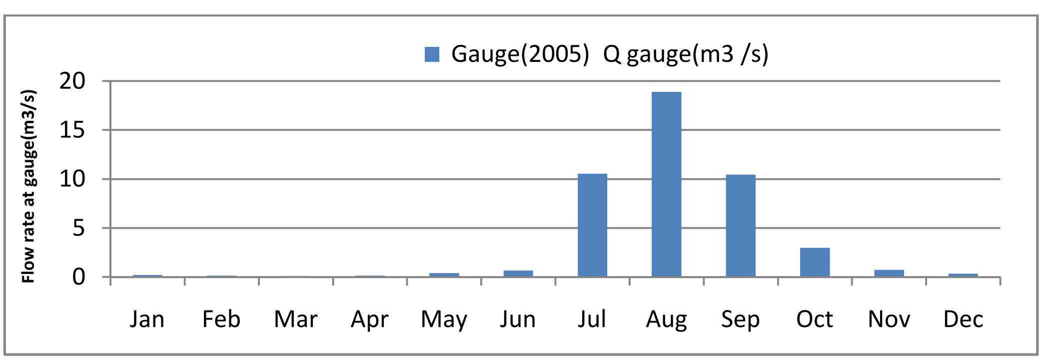


Figure 3-14: Flow rate at gauge station

Table 3-5: monthly average Flow rate

Month	Gauge(2005)	Site k.yohanes	Site k.yohanes	Site Kundab	Site kundab
	$Q_{gauge}(m^3/s)$	A_{site}/A_{gauge}	$Q_{site}(m^3/s)$	A_{site}/A_{gauge}	$Q_{site}(m^3/s)$
Jan	0.201	0.211	0.042411	0.2654	0.053345
Feb	0.133	0.211	0.028063	0.2654	0.035298
Mar	0.1	0.211	0.0211	0.2654	0.02654
Apr	0.129	0.211	0.027219	0.2654	0.034237
May	0.399	0.211	0.084189	0.2654	0.105895
Jun	0.644	0.211	0.135884	0.2654	0.170918
Jul	10.543	0.211	2.224573	0.2654	2.798112
Aug	18.888	0.211	3.985368	0.2654	5.012875
Sep	10.451	0.211	2.205161	0.2654	2.773695
Oct	2.979	0.211	0.628569	0.2654	0.790627
Nov	0.72	0.211	0.15192	0.2654	0.191088
Dec	0.334	0.211	0.070474	0.2654	0.088644

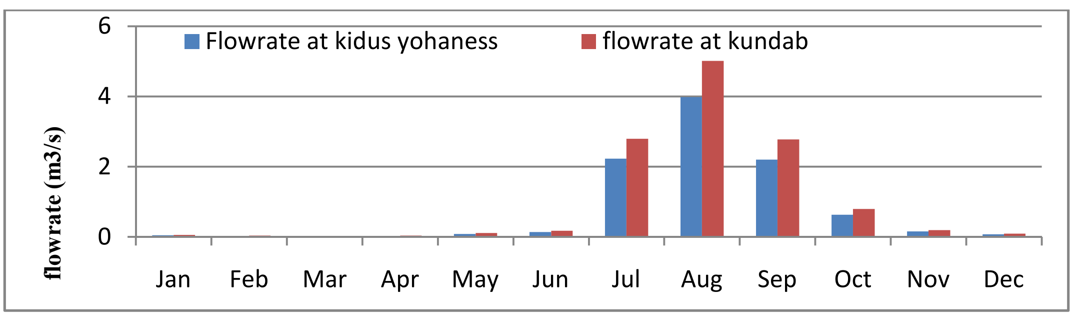


Figure 3-15: Flow rate at the sites (calculated)

As seen from the figure and from the table the flow rate is maximum at summer season and minimum at winter season of the country. This calculated flow rate is feed to the software for the analysis

CHAPTER FOUR

4 System Optimization and Modeling

4.1 Introduction

HOMER, the micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. In the design of power system, many decisions must be made about the configuration of the system i.e. about the components that make sense to include in the system, the amount and size of component to be used etc. The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.

In the input window, the software takes the model with inputs, which describe technology options, component costs, and resource availability. Then HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that can be viewed as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help us to compare configurations and evaluate them on their economic and technical merits.

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

Sensitivity Analysis: - When we define sensitivity variables as inputs, HOMER repeats the optimization process for each sensitivity variable that we specify.

4.2 Basic Components and Model of Hybrid System

4.2.1 Inverter

The output power from wind, hydro and biomass is AC and can be connected directly to the load because the load considered here all are AC loads. But the power from the PV is DC power and converting this power is needed.

An inverter is an electrical device that converts DC power to AC power at a desired output voltage or current. Its typical application is to convert DC power from a battery or PV array into AC power for use with conventional, utility-powered household appliances. Basically, there are three kinds of DC-AC inverters; square wave, modified sine-wave, and pure sine wave inverters. Of the three, the square wave type is the simplest and least expensive, but with the poorest quality output signal. The modified sine wave type is suitable for many load types and is the most popular low-cost inverter. Pure sine-wave inverters produce the highest quality signal and are used for sensitive devices such as medical equipment, laser printers, stereos, etc. The working principle of most inverters is to use a low DC voltage input and to first step-up the voltage to a level corresponding to that of the peak value of the desired AC voltage and then generate the desired AC voltage by using a full-bridge or half bridge electronic circuit configuration. The output voltage of the inverter is controlled by electronic circuitry [4].

4.2.2 Battery

Figure 4-1: Dep-cycle batteries

Basically, a battery is a device that stores energy for later use. It is a combination of electrochemical cells that can store chemical energy that has the potential to be converted into electric voltage or, to put it simply; it is a device that converts chemical energy directly to electrical energy. Lead-acid battery is the type of battery commonly used in stand-alone power systems. With regard to their applications, the major ones are automotive (starting), marine, and deep-cycle. Deep-cycle batteries are used in renewable energy applications. Deep Cycle batteries are designed to be discharged as low as 80 % and recharged over and over again and therefore have much thicker plates. It is important to note that companies recommend that hybrid system batteries should not be discharged beyond 50% of their capacity. Deep Cycle batteries deliver a consistent voltage as the battery discharges. With regard to the effect of temperature on batteries, the battery capacity is reduced as the temperature goes down, and is increased as the temperature goes up. The standard rating for batteries is 25^0C. Battery Ah capacity drops to 50% at approximately -27 ^{0}C. At freezing (≈0˚C), capacity is reduced by 20% [4].

4.2.3 PV Module

In addition to solar resource, the amount of Electricity produced by PV systems depends primarily on the following factors; these are Cell type and efficiency, Module efficiency, System efficiency and Module reliability.

Two categories of PV cells are used in most of today's commercial PV modules: C-Si (crystalline silicon) and thin-film. The C-Si category, called first-generation PV, includes mono-crystalline and multi-crystalline PV cells, which are the most efficient of the mainstream PV technologies and accounted for about 86% of PV produced in 2010 .These cells produce electricity via C-Si semiconductor material derived from highly refined poly-silicon feedstock.

Mono-crystalline cells, made of single silicon crystals, are more efficient than multi-crystalline cells but are more expensive to manufacture.

The thin-film category, called second-generation PV, includes PV cells that produce electricity via extremely thin layers of semiconductor material made of a-Si (amorphous silicon), CIS (copper indium (di)selenide), CIGS(copper indium gallium (di) selenide), or CdTe(cadmium telluride). Another PV cell technology (also second generation) is the multi-junction PV cell.

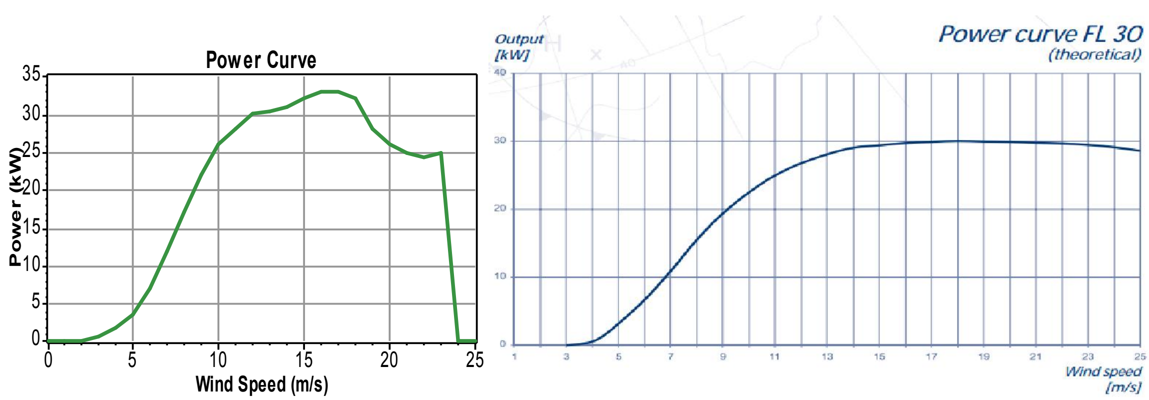
Multi-junction cells use multiple layers of semiconductor material (from the group III and V elements of the periodic table of chemical elements) to absorb and convert more of the solar spectrum into electricity than is converted by single-junction cells. Combined with light-concentrating optics and sophisticated sun-tracking systems, these cells have demonstrated the highest sunlight-to-electricity conversion efficiencies of any PV technologies, in excess of 40%.The efficiencies of all PV cell types have improved over the past several decades. The highest-efficiency research cell was achieved in 2010 in a multi-junction concentrator at 42.3% efficiency. Other research-cell efficiencies range from 15% to 25% for crystalline silicon cells, 10% to 20% for thin film, and about 5% and to 10% for the emerging PV technologies organic cells and dye-sensitized cells, respectively. The efficiency of PV modules is lower than the efficiency of the cells from which they are made. Table 6.1 shows the efficiency of the typical module [25].

Table 4-1: commercial module efficiency, 2010

Technology	Commercial Module efficiency
Mono-crystalline silicon	14%
Multi-crystalline silicon	14%
cadmium telluride	11%
amorphous silicon	6%
copper indium gallium (di) selenide	11%
Low-concentration CPV with 20%-efficient silicon cells	15%
High-Concentration CPV with 38% efficient III-V multi junction cells	29%

4.2.4 Wind Turbine

Since the start of wind power use, the FL 30 has proven that Fuhrländer concepts fit up to today. This centrally controlled compact turbine with blade tip brake runs totally uncomplicated on its slim lattice mast in various urban and rural locations. It has a technologically simple design and generates kilowatt of clean wind power. This machine is also suitable for remote locations without demands for the electricity network or the infrastructure mainly in the market outside Europe.



(a) (b)

Figure 4-2: Wind power of FL30; (a) HOMER synthesis; (b) company brochure sheet

4.2.5 Generator Selection

Wind generators: - The wind energy conversion system consists of the rotor shaft with bearings, brakes, an optional gearbox, as well as a generator and optional clutches. Among these, the generator is one of the most important components of a power transmission unit. In contrast with the generators used in other conventional energy options, the generator of a wind turbine has to work under fluctuating power levels, in tune with the variations in wind velocity. Most of the wind turbines are operational with induction generators. They are simple and strong in construction and offer impressive efficiency under varying operating conditions. Induction machines are relatively inexpensive and require minimum maintenance and care**.** Characteristics of these generators like the over speed capability make them suitable for wind turbine application [14]. It has a slightly softer connection to the network frequency than the synchronous generator, as it allows a limited amount of slip, or variation, in generator rpm. Three-phase induction generators are mostly used in wind turbines [13]. Unlike the induction generator, synchronous generators are used in most of the electrical power consumed in the world. The generator works at a constant speed related to the fixed frequency. Therefore, it is not well suited for variable speed operation in the wind plants.

Micro-hydro Generator:-The standard generators in use on micro hydropower projects are the synchronous generator and the induction motor used as a generator. The synchronous generator supplies its own excitation current through either a rectifier system or an external dc generator or battery system. The generator can also be used with utility system interties. This requires synchronizing equipment to determine when the unit can be safely connected to the power line. The equipment is generally a system of lights or an indicating dial to indicate when the generator voltage is in phase with the voltage of the utility. The induction generator is actually an induction motor used as a generator. It is capable of operating as a generator only when connected to an outside electrical power system. The generator output voltage does not appear at the output terminals until after the generator is connected to the outside power system. Thus, there is no way to synchronize an induction generator with an outside power system as is done with a synchronous generator. To function as a generator, an induction motor must be driven about 1 to 5% faster than synchronous speed, or 2 to 6% faster than the speed it would have when functioning as a motor. The amount of output power that is generated by an induction generator is approximately proportional to the excess speed above synchronous speed. This excess speed is called slippage. There are two ways to place an induction generator in operation. One method is to bring the machine up to speed by starting it as a motor, then overdrive the unit with the turbine to generate electricity. A second method is to bring the induction machine up to speed with the turbine and then close the main breaker to interconnect the generator with the line. The second method of starting an induction generator has been found to reduce the transients that are noted on a power line when an induction machine is connected to the line. The generator must be connected to the power line before the turbine over speeds the unit; otherwise damage to the machinery may occur. An induction generator requires from the power line a magnetization current that is out of phase with the normal power. This need for magnetization current is a requirement of the unit operating either as a Motor or as a generator. [45]

Diesel generator: - A diesel generator is simply a normal electric generator driven by a diesel engine (prime mover). An electrical generator is an electromechanical system that converts mechanical energy into electrical energy through the interaction of electromagnetic and electrostatic fields within the system [4].

4.3 Load Estimation

By considering the peoples socioeconomic activity the following loads are considered i.e. lighting, radio receiver and television set, water pumps, stoves, Electric mitad (Baker of Ethiopian traditional food ”injera”), Refrigerator, computer, printer and photo-coppery. Mobile Cell phone and megaphone are also considered. The loads are inclusive both the primary school and health post. The estimation and analysis has done based on the number of people in the area .Since the consideration of resource type is different for the villages, the load data and the model is carried out separately for each village.

The load can be categorized in to two types as primary load and deferrable load. According to the homer definitions, Primary load is electrical load that must be met immediately in order to avoid unmet load .Deferrable load is electrical load that must be met within some time period, but the exact timing is not important. These loads are normally classified as deferrable because they have some storage associated with them. There is some flexibility as to when the pump actually operates, provided the water tank does not run dry.

Figure 4-3: Proposed load appliance used at the sit

4.3.1 Load at Kidusyohanes

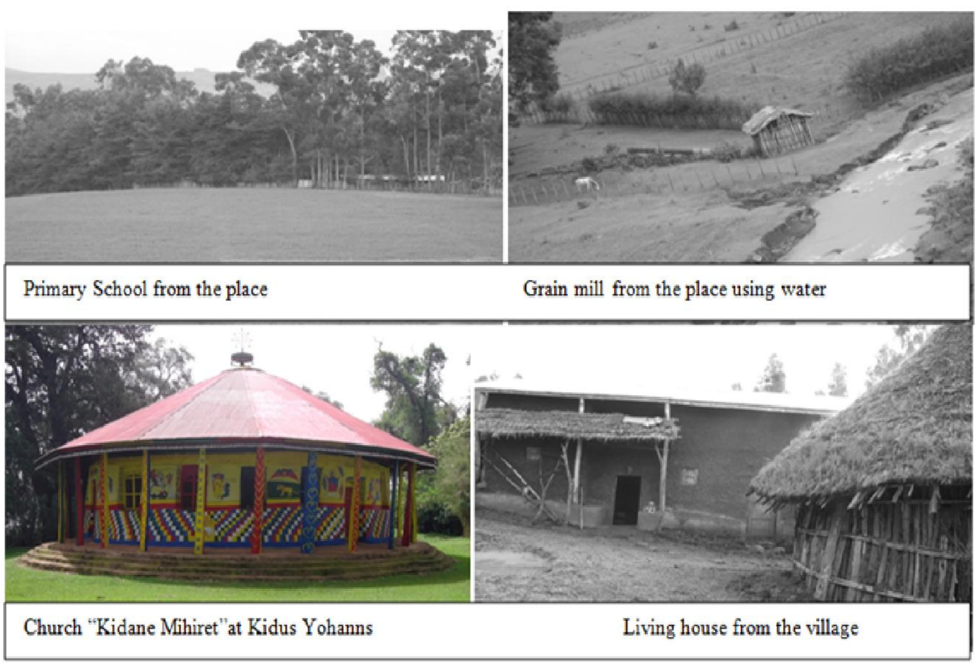


Figure 4-4: Typical load consumers Taken from the village

Primary load: -Primary loads are loads that met immediately to avoid unmet load. Currently the country is in a great revolution to replace the incandescent lamp by energy saving one. So, in case of lighting 4CFL of 11w bulb is considered for the three room regular house in the area and one night light is assumed. The light for school, night school, and health center has taken to be 20w CFL for indoor light and 40w CFL are considered for external light. There is a church in each village as shown in figure-4.4. So, the load is assumed to be 11w CFL, 20wCFL and 23w megaphone. The people in the area used to fire wood for cooking their food. As mentioned earlier in this text this is the cause of both global warming and human health problem. To alleviate this problem 1kw electric stove and 2.5kw "electric mitad" is considered for each house hold and the operation time is scheduled according to the working habit of the people.

In case of "electric mitad" the community baking habit is assumed to be two times a week and these two days are not fixed. So, randomly the load is assumed to be shared on the week days, which is 16.53kw with the frequency is two times a week. Also the baking activity is not repeat in a day i.e. if one house hold bake "injera " from 6:00-7:00 no baking is takes place again in that day but may be after 3 or 4 days. So, again the load will be shared in a day for three period of time which is 5.51kw per the given period of time. The 1kw stove is used to cook "watt" another Ethiopian local food to be eaten with "injera" and the activity is repeated even in a day.

The load is also categorized as week load and weekend load. The weekend days are the holydays in the area so, in these days no milling is takes place. The Televisions and radio may play more than the week days and learning and teaching activity may not perform in formal way in the school.

The school is closed in February for the semester brake and in July and August for annual break. In July and August irrigation pump is not used because of the seasonal rain fall of the area and in June and September 30% reduction is assumed. These conditions are applicable for all the villages.

Table 4-2: Scheduling of home appliance

Appliance	Duration	Total power(kw)
Lighting	18:00-23:00	5.346
Night Light	23:00-6:00	1.782
Stove	6:00-7:00,7:00-8:00,17:00-18:00	162
Electric mitad(stove)	6:00-7:00,7:00-8:00,17:00-18:00	5.51
TV	6:00-8:00,18:00-23:00/10:00-23:00	11.34
DVD	6:00-8:00,18:00-23:00	4.05
Radio	6:00-8:00, 17:00-23:00/10:00-23:00	0.81
Cellular phone	6:00-7:00,19:00-20:00,20:00-21:00	0.972

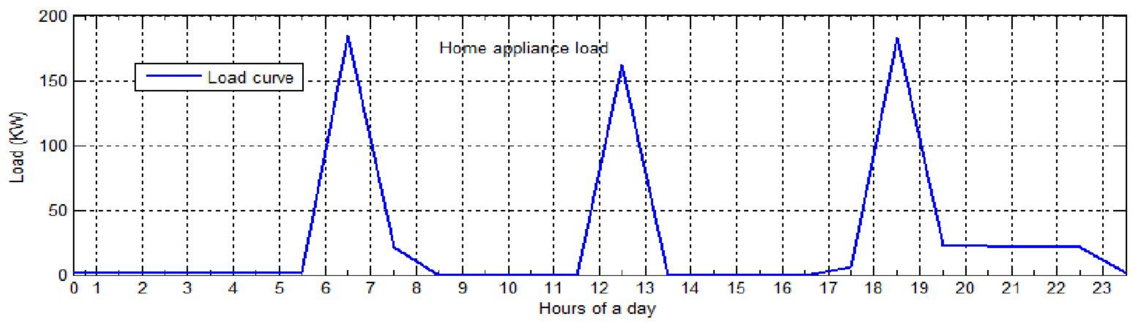


Figure 4-5: Load distribution for home appliance for a day

School: - There is no formal conduction of class at the weekend days & summer season (July and August, Annual break). February is Semester break and almost 80% of the load is not applicable only external light will be applied.

Table 4-3: Scheduling of school load

Appliance	Duration	Total Power(kw)
Lighting	17:00-20:00	0.320
External light	18:00-6:00	0.320
TV	9:00-12:00,15:00-17:00	0.07
Radio	8:00-12:00,14:00-17:00	0.02
Computer	8:00-12:00,14:00-17:00	0.448
Printer	8:00-9:00,11:00-12:00/14:00-15:00	0.225
Copy machine	8:00-9:00,11:00-12:00/14:00-15:00	0.225

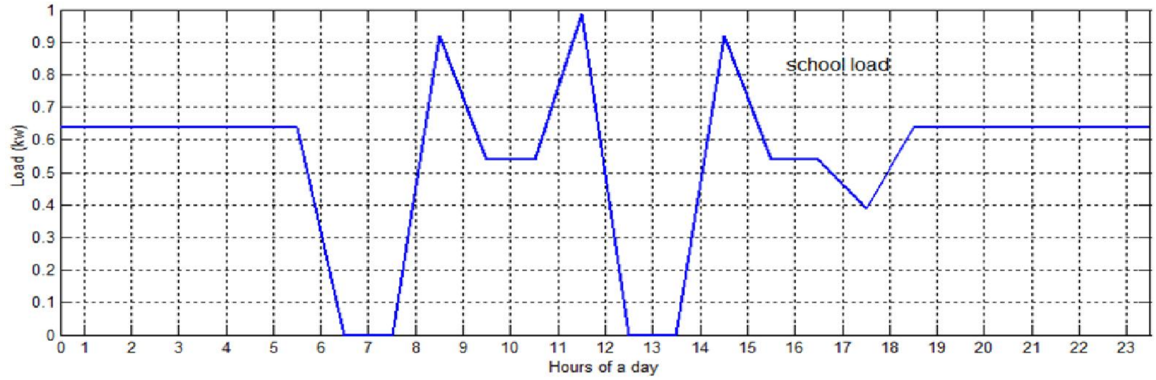


Figure 4-6: Load distribution for school load for a day

Health center: -The refrigerator is plugged in the whole day (24 hours) but the actual power consumption time is assumed to be 8hrs per day. The health center is assumed to be open to the whole week and weekend days.

Table 4-4: Scheduling of health center load

Appliance	Duration	Total (kw)
Lighting	18:00-6:00	0.4
External light	18:00-6:00	0.16
TV	8:00-10:00,18:00-23:00	0.07
Radio	8:00-12:00,17:00-20:00	0.005
Laboratory equipments	10:00-11:00,14:00-15:00	1
Refrigerator	0:00-23:00	0.5

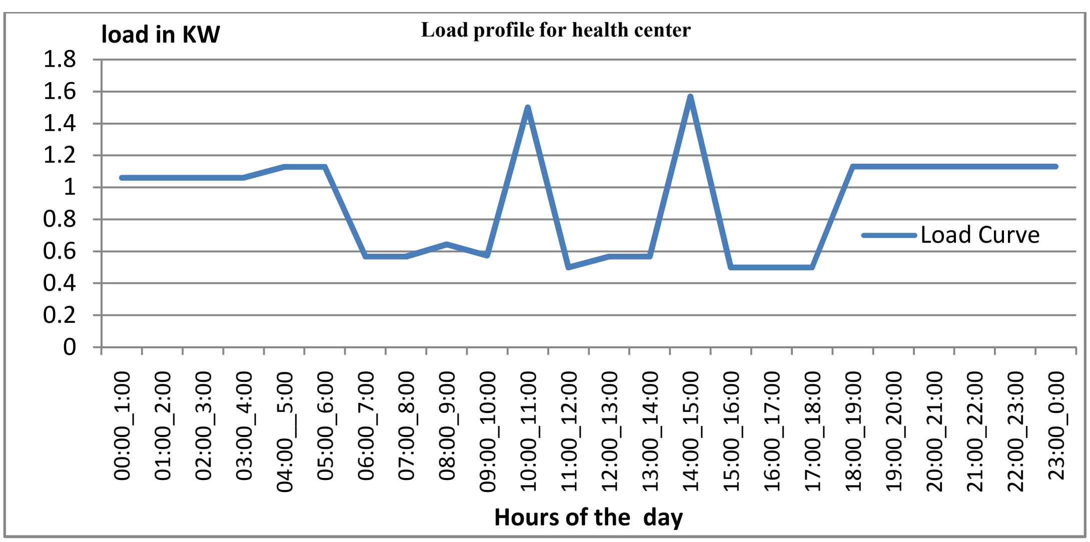


Figure 4-7: Load distribution for health center in a day

Church: - There is at least one church in the village and the power consumption is scheduled from the customary practice of the people in the church.

Table 4-5: Scheduling of church load

Appliance	Duration	Total watt(kw)
Lighting	4:00-9:00,12:00-15:00/3:00-11:00	0.176
External light	18:00-6:00	0.12
Megaphone	4:00-9:00,12:00-15:00/3:00-11:00	0.069

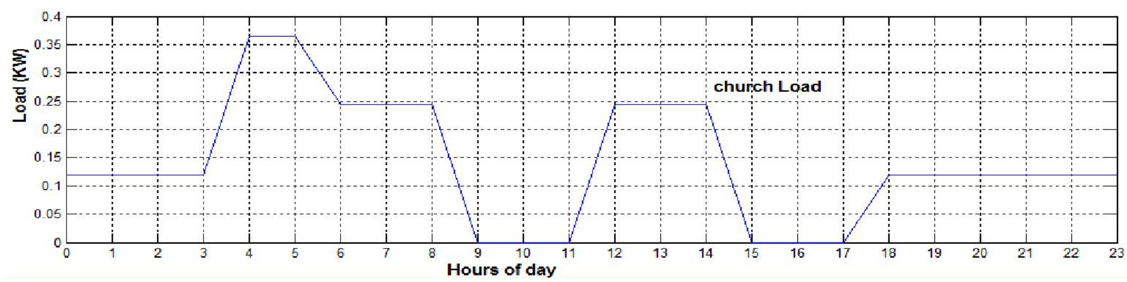


Figure 4-8: Load distribution for school load for a day

Milling house:-The weekend days are religious holydays for the inhabitants, so milling does not work at the weekend days. There are also different holydays from the week day but in this paper these days considered as working days.

Table 4-6: scheduling of milling house

Appliance	Duration	Total watt(kw)
Lighting	18:00-21:00	0.12
flour mills	8:00-12:00,14:00-20:00	26

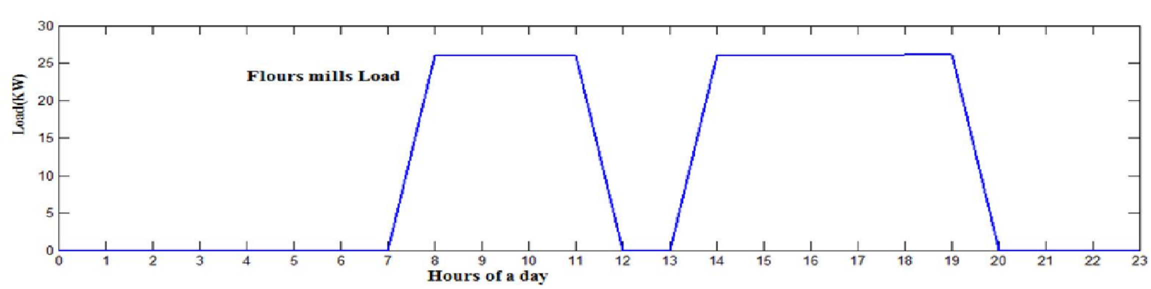


Figure 4-9: Flour mill Load distribution in a day

Deferrable load:-In case of deferrable load Water pump both pump for irrigation and well pump for drinking water consumption are assumed. By assuming 100L [4] water per house hold for daily demand and 373 W rating 68L/min pumping capacity and a total of 6 well pumps are assumed. Currently there is no any irrigation pump in the village this is most probably because of lack of electric energy and irrigation water pump of 8 are assumed with 180W rating and the capacity of pumping 34L/min. The peak deferrable load is 8*0.373= 2.984KWand 10*0.18=1.8KW for both well pump and irrigation pump respectively.

For well pump a water storage capacity of 3 days are assumed this means thank must store for 3days*100l/day*162family= 48600L. For irrigation the pumps are assumed to run for 4hrs/day to store for 2days. The deferrable load is considered the same for kidusyohanes and Kundab. The summarized value is shown in table 4.7.

Table 4-7: Average deferrable load

Appliance	Watt	Quantity	Running time /day	Duration	Total power(kw)	Capacity (kwh)	ADL (kwh/d)
well pump	373w (68L/min)	6	0.496hrs each	Not known	2.238	4.4387	1.48
Irrigation pump	180w (34L/min)	10	4each	Not known	1.8	14.4	7.2

The irrigation pump is not applicable completely in July and August (seasonal rain fall) and it is reduced by 30% in June and September.

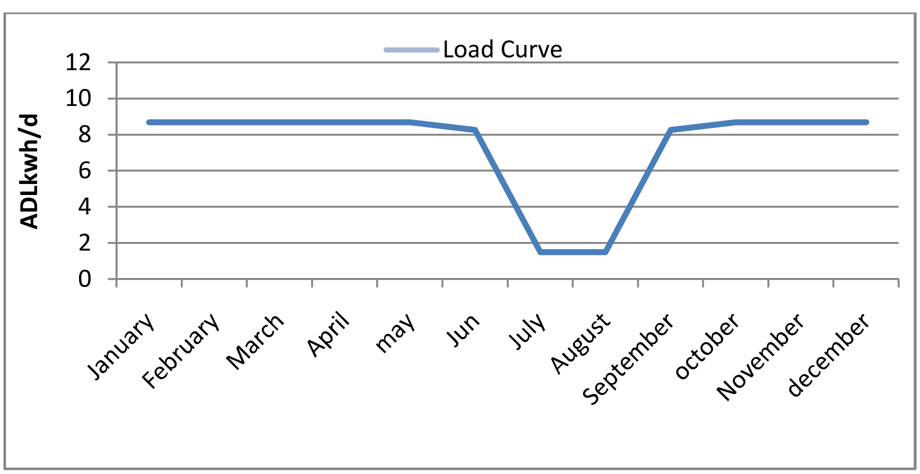


Figure 4-10: Monthly average Deferrable load

Table 4-8: (a) Monthly average load; (b) load by type of appliance

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
week load	222.1	220.4	222.1	222.1	222.1	222.1	220.4	220.4	222.1	222.1	222.1	222.1
weekend load	194.6	194.6	194.6	194.6	194.6	194.6	194.6	194.6	194.6	194.6	194.6	194.6
Deferrable load/power	4.0	4.0	4.0	4.0	4.0	3.5	2.2	2.2	3.5	4.0	4.0	4.0
Total weekend	198.7	198.7	198.7	198.7	198.7	198.1	196.9	196.9	198.1	198.7	198.7	198.7
Total week	226.1	224.5	226.1	226.1	226.1	225.6	222.7	222.7	225.6	226.1	226.1	226.1

(A)

Appliance \ Rating & type	power(kw)		Energy(kwh/d)	
	week	weekend	week	weekend
Home	191.81	191.81	536.092	680.892
School	1.628	0.32	7.1165	3.84
Health cent.	2.135	2.135	13.245	13.245
Flour mills	26.12	0	260.36	0
Church	0.365	0.365	3.331	3.331
Total primary	222.058	194.63	820.1445	701.308
Deferrable	4.038	4.038	8.68	8.68
Total	226.096	198.668	828.8245	709.988

(B)

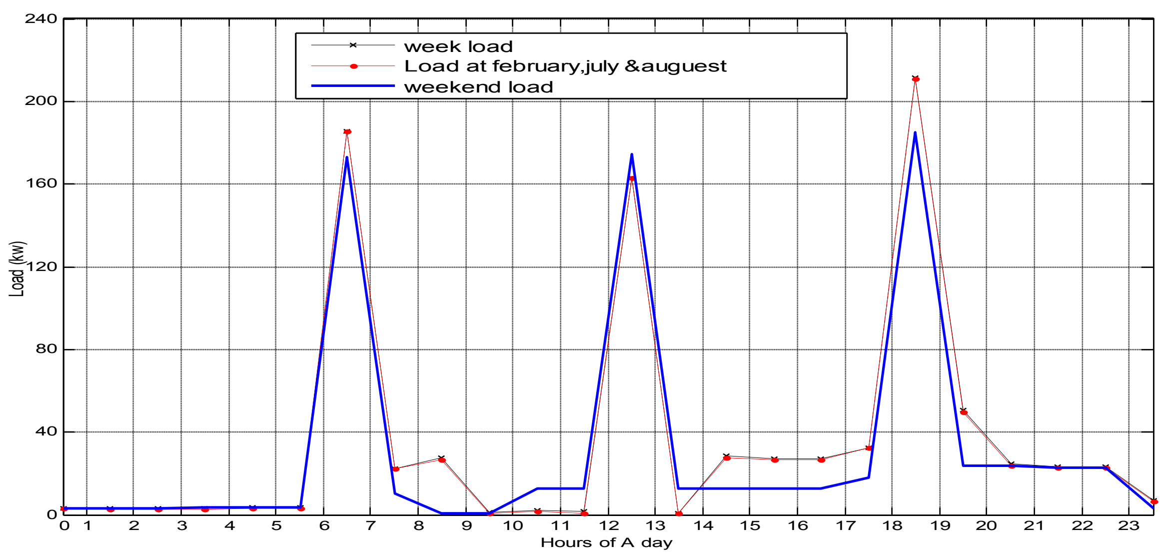


Figure 4-11: Comparison of week, weekend and seasonal load

4.3.2 Load at Kundab

In case of "electric mitad" the community baking habit is assumed two times a week and these two days are not fixed. So, randomly the load is assumed to be shared on the week days i.e. 18.77kW and the frequency is two times a week. Also the baking activity is not repeat in a day i.e. if one hose hold bake "injera " from 6:00-7:00 no baking is takes place again in that day but may be after 3 or 4 days. So, again the load will be shared in a day for three period of time i.e. 6.26kw per the given period of time. The 1kw stove is used to cook "wate" another Ethiopian local food to be eaten with "injera" and the activity is repeated even a day.

Table 4-9: Scheduling of Home appliance at Kundab

Appliance	Duration	Total power(kw)
Lighting	18:00-23:00	6.072
Night Light	23:00-6:00	2.024
Stove	6:00-7:00,7:00-8:00,17:00-18:00	184
Electric mitad (stove)	6:00-7:00,7:00-8:00,17:00-18:00	6.259
TV	6:00-8:00,18:00-23:00/10:00-23:00	12.88
DVD	6:00-8:00,18:00-23:00	4.6
Radio	6:00-8:00, 17:00-23:00/10:00-23:00	0.92
Cellular phone	6:00-7:00,19:00-20:00,20:00-21:00	1.104

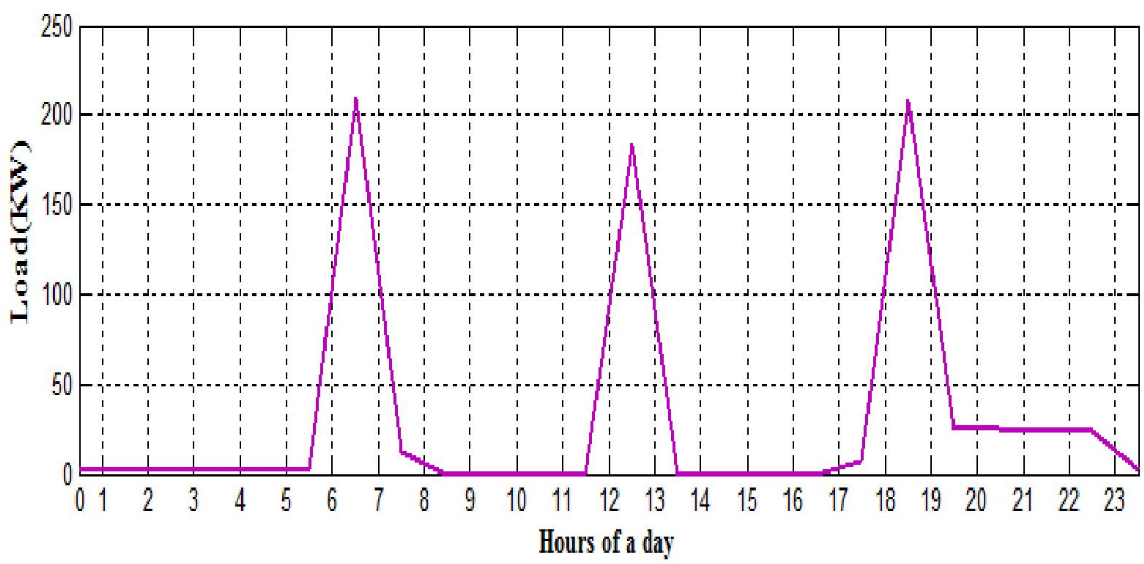


Figure 4-12: Load distribution in a day of Home Appliances

Table 4-10: (a) monthly average load; (b) load by type of appliance

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
week load	248.1	246.5	248.1	248.1	248.1	248.1	246.5	246.5	248.1	248.1	248.1	248.1
weekend load	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7
Deferrable load/power	4.0	4.0	4.0	4.0	4.0	3.5	2.2	2.2	3.5	4.0	4.0	4.0
Total weekend	224.7	224.7	224.7	224.7	224.7	224.2	222.9	222.9	224.2	224.7	224.7	224.7
Total week	252.1	250.5	252.1	252.1	252.1	251.6	248.7	248.7	251.6	252.1	252.1	252.1

(A)

Rating & Type	power(kw)		Energy(kwh/d)	
Appliance	week	weekend	week	weekend
Home	217.859	217.859	607.761	773.361
School	1.628	0.32	7.1165	3.84
Health cent.	2.135	2.135	13.245	13.245
Flour mills	26.12	0	260.36	0
Church	0.365	0.365	3.331	3.331
Total primary	248.107	220.679	891.8135	793.777
Deferrable	4.038	4.038	8.68	8.68
Total	252.145	224.717	900.4935	802.457

(B

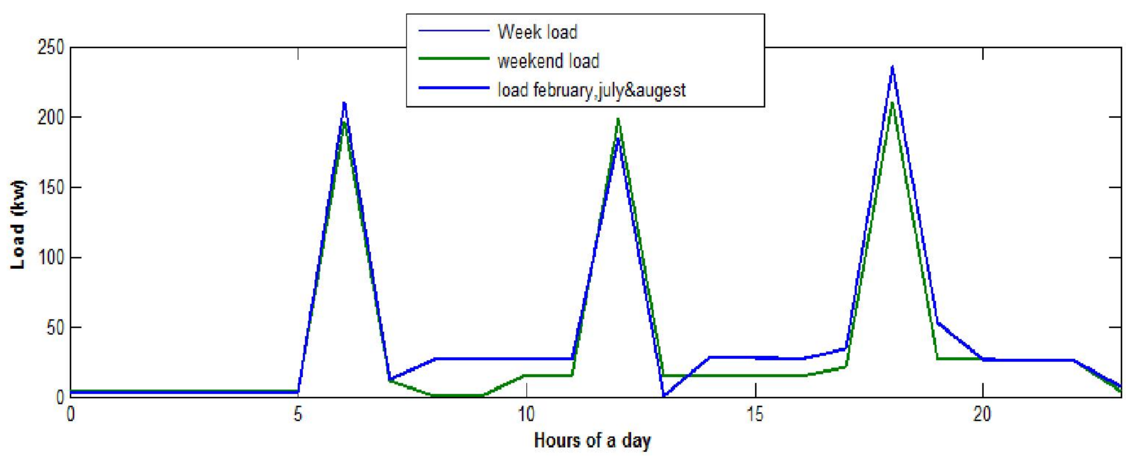


Figure 4-13: Comparison of week, weekend and seasonal load

4.3.3 Load at Debre

Like the case of Kidusyohanes and Kundab the load at this site is scheduled based on the activity of the people. Except the difference in number of house hold the assumption is the same for all cases.

Table 4-11: Scheduling of Home load

Appliance	Duration	Total power(kw)
Lighting	18:00-23:00	3.696
Night Light	23:00-6:00	1.232
Stove	6:00-7:00,12:00-13:00,18:00-19:00	112
Electric mitad (stove)	6:00-7:00,7:00-8:00,17:00-18:00	3.809
TV	6:00-8:00,18:00-23:00/10:00-23:00	7.840
DVD	6:00-8:00,18:00-23:00	2.800
Radio	6:00-8:00, 17:00-23:00/10:00-23:00	0.560
Cellular phone	6:00-7:00,19:00-20:00,20:00-21:00	0.672

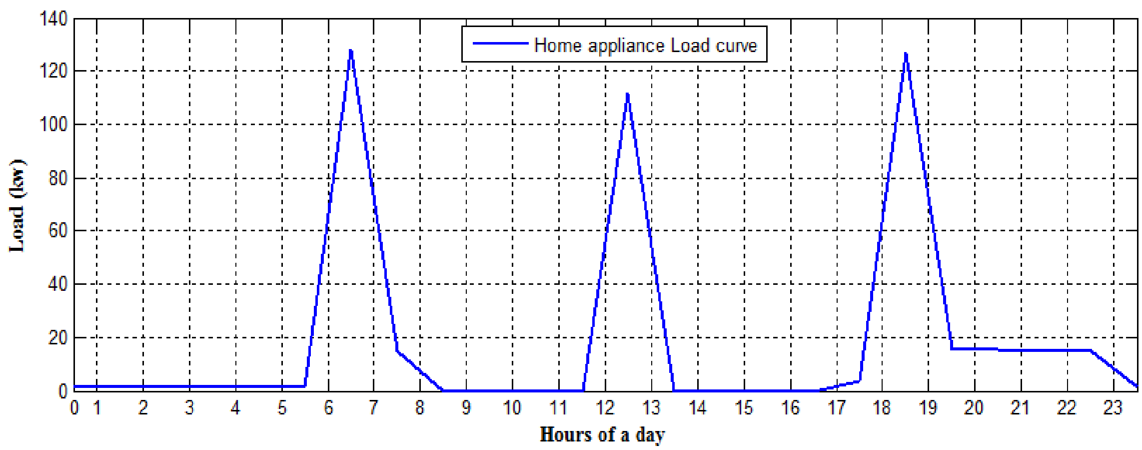


Figure 4-14: Load distribution for home appliance in a day

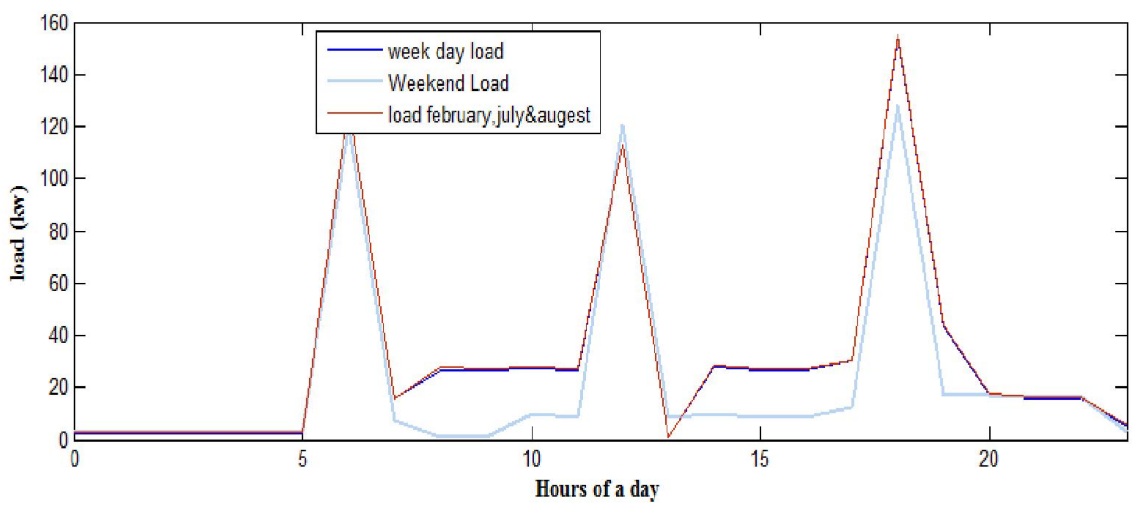


Figure 4-15: Comparative loads

Table 4-12: (a) monthly average load; (b) load by type of appliance

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
week load	162.9	161.2	162.9	162.9	162.9	162.9	161.2	161.2	162.9	162.9	162.9	162.9
weekend load	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3
Deferrable load/power	3.3	3.3	3.3	3.3	3.3	2.9	1.9	1.9	2.9	3 .3	3.3	3.3
Total weekend	145.6	145.6	145.6	145.6	145.6	145.2	144.2	144.2	145.2	145.6	145.6	145.6
Total Week	166.2	164.5	166.2	166.2	166.2	165.7	163.1	163.1	165.7	166.2	166.2	166.2

(a)

Rating & type / Appliance	power(kw)		Energy(kwh/d)	
	week	weekend	week	weekend
Home	132.609	139.47	390.532	470.739
School	1.628	0.32	7.1165	3.84
Health cent.	2.135	2.135	13.245	13.245
Flour mills	26.12	0	260.36	0
Church	0.365	0.365	3.331	3.331
Total primary	162.857	142.29	674.5845	491.155
Deferrable	3.305	3.305	6.78	6.78
Total	166.162	145.595	681.3645	497.935

(b)

Deferrable load: - The peak deferrable load is 5*0.373= 2.984KWand 8*0.18=1.8KW for both well pump and irrigation pump respectively. The summarized result is shown in the table below.

Table 4-13: Average deferrable load

Appliance	Watt	Quantity	Running time/day	Duration	Total Power(kw)	Storage capacity(kwh)	ADL (kwh/d)
Well pump	373 (68l/min)	5	0.55hrs each	Not known	1.865	3.07	1.02
Irrigation Pump	180w (34L/min)	8	4	Not known	1.44	5.76	5.76

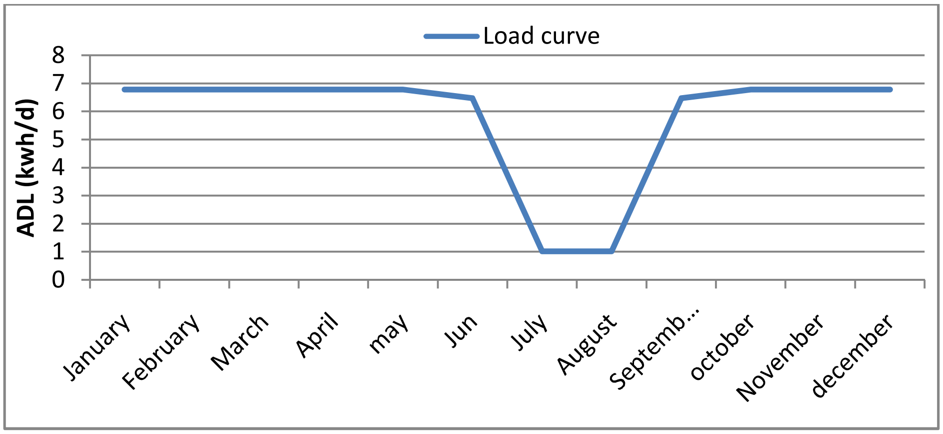


Figure 4-16: monthly average Deferrable load

4.4 Forecasting Techniques

The population growth rate from 2004 to 2007 was 2.6 and according to the World Bank prediction of population growth of Ethiopia for the next years is 2.6 [42]. Based on the number of current population the household is predicted for the next 10 years and 207,235, 143 houses are found for Kidusyohanes, Kundab and Debre respectively. According to these numbers the load demand is estimated to be 279.8, 307.2and 195.0kw Kidusyohanes, Kundab and Debre respectively. The purpose of this forecasting is not to use the data as input for the simulation but based on the output of the simulation and the forecasted load the comment will be given in the conclusion.

4.5 The Model of the Hybrid System

The Hybrid Optimization Model for Electric Renewable (HOMER) software is used as a tool to carry out the research. As discussed earlier in this text, the main objective of the research is to assess the feasibility hybrid PV/wind/micro-hydro/biomass. The model of the system is shown in the figure 4.17. The power conditioning units are DC-DC and AC-DC converters, the power from the PV is DC power and by DC-AC convertors it converted to ac power and integrated to the system grid. AC-DC convertor is uses to convert the power for the battery. This DC power is again converted to AC power as the load considered is almost AC load.

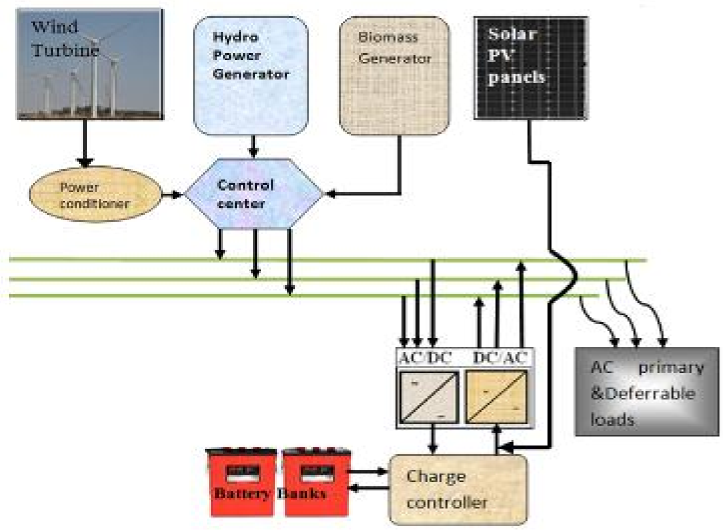


Figure 4-17: Model of the micro hydro/wind/PV & Biomass hybrid system

4.6 Input Data to HOMER

4.6.1 Cost Survey and Estimation

To model a system the cost of each and every component of the hybrid components has its own effect. Globally the cost of wind and PV cells decreasing year to year and it hopes the bright future in terms of the energy demand [36].For the estimation of the investment cost the market online and different papers, annual reports and journals are revised for reference it puts in the appendix B.

4.6.2 Common Inputs to All Sites

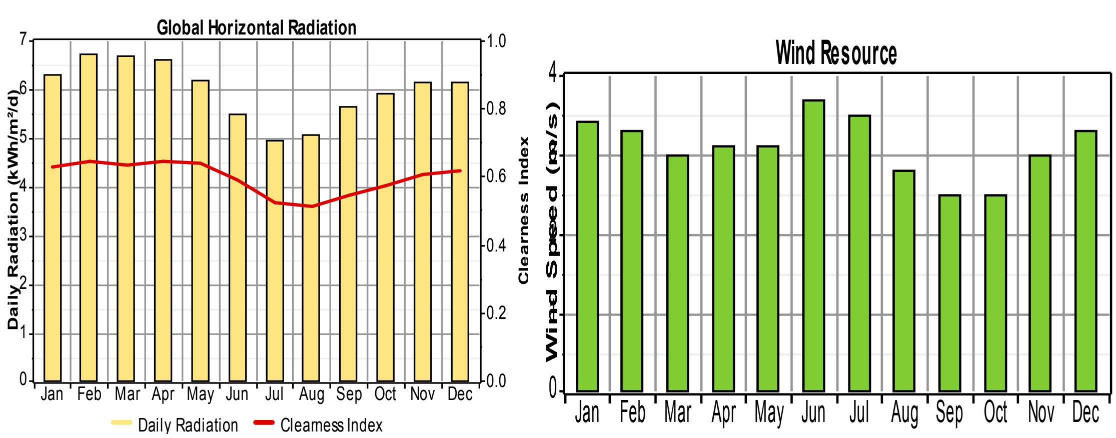


Figure 4-18: Synthesized input of solar and wind resource (10m height)

As discussed earlier the villages are located in neighborhood. The wind speed and the solar radiation are almost the same. The synthesis from HOMER for solar and wind resource is shown as the follows in Fig 4.18.

4.6.3 Specific Inputs for Kidusyohanes

Table 4-14: component inputs for Kidusyohanes

	Size(KW)	Capital($)	Replaceme nt cost($)	Operation &maintena	Size considered	Quantities	Life Time
PV	1	1500-2000	1500-2000	0	0,300,356, 385,397,425	------	20yrs
Wind	30	59,490	44617.5	1189.8	- - - - - - - -	0,5,10,12	25 yrs
Hydro	58.4	65000	30000	1000	58.4	-----	>25yrs
Biomass	20	20,000	14000	($/hr) =0.05	0,160,200, 245,284	-----	15000hrs
Battery	Surrette 4KS25 P1900	782	456	15	-----	0,875,901,920, 925,945,960,975	10569kwh
Convertor	1	714	535.5	14	------	0,240,260,280	15yrs

In addition to wind and solar the hybrid system at Kidusyohanes is considered the biomass and hydro resources. The primary and deferrable peak loads are 212 and 4kw respectively. The hydropower resource is in Litters per second and the biomass resource is in tone per day as shown in the figure below.

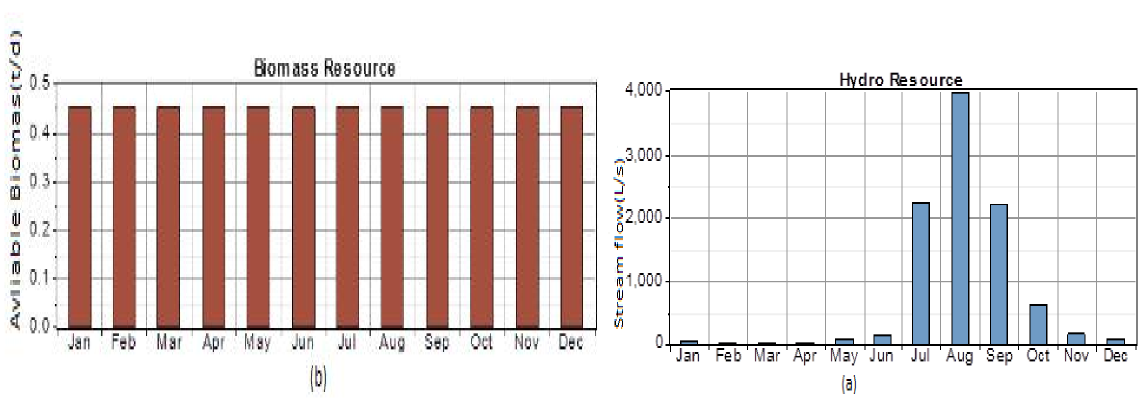


Figure 4-19: The synthesized output of hydro and biomass resource for Kidusyohanes: (a) hydro resource; (b) biomass resource

As discussed in this chapter earlier the load is categorized mainly in to two i.e. primary load and deferrable load. Primary load again divided in week load and weekend load and this load is feed in to homer. From the figure Fig.4.20 (a) is week day load profile and (b) is weekend load profile. The synthesized load is shown below in figure 4.20.

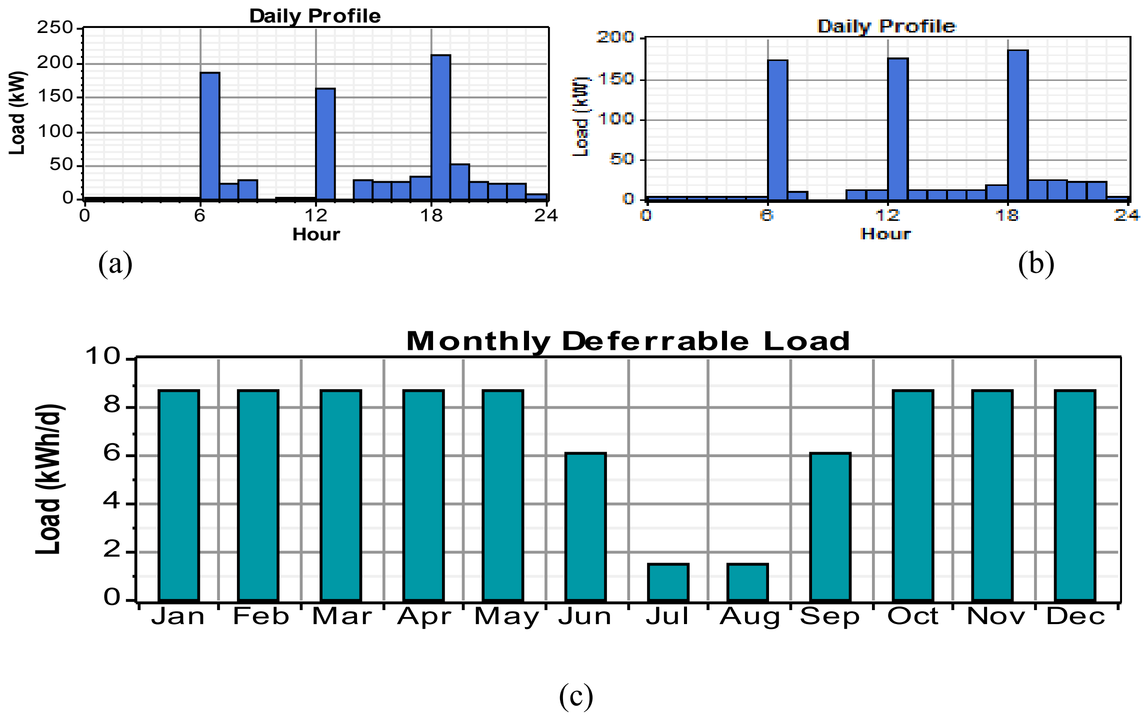


Figure 4-20: Week load profile (a) weekend load profile (b) deferrable load profile(c)

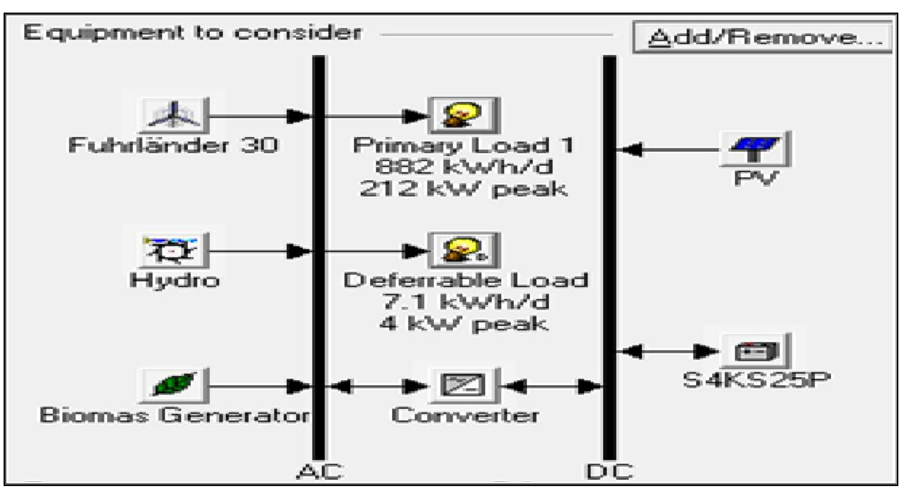


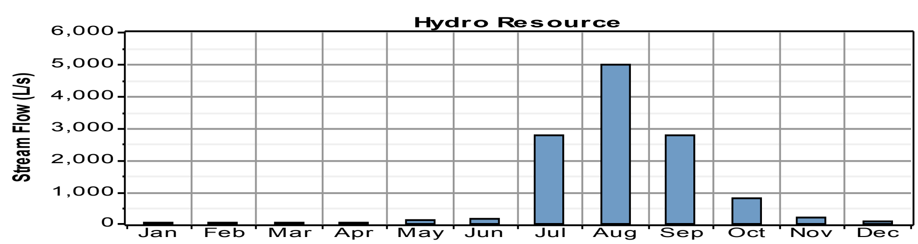
Figure 4-21: Model of the hybrid system from the software

4.6.4 Specific Inputs at Kundab

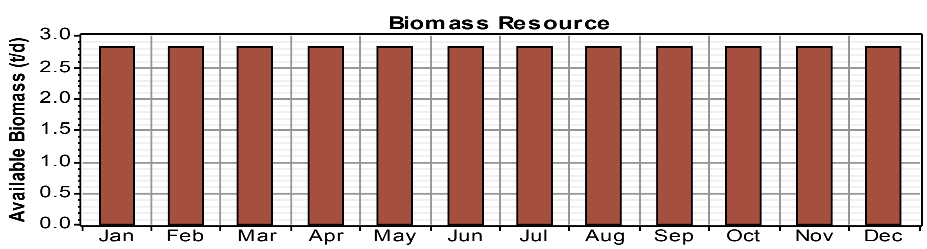
Table 4-15: Component inputs for Kundab

	Size(Kw)	Capital($)	Replacement Cost($)	Operation & maintenance	Size considered	Quantities	Life Time
PV	1	1500-2000	1500-2000	0	0,200,220,230,240,300,356	------	20yrs
Wind	30	59,490	44617.5	1189.8	- - - - - - -	0,1,2,5,10	25 yrs
Hydro	37.8	65000	30000	1000	37.8	-----	>25yrs
Biomass	20	20,000	14000	($/hr)0.05	0,200,245,284	-----	15000hrs
Battery	Surrette 4KS25P 1900	782	456	15	-----	0,805,915, 940,952, 961,974	10569kwh
Convertor	1	714	535.5	14	------	0,280,300	15yrs

Like kidusyohanes, at Kundab the hybrid system consists of hydro and biomass in addition to solar and wind. The peak load for this village is 237kw for primary load and 4kw for deferrable load.



(a)



(b)

Figure 4-22: (a) Flow rate inputs; (b) biomass resource inputs

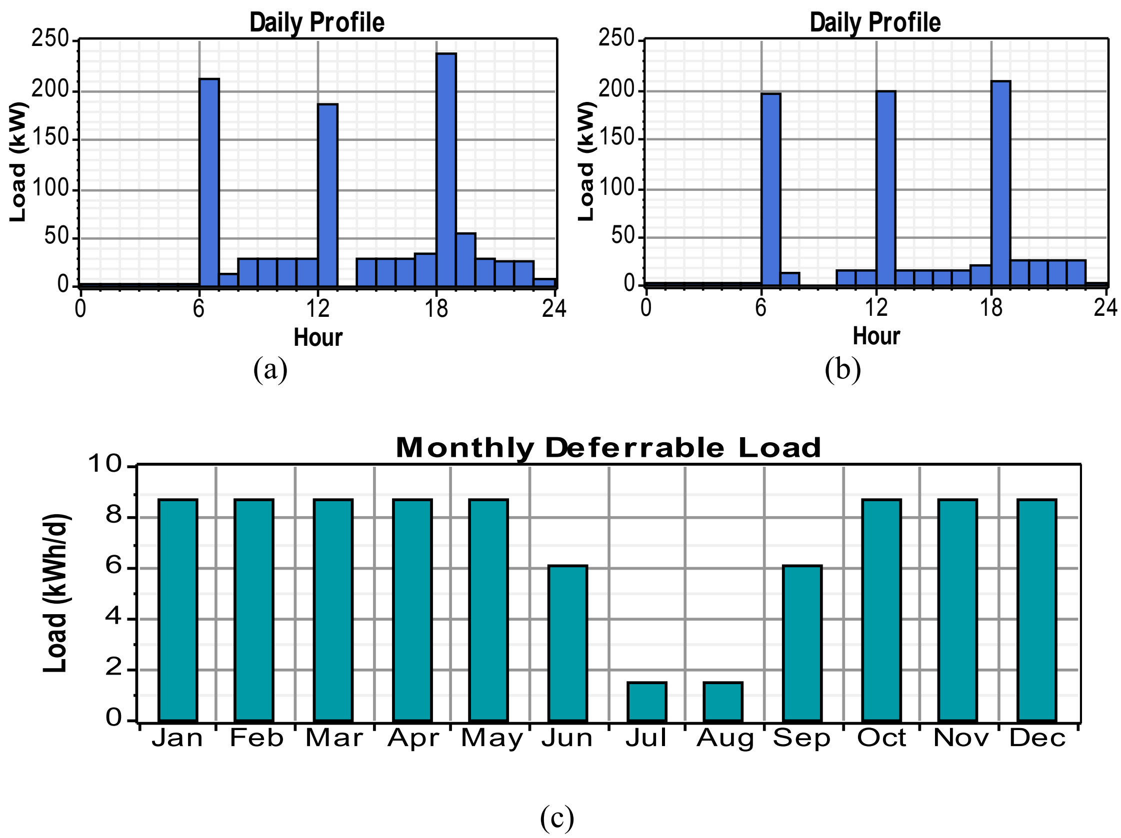


Figure 4-23: (a) week day load profile; (b) weekend day load profile; (c) deferrable load profile

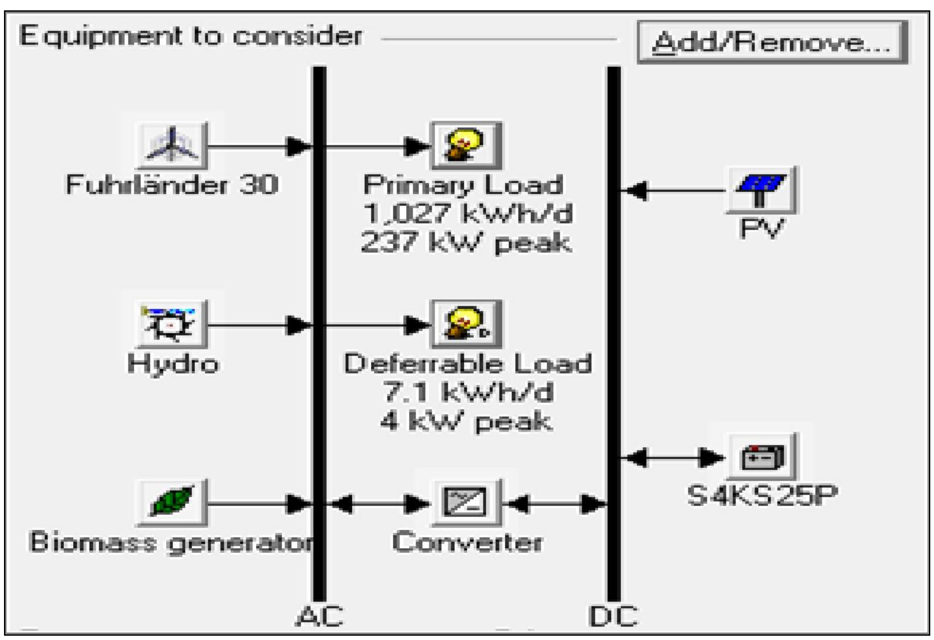


Figure 4-24: Model of hybrid system from software

4.6.5 Specific Inputs for Debre

Table 4-16: Component inputs for Debre

	Size(kw)	Capital($)	Replacement Cost($)	Operation& Maintenance	SizeConsidered (kw)	Quantities (Numb)	Life Time
PV	1	1500-2000	1500-2000	25	0,294,324, 372,397	--------	20yrs
Wind	30	59,490	44617.5	1189.8	--------	0,1,2,5,10	25 yrs
Biomass	20	20,000	14000	($/hr)0.05	0,160,200	------------	15000hrs
Desile	1	117	78	$0.09/hr	0,180,200	------------	15000hrs
Battery	Surrette 4KS25P 1900	782	456	15	---------	0,685,794,852, 896,945,964	9645kwh
Convertor	1	734	535.5	14	0,200,220	--------	15yers

In this site the system is modeled without hydro components rather it consists of wind, solar and biomass system. But the system is simulated two times with and without diesel generator. It is analyzed with and without the diesel generator for the case of reliability. The peak load for primary and deferrable is 155kw and 3.3kw respectively.

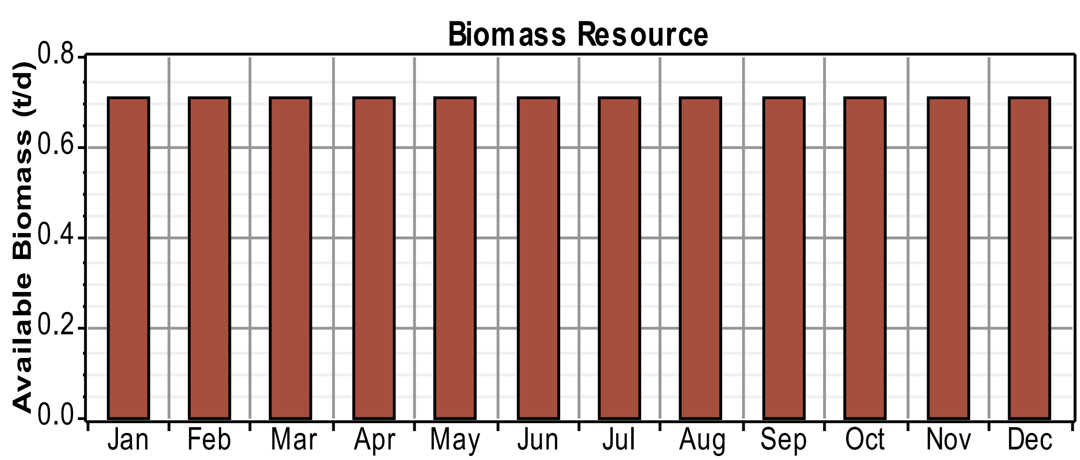
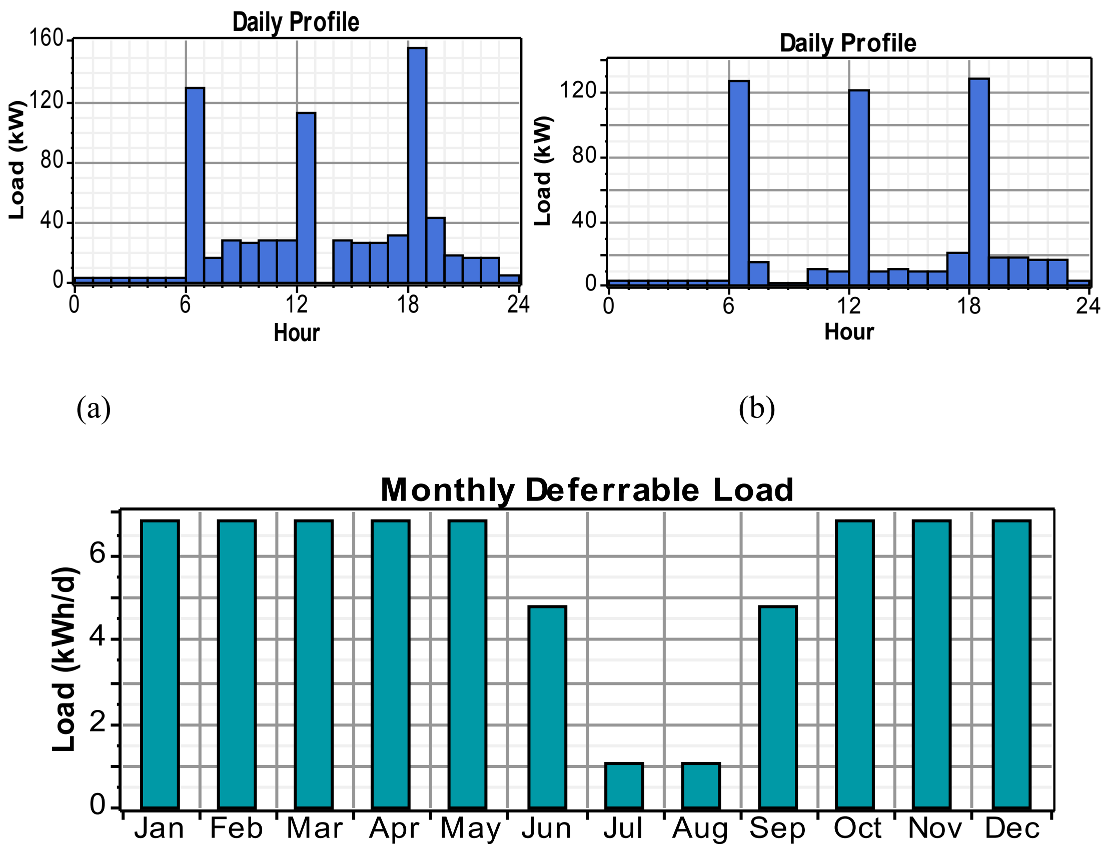


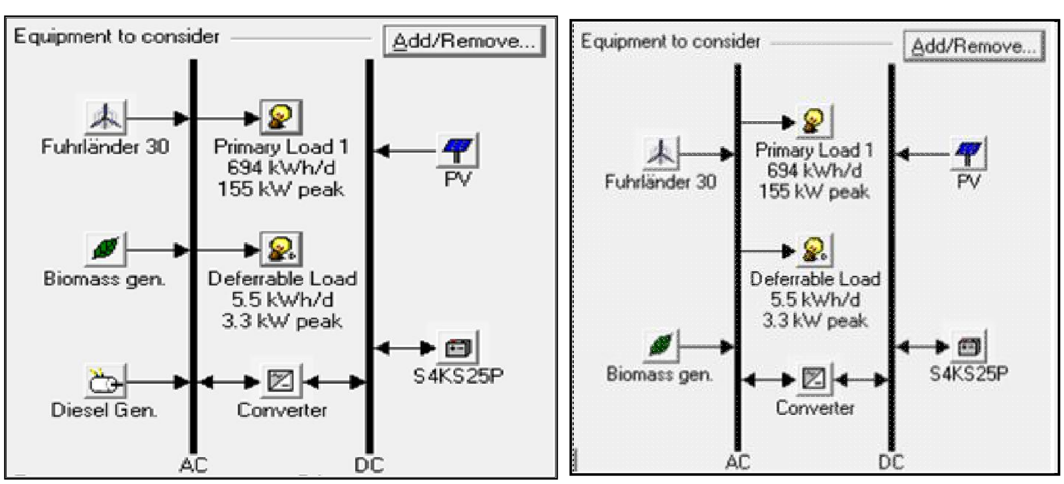
Figure 4-25: Biomass Resource input for Debre



(a) (b)

(c)

Figure 4-26: (a) Week load profile;(b)weekend load profile;(c)Deferrable load profile



(a) (b)

Figure 4-27: Hybrid model from software (a) with diesel; (b) without diesel

4.6.6 Sensitivity Input for the Sites

It is possible to perform a sensitivity analysis by entering multiple values for a particular input variable. An input variable for which have multiple specified values is called a sensitivity variable

The reasons it might want to enter multiple values for a particular input variable are, first, we might be uncertain as to what the exact value of some variable should be. By specifying a range of values, we can determine how important that variable is, and how the answers change depending on its value. In other words, we can determine the sensitivity of the outputs to changes in that variable.

Second is to make a single analysis applicable to more than one installation. For most similar case in all respect and different in some values of the variables this consideration is important [11].

The analysis is done for both the price variations for diesel and biomass and the resource variation for solar, wind and stream flow. As explained in the previous chapters the solar and wind resource is found from the satellite estimation. This gap will be filled by the sensitivity value.

Table 4-17: Sensitivity inputs for, Debre, kidusyohanes and Kundab

Sensitivity input for Debre			Sensitivity input for Kidusyohaness				Sensitivity input for Kundab		
Solar (kWh/m²/d)	Wind (m/s)	Stream Flow(L/s)	Solar (kWh/m²/d)	Wind (m/s)	Biomass Price($/t)	Diesel ($/L)	*Solar (kWh/m²/d)*	*Wind (m/s)*	*Stream Flow(L/s)*
5.99	3.1	1,017	5.99	3.1	17	0.8	*5.99*	*3.1*	*808.6*
4	4	600	4	4	20	0.7	*4*	*4*	*400*
3	5	400	3	5	25	0.6	*3*	*5*	
2	6	200							

CHAPTER FIVE

5 Simulation Results and Discussion

5.1 Types of Outputs

We can see the result of the simulation either in optimized form or in sensitivity form. In the optimization result, we can see the output again in categorized form which ranking shows the least-cost system of each type and in overall system rankings in the top-ranked system configurations according to increasing net present cost.

In Sensitivity form, the tabular sensitivity results consist of a list showing the least-cost system for each sensitivity case. When the analysis involves more than one sensitivity variable, a graph (optimal system type charts, surface plots, and line graphs.) often conveys the results in a more meaningful way than a table can.

5.2 Simulation Studies of Hybrid System at Kidusyohanes

5.2.1 Optimum Result

As discussed above in this chapter the following table (Table 5.1) and figure 5.1 shows the result in categorized form. The hybrid components considered in this system are hydro, wind, solar and biomass. From the table it may seen that the least NPC $1,018,702 and the Levelized cost of energy (COE) is $0.246/kwh. The hydro power with 58.4kw generating capacity and the PV with 300kw together with 875S4KS25P battery are considered feasible for the least NPC. By considering the EEPCo tariff information (201-300) kwh range, the domestic tariff is 0.55birr/kwh (Ethiopian birr) which is $0.03056/kwh. From this we can observe that the Levelized cost of energy (COE) is expensive for the supposed system. The 256KW PV and 875 S4KS25P battery is placed to the second most feasible system but as we observe the cost of energy is increased from $0.246/kwh to $0.263/kwh with $0.017/kwh difference. The Biomass and solar combination with the battery 960S4KS25P is ranked in the third place with the cost of energy $0.268/kwh. From the figure we can observe that the energy production share of the hydro power system is more in July, August, September and October. This seems reasonable because the flow rate is high in these months than the other. The output of the system also contains the combination of all the components considered but it is placed at the rank of 8th with total NPC $1,605,347 and the COE of $0.387/kwh which is a bit expensive.

Table 5-1: Results in categorized form

Rank	PV (kW)	FL30	Hydro(kW)	Bio (kW)	S4KS25P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Ren. fraction	Biomass (ton)	Bio (hrs)
1	300		58.4		875	240	$836,788	14,231	$1,018,702	0.24	1		
2	356				875	260	$898,068	14,996	$1,089,769	0.26	1		
3	300			160	960	260	$946,110	13,045	$1,112,872	0.26	1	19	85
4	300		58.4	160	875	240	$996,788	12,632	$1,158,266	0.27	1	5	31
5	300	5			875	260	$1,083,518	25,672	$1,411,691	0.34	1		
6	300	5	58.4		875	240	$1,134,238	26,107	$1,467,975	0.35	1		
7	300	5		160	875	260	$1,243,518	23,682	$1,546,248	0.37	1		0
8	300	5	58.4	160	875	240	$1,294,238	24,337	$1,605,347	0.38	1	3	19

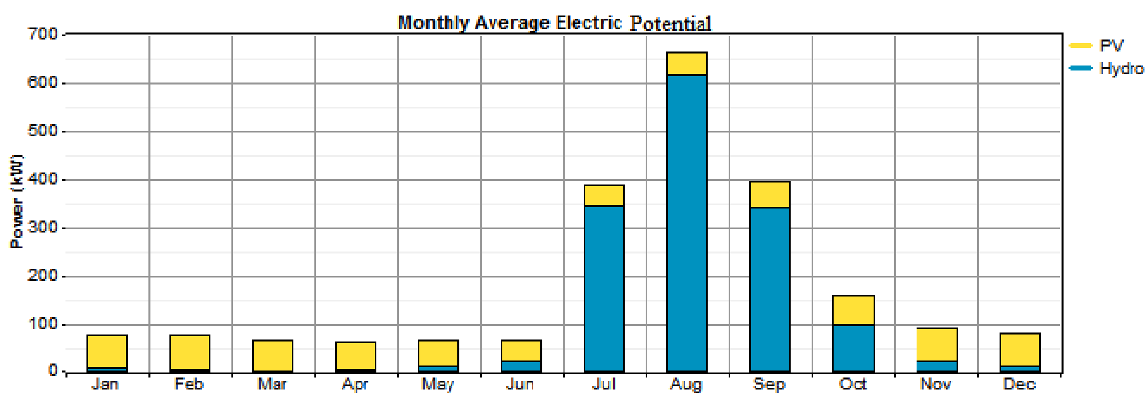
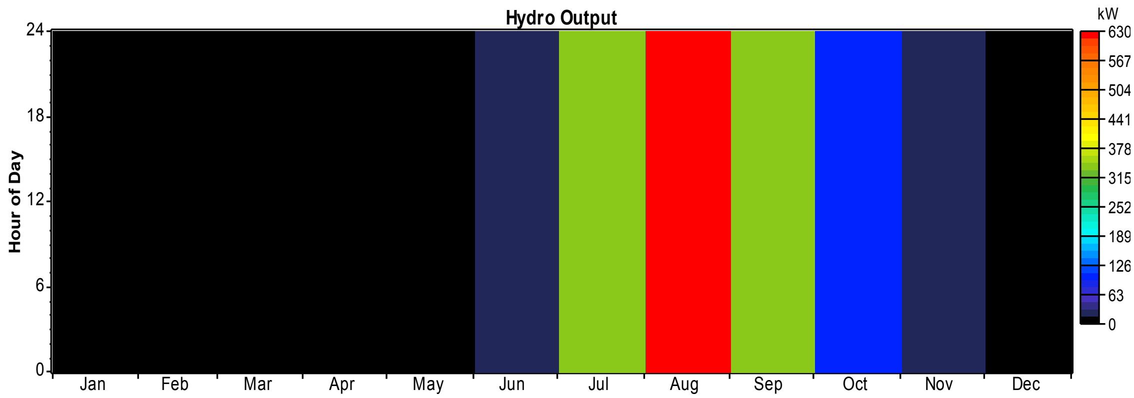
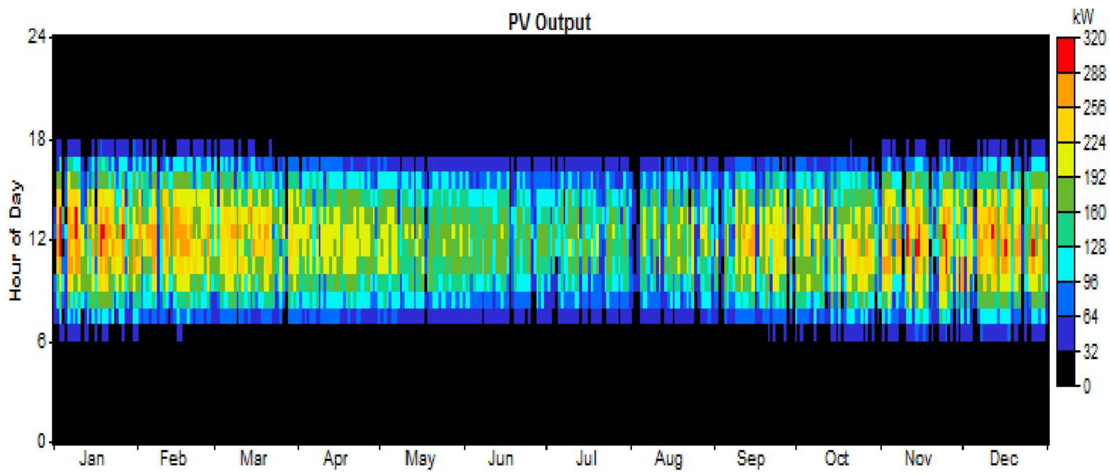


Figure 5-1: Monthly Average energy potential

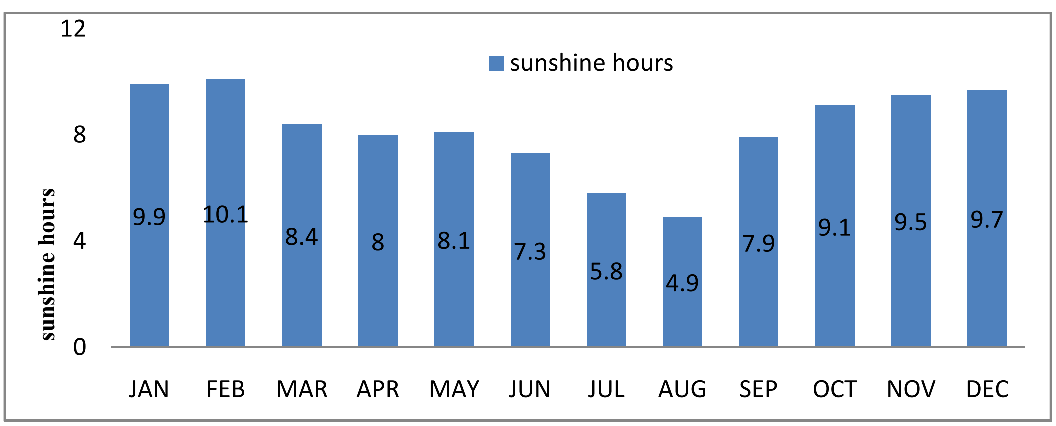
It is known that the location of Ethiopia is around the equator and the country has 12hrs sunshine. But the bright sunshine that used to produce PV power is not the same for all the months of the year .From the figure (Fig. 5.2 (c)) we can observe the sunshine duration for different months are not the same. The power output from the PV panel is also in accordance to the sunshine duration hours (figure 5.2(b)).From the figure we can observe that the maximum power output is around 12hrs (sun is over head).For hydro power output the output is maximum during the summer season when the flow rate very high as it can be seen from figure 5.19(a).In these season the power is produced in mach quantity and it may the cause of the excess energy.



(a)



(b)



(c)

Figure 5-2:(a) Hydropower output; (b) PV power output; (c) Sunshine hours

When we observe the electrical output there are three common things to be considered i.e. energy production, consumption and the excess electricity. For this case the hydropower is covered the production of 68% and 32% found from the PV. From the produced energy almost all (99%) is consumed by the AC primary load this is because the deferrable load is much smaller than the primary load. The capacity shortage is considered zero in the input of the software that is way no capacity shortage in the output of the system. This condition confirms that the system can support all the demand without the shortage at any time. Since there is 34% excess electricity, no unmeet load is found in the result and this much excess electricity may arise from unequal distribution of the resource throughout the month. The excess electricity is small in January and April but it is very much in July and august as accordance of the input resource of hydro and this assured that this energy is truly found from the hydro resource. The figure (figure 5.3) shows some of the selected months of hourly profile for excess electricity. As we notice from the figure 4.19(a) the hydro resource has big difference from month to month. Whenever the excess electricity is found in each hour of a day, it is added to result the entire year excess electricity. The total production can exceed the sum of the total load served plus the excess energy because of battery losses and conversion losses. The result here is assured this condition 55609kwh/yr lost. Based on the forecasted output, the load demand will increase from 226.09kw (2013) to 279.8kw in 2023.but 34% excess energy will serve for the reservation of this demand increment and the system can support all the load connected to it.

Table 5-2: Energy production, energy consumption and excess energy

Energy source	Energy production		Types of Load appliance	Energy Consumption		Quantity	Excess energy	
	kwh/yr	%		Kwh/yr	%		Kwh /yr	%
PV array	505408	32	AC primary load	988426.8	99	Excess electricity	542980	34
Hydro turbine	1091592	68	Deferrable load	9984.11	1	Unmet electric load	0.000383	0
Total	1597000	100	Total	998411	100	Capacity shortage	95.8	0

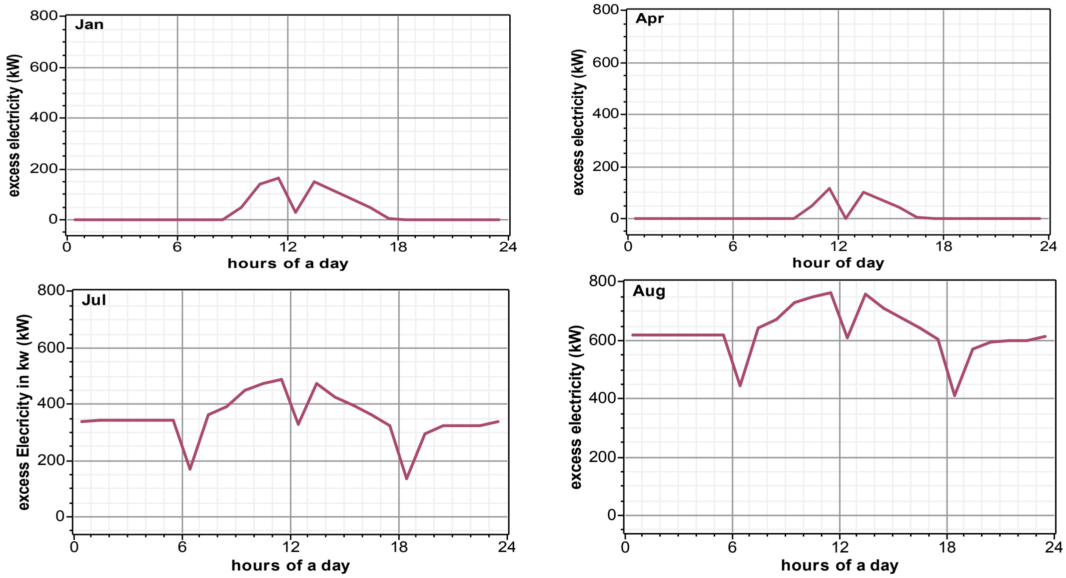


Figure 5-3: Selected month’s hourly profile of excess electricity

The output of the system may include all the components (PV, hydro, wind and biomass) considered or some of them. For the sake of comparison the system with all components is selected from the table 5.1 which is listed in rank 8 from categorized form of the output. As seen from the table the Levelized cost of energy is (COE) \$0.387/kwh which is expensive than the least NPC system with the COE \$0.246/kwh. The following table (table 5.3) and figures (figure5.4) shows the energy production and consumption from the higher NPC relative to the least NPC that includes all the components i.e. solar wind, hydro and biomass. If we have an intension of including all the components in the system we may penalized with \$0.141/kwh.

Table 5-3: Energy production, energy consumption and excess energy

Energy source	Energy Production		Types of Load appliance	energy consumption		Quantity	excess energy	
	Kwh/yr	%		Kwh/yr	%		Kwh/yr	%
PV array	505408	30	AC primary load	988426.89	99	Excess electricity	594848.5	35.4
Wind turbine	82439	5	Deferrable load	9984.11	1	Unmet electric load	0.000168	0
Hydro turbine	1091592	65	Total	998411	100	Capacity shortage	0	0
Biomass generator	924	0						
Total	1680363	100						

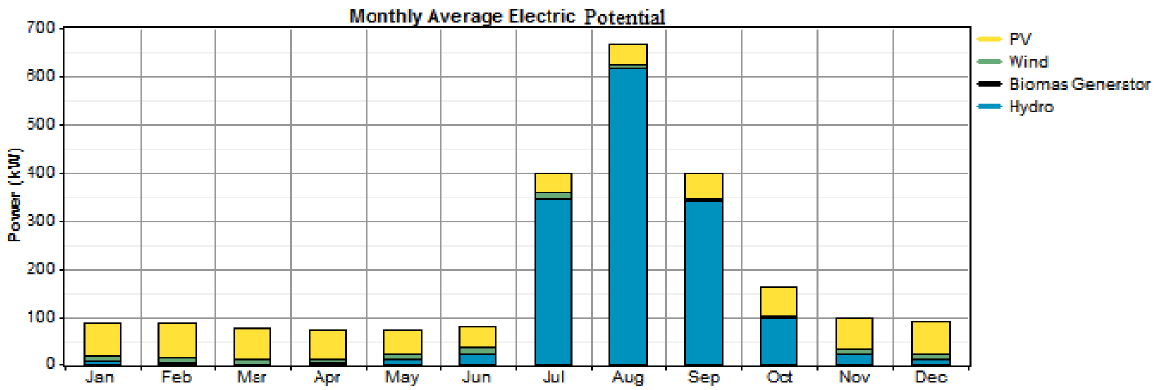


Figure 5-4: Electric energy production from all the components

5.2.2 Sensitivity Analysis of Hybrid System at Kidusyohanes

For the sensitivity input of wind speed, solar radiation and stream flow the correspondence output is listed in table 5.4. The optimal system type (OST) graph is obtained from the highest-level view of the sensitivity results. It shows the least-cost type of system (PV- hydro-battery is one type of system, Hydro-PV- bio- battery, hydro-wind- Bio battery is another) versus two sensitivity variables (wind speed and global solar adiation). The Optimal system type (Fig 5.5) output shows the same information as table 5.4.

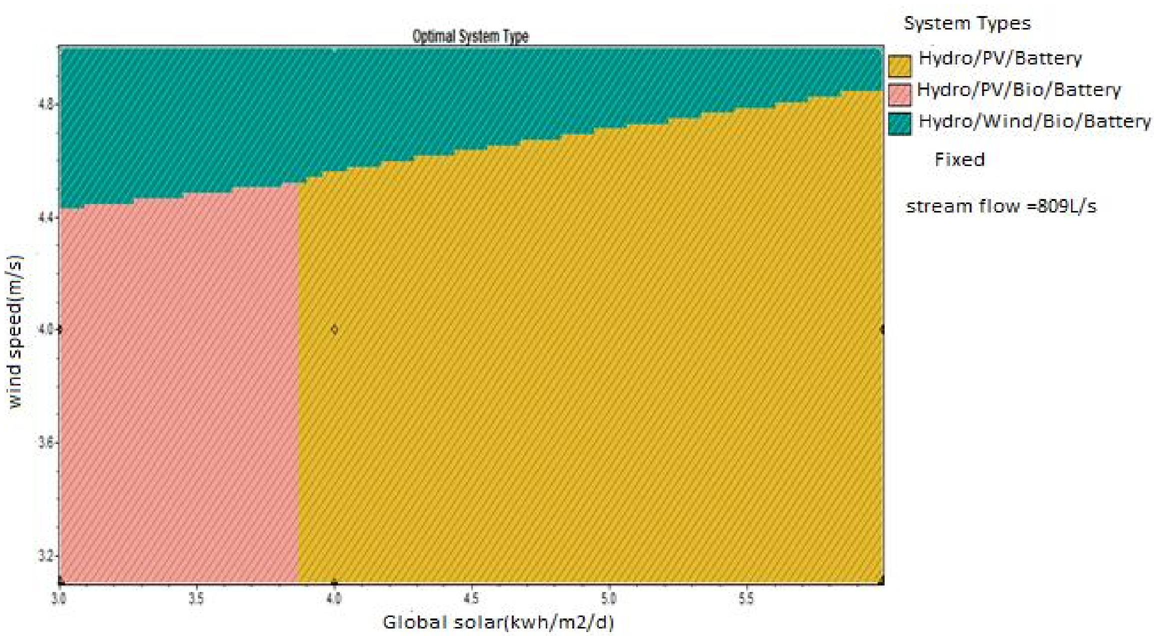


Figure 5-5: Sensitivity result of optimal system type

The graphic format makes it easier to see under which conditions the different types of systems are optimal. From figure 5.5 we can observe that hydro component is included in all the combinations. For wind speed less than 4.4m/s and solar radiation above 3.9kwh/m2, PV is selected together with hydro and Battery. When the solar radiation is less than 3.9kwh/m2 bio mass is included in the system in addition to Hydro and PV. The wind component is included in to the system when the wind speed is greater than 4.4m/s and when the solar radiation is increasing the wind selection to the system is become decreasing.

Table 5-4: Sensitivity Result In tabular form

Rank	Solar (kWh/m²/d)	Wind (m/s)	Stream Flow (L/s)	PV (kW)	FL30	Hydro (kW)	Bio (kW)	S4KS25P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Ren. fraction	Biomass (t)	Bio (hrs)
1	5.9	3.1	808.6	300		58.4		875	240	$836,788	14,231	$1,018,702	0.246	1		
2	5.9	3.1	400	300		58.4		875	260	$851,068	14,795	$1,040,202	0.251	1		
3	5.9	4	808.6	300		58.4		875	240	$836,788	14,231	$1,018,702	0.246	1		
4	5.9	4	400	300		58.4		875	260	$851,068	14,795	$1,040,202	0.251	1		
12	4	5	400		5	58.4	160	960	240	$694,280	23,183	$990,630	0.239	1	81	366
17	3	5	808.6		5	58.4	160	901	240	$694,251	20,546	$956,899	0.231	1	43	192
18	3	5	400		5	58.4	200	945	260	$748,553	22,785	$1,039,825	0.251	1	75	268
19	3	4	808.6	300		58.4	160	960	240	$996,830	16,328	$1,205,560	0.291	1	60	274

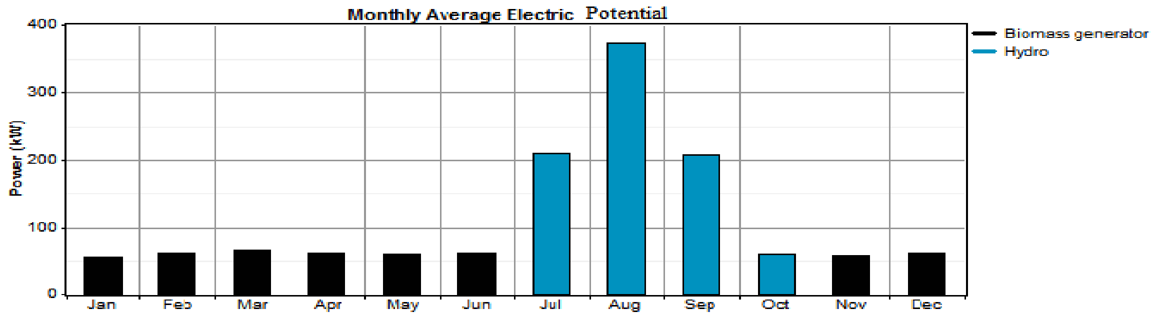
5.3 Simulation Studies of Hybrid System at Kundab

5.3.1 Optimum Result

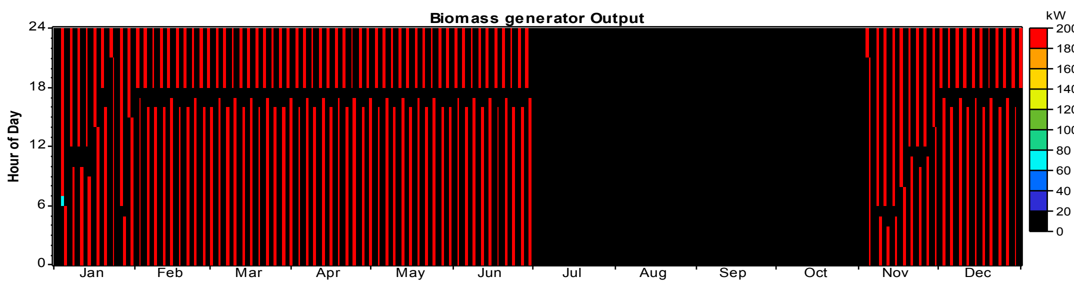
As the case of kidusyohanes the model of the system in this case consists of hydro-PV-Wind-biomass components. From the table 5.5 and figure 5.6(a) shows the result from the categorized form. From the table we can observe the least NPC $1,050,286 and the Levelized cost of energy (COE) is $0.218/kwh. The hydro power with 37.8kw generating capacity and the bio-generator with 200kw together with 915S4KS25P battery are considered feasible for the least NPC. By considering the EEPCo tariff information (201-300) kwh range the domestic tariff is 0.55birr/kwh (Ethiopian birr) which is \$0.03056/kwh. From this we can observe that the Levelized cost of energy (COE) is expensive for the supposed system. The 1FL30 wind turbine, 37.8kw hydro,200kw bio generator and 974S4KS25P battery is placed to the second most feasible system but as we observe the cost of energy is increased from \$0.218/kwh to \$0.231/kwh with \$0.013/kwh difference. The PV, hydro and biomass combination with the battery 952S4KS25P is ranked in the third place with the cost of energy \$0.231/kwh. From the figure we can observe that the energy production share of the hydro power system is more in July, August, September and October like at kidusyohanes. This seems reasonable because the flow rate is high in these months than the other. The output of the system also contains the combination of all the components considered but it placed at the rank of 5th with total NPC \$1,182,905 and the COE of \$0.245/kwh which is a bit expensive than the aforementioned systems. Like the case of kidusyohanes, the hydro power outputs is maximum during the summer season when the flow rate very high as it can be seen from figure 5.6.In these seasons the power is produced in mach quantity and it may the cause of the excess energy. Electric energy production from the least NPC of optimized form is shown below in the table 5.6.

Table 5-5:Result from optimized form

Rank	PV (kW)	FL30	Hydro (kW)	BioG (kW)	S4KS25P	Converter (kW)	Initial capital	Operating cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. fraction	Biomass (t)	BioG (hrs)
1			37.8	200	915	280	\$465,546	45,742	\$1,050,286	0.218	1	502	1,767
2		1	37.8	200	974	280	\$525,076	46,063	\$1,113,922	0.231	1	477	1,679
3	200		37.8	200	952	280	\$865,571	19,538	\$1,115,332	0.231	1	129	468
4	230			200	915	280	\$860,546	21,263	\$1,132,359	0.235	1	160	578
5	200	1	37.8	200	940	280	\$925,053	20,171	\$1,182,905	0.245	1	104	376
6	356		37.8		915	280	\$977,546	16,566	\$1,189,313	0.247	1		
7	220	1		200	940	280	\$900,053	23,230	\$1,197,017	0.248	1	157	568
8				200	915	280	\$400,546	67,468	\$1,263,019	0.262	1	766	2,699
9	385	1			805	280	\$1,029,961	18,560	\$1,267,219	0.263	1		
10	356	1	37.8		805	280	\$1,036,961	18,938	\$1,279,054	0.265	1		



(a)



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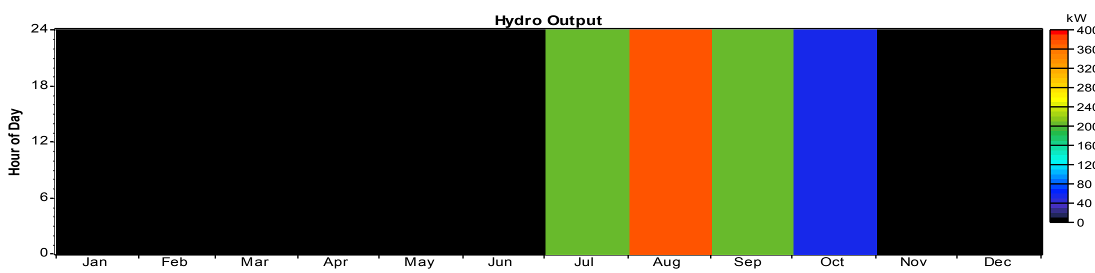

(c)

Figure 5-6: (a) composition of electric energy productions; (b) Biomass contribution; (c) Hydro contribution

When we observe the electrical output there are three common things to be considered i.e. energy production, consumption and the excess electricity. For this case the hydropower is covered the production of 64% and 36% found from the Biomass generator. From the produced energy almost all (99%) is consumed by the AC primary load this is because the deferrable load is much smaller than the primary load. The capacity shortage is considered zero in the input of the software that is way no capacity shortage in the output of the system. This condition confirms that the system can support all the demand without the shortage at any time throw out its life time. The excess electricity is small in January and April but it is very much in July and august as accordance of the input resource of hydro and this assured that this energy is truly found from the hydro resource. The figure (figure 5.7) shows some of the selected months of hourly profile for excess electricity. From this we can conclude that the contributor for the excess energy is mainly hydropower system. As we notice from the figure 4.19(a) the hydro resource has big difference from month to month. Whenever the excess electricity is found in each hour of a day, it is added to result the entire year excess electricity. The total production can exceed the sum of the total load served plus the excess energy because of battery losses and conversion losses.

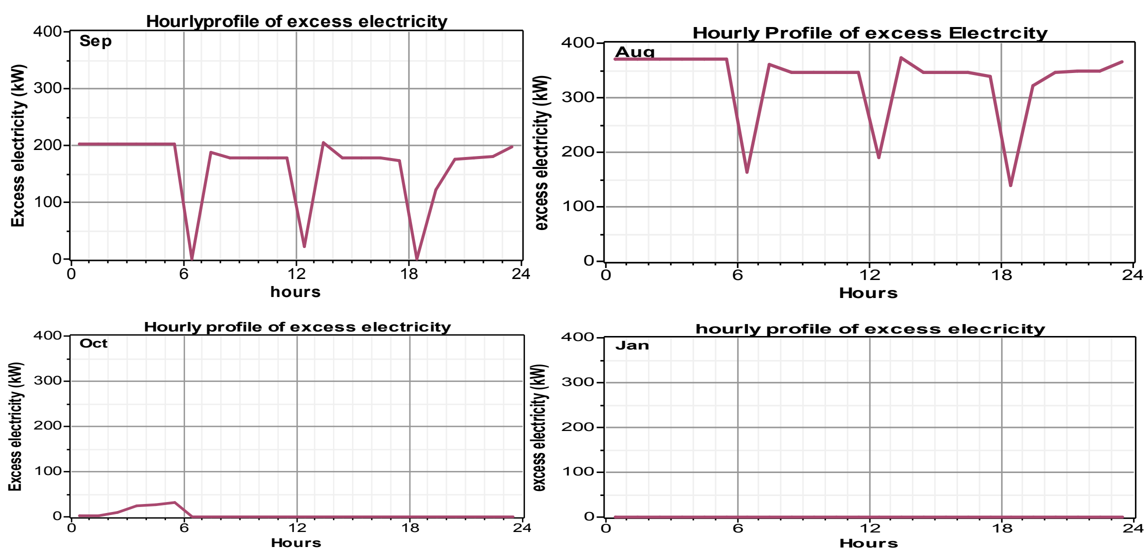

Figure 5-7: Selected month's hourly profile of excess electricity

Table 5-6: Energy production, energy consumption and excess energy

Energy source	Energy production		Types of load appliance	Energy consumption		Quantity	excess energy	
	kWh/yr	%		kWh/yr	%		kWh/yr	%
Hydro turbine	626,438	64	ACprimary load	374,853	99	Excess electricity	485,616	49.6
Biomass generator	353,264	36	Deferrable load	2,567	1	Unmet electric load	0.0001	0
Total	979,702	100	Total	377,420	100	Capacity shortage	0	0

The power loses in this case.116666kwh/yr. The excess energy produce here is 49.6% this will compensate the increase in demand for the next few years. From the forecasted the load will be increased from 252.1kw (2013) to 307.2kw (2023) but the excess energy will support for the increase in load demand.

If we are interested to design the model with all the components considered is included in to the system, the output from the simulation is look like below figure5.8. This will increase the reliability of the system but the cost of energy as well as the NPC is increased from least NPC selected one. As we can observed from table 5.7 the share of energy production is mostly depends on hydro component i.e.60%, 32%, 7% and 2% for hydro- PV-Biomass-Wind respectively.

Table 5-7: Energy production, consumption and excess electricity

Energy source	Energy Production		Types of Load appliance	Energy consumption		Quantity	excess electricity	
	kWh/yr	%		kWh/yr	%		kWh/yr	%
PV array	336,940	32	AC primary load	374,853	99	Excess electricity	590,467	56.3
Wind turbine	16,488	2	Deferrable load	2,564	1	Unmet electric load	0.00046	0
Hydro turbine	626,438	60	Total	377,418	100	Capacity shortage	5.26	0
Biomass generator	69,707	7						

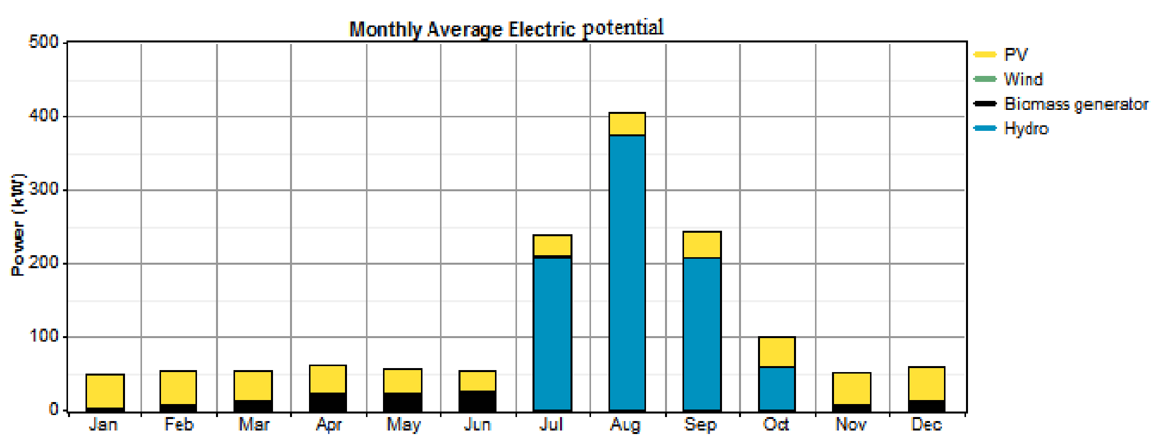

Figure 5-8: Monthly average energy production from all the components

5.3.2 Sensitivity Analysis of Hybrid System at Kundab

For the sensitivity input of wind speed, solar radiation and stream flow the correspondence output is listed in table 5.8. The optimal system type (OST) graph gives the highest-level view of the sensitivity results. It shows the least-cost type of system (hydro-Bio-battery is one type of system, Hydro-PV- bio- battery, hydro- wind- Bio battery, Hydro-wind-PV-battery is another) versus two sensitivity variables. The Optimal system type (Fig 5.8) output shows the same information as table 5.8. The graphic format makes it easier to see under which conditions the different types of systems are optimal.

Table 5-8: sensitivity result in Tabular form

Rank	Solar (kWh/m²/d)	Wind (m/s)	Stream Flow (L/s)	PV (kW)	EL 30	Hydro (kW)	BioG (kW)	S4KS25P	Converter(kW)	Initialcapital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Ren. fraction	Biomass (t)	BioG (hrs)
1	5.99	3.1	1017			37.8	200	915	280	$465,546	45,742	$1,050,286	0.21	1	502	1,767
2	5.99	3.1	600			37.8	200	915	280	$465,546	47,863	$1,077,399	0.22	1	526	1,854
3	5.99	3.1	400			37.8	200	952	280	$465,571	48,889	$1,090,531	0.22	1	538	1,895
4	5.99	3.1	200	200		37.8	200	915	280	$865,546	20,697	$1,130,124	0.23	1	146	529
12	5.99	5	200	230	2	37.8		805	280	$844,451	18,612	$1,082,370	0.22	1		
29	4	6	1017		1	37.8	200	961	280	$525,068	39,374	$1,028,401	0.21	1	398	1,400
17	4	3.1	1017			37.8	200	915	280	$465,546	45,742	$1,050,286	0.21	1	502	1,767
33	3	3.1	1017			37.8	200	915	280	$465,546	45,742	$1,050,286	0.21	1	502	1,767
49	2	3.1	1017			37.8	200	915	280	$465,546	45,742	$1,050,286	0.21	1	502	475
64	2	6	200		5		200	974	280	$698,036	26,289	$1,034,102	0.21	1	133	

From figure 5.9 we can observe that hydro component is included in all the combinations. For stream flow less than 300l/s and wind speed less than 4.7m/s hydro- PV-Bio- battery is selected as optimal system. For a stream flow >300L/s and the wind speed is less than around 5m/s the Hydro-bio-battery combination is selected as optimal system type. Hydro-PV-bio-battery is selected as optimal system when stream flow is >600L/s and the wind speed is 5m/ and increasing. For wind speed >4.7m/s Hydro- Wind-PV-battery system is selected for 200L/s flow rate but slowly dominated by Hydro-bio-battery/Hydro-wind-bio-battery system as the flow rate is increased.

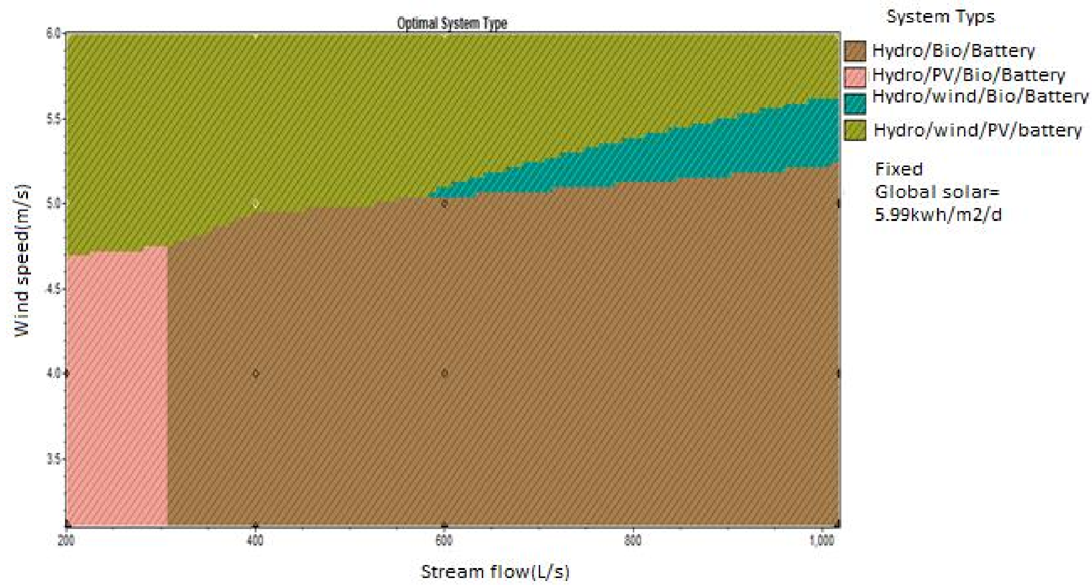

Figure 5-9: Graphical form of sensitivity result

5.4 Simulation Studies of Hybrid System at Debre

5.4.1 Optimum Result

As discussed earlier, in this site the system is modeled without hydro components. In place of hydro the system is analyzed with and without diesel generator. The discussion separately shows the influence of the generator in the system. The following table 5.9 and figure 5.9 shows the output from categorized form. The least COE ($0.285/kwh) of the system consists of only PV-battery hybrid components with least NPC of $872,051. By considering the EEPCo tariff information (201-300) kwh range the domestic tariff is 0.55birr/kwh (Ethiopian birr) which is $0.03056/kwh. From this we can observe that the Levelized cost of energy (COE) is expensive for the supposed system. The PV-diesel-battery hybrid system is placed in the second place but the contribution of the diesel in this case negligible. As we can see the hours of operation from table 5.9 it is 64hrs that is why the consumed liter is not displayed in the table. In addition the solar PV is the same for the least cost (rank1) and rank2 these assure that the contribution of the diesel is negligible. At rank7 the contribution of diesel generators sounds more with the COE $0.409/kwh and NPC of $1250725. The renewable fraction is also 55%.

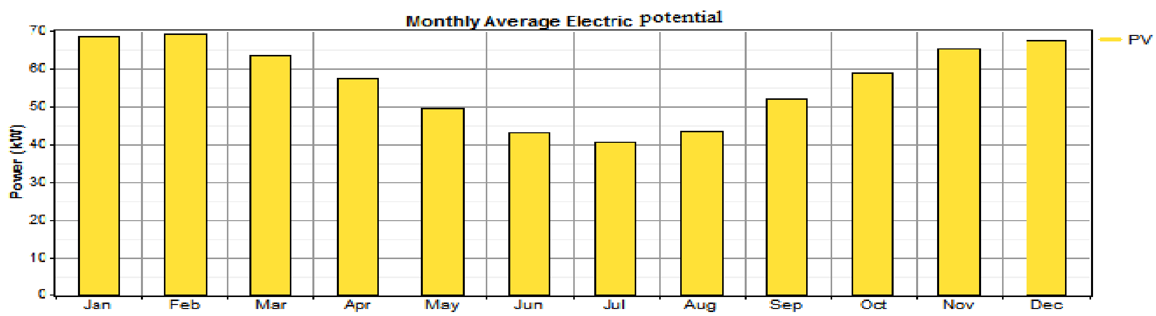

Figure 5-10: Electric energy productions for Debre

Table 5-9: Optimized form of output including diesel

Rank	PV (kW)	FL30	Bio (kW)	DiesG (kW)	S4KS25P	**Converter (kW)**	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	**Renewable fraction**	Diesel (L)	Biomass (t)	Bio (hrs)	DiesG (hrs)
1	294				685	200	$731,269	11,756	$872,051	0.28	1				
2	294			180	685	200	$752,329	11,530	$890,405	0.29	1				64
5	294	4			685	200	$969,229	21,168	$1,222,725	0.4	1				
7			160	180	852	200	$324,443	77,335	$1,250,558	0.40	0.55	48,233	258	1,135	812
10		4	160	180	964	200	$562,480	71,937	$1,423,953	0.46	0.7	35,395	256	1,126	596
11		4		180	852	200	$402,403	124,350	$1,891,550	0.61	0.18	96,305			1,622
12				180	964	200	$164,520	145,412	$1,905,894	0.62	0	123,015			2,071
13	294		160	180		200	$911,860	216,568	$3,505,356	1.14	0.69	127,764	258	1,459	4,328
14	294	4	160	180		200	$1,149,820	214,881	$3,723,115	1.21	0.73	119,933	258	1,466	4,064
15	294			180		200	$751,860	254,346	$3,797,765	1.24	0.58	171,498			5,654
16	294	4		180		200	$989,820	253,152	$4,021,422	1.31	0.62	163,693			5,424

When we observe the electrical output there are three common things to be considered i.e. energy production, consumption and the excess electricity. For this case the PV system is support 100% of energy production. Like the previous cases, from the produced energy almost all (99%) is consumed by the AC primary load this is because the deferrable load is much smaller than the primary load. The capacity shortage is considered zero in the input of the software that is way no capacity shortage in the output of the system. This condition confirms that the system can support all the demand without the shortage at any time throughout its life time. The total production can exceed the sum of the total load served plus the excess energy because of battery losses and conversion losses. The power loses in this case is 66984kwh/yr. The excess energy produce here is 34.9% this will compensate the increase in demand for the next few years. From the forecasted the load will be increased from 166.2kw (2013) to 195kw (2023) but the excess energy will support for the increase in load demand. The only contributor component is the solar PV system as we can see from figure 5.2(c) the sunshine hours is low at July and August. From figure 5.10 we can assure that the excess energy is arise from the months with longer sunshine hours. Even for the months with shorter sunshine hours there is considerable amount of excess energy during the day (sun is over head around 12hrs)

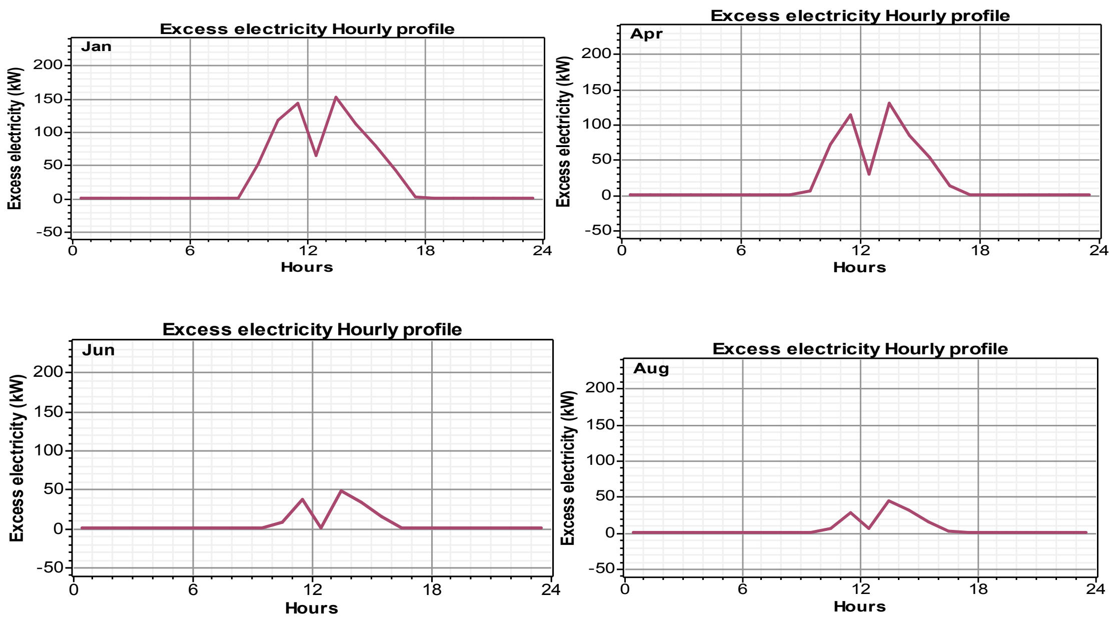

Figure 5-11: Excess energy output from selected months

Table 5-10: Energy production, consumption and excess electricity

Energy source	Energy production		Types of load appliance	Energy consumption		quantity	Excess Energy	
	Kwh/yr	%		kwh/yr	%		kwh/yr	%
PV array	405,301	100	Ac primary load	253,296	99	excess electricity	173,028	34.9
Total	495,301	100	Deferrable load	1,993	1	Unmet load	0.000155	0
			Total	255,289	100	capacity shortage	0	0

As the case for kidusyohanes and Kundab, if we are interested to design the model with all the components considered is included in to the system, the output from the simulation is look like below figure5.11. This will increase the reliability of the system but the cost of energy as well as the NPC is increased from least NPC selected one. As we can observed from table 5.11 the share of energy production is mostly depends on PV component i.e.55%, 27%, 10% and 7% for PV-diesel-Biomass-Wind respectively. The production of excess electricity is also increased from 34.9% to70.7%.

Table 5-11: Energy production, consumption and excess energy

Energy source	Energy production		Types of load appliance	Energy Consumption		Quantity	Excess Energy	
	kWh/yr	%		kWh/yr	%		kWh/yr	%
PV array	495,301	55	AC primary load	253,296	99	Excess electricity	633,753	70.7
Wind turbines	65,951	7	Deferrable load	1,995	1	Unmet electric load	0	0
Biomass gen.	89,978	10	Total	255,291	100	Capacity shortage	0	0
Diesel Gen.	245,660	27						
Total	896,890	100						

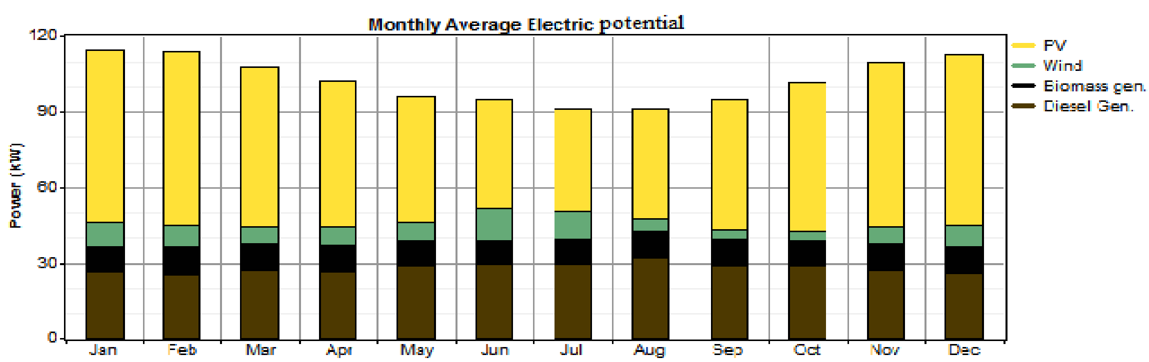

Figure 5-12: Monthly Average energy production from all the components included

5.4.2 Sensitivity Analysis of Hybrid System at Debre

The optimal system type (OST) graph gives the highest-level view of the sensitivity results. It shows the least-cost type of system (PV-battery, PV-bio-Battery, PV-Diesel-battery, Wind-Bio-battery, and Wind-Bio-Diesel-battery) versus two sensitivity variables. The graphic format makes it easier to see under which conditions the different types of systems are optimal. From the graph we can observe that PV- battery is selected when the solar radiation is greater than 5.6kwh/m2/d. For wind speed less than 3.9m/s and the solar radiation less than around 3.45kwh/m2/d PV-Bio-battery is selected as best combinations. For the solar radiation between (3.45-5.6)kwh/m2/d and wind speed starting at 4m/s and increases slowly the combination of PV-Diesel-Battery is selected to be convenient. For wind speed >4m/s and wind-Bio-battery is selected but when the solar radiation is become increasing the system with PV-Diesel-battery up to 5.6kwh/m2/d and PV-Battery above 5.6kwh/m2/d will take over.

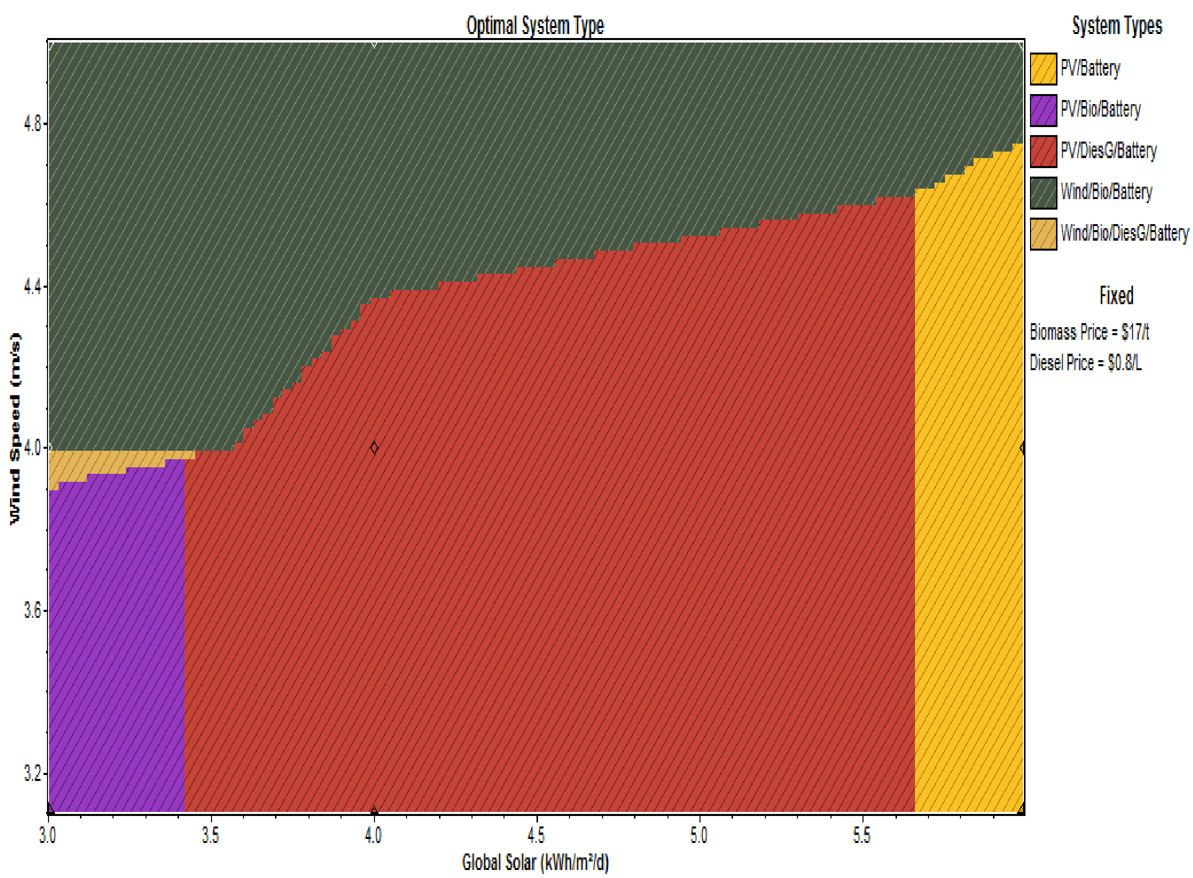

Figure 5-13: Graphical form of sensitivity output

No-diesel output: The output of the system from the model which not included diesel generator is shown below. From the result it is shown that the system is supported with 294KW PV/685 S4KS25P when the diesel is included and 285 kw PV/700 S4KS25P when the diesel is excluded. The COE is $0.285 and 0.279/kwh for system with & without diesel respectively. From the output we can observe that when the PV power selected is decreased the battery will increase. This makes the reduction of the COE because of the lower cost of the battery in comparison to the PV cost. But, we can conclude that the diesel generator system is included for the case of reliability i.e. reliability is increased whenever the source connected is increased. Even if the generator is not selected as least COE system, the COE is increased when the diesel is included in to the component in put.

Table 5-12: The optimization result of Debre with no diesel generator included

Rank	PV (kW)	FL30	Bio (kW)	S4KS25P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Biomass (t)	Bio (hrs)
1	285			700	200	$713,279	11,568	$851,814	0.279	1		
2	250	1		700	200	$702,769	13,190	$860,725	0.282	1		
3	250		160	780	200	$803,334	9,257	$914,185	0.299	1	4	18
4	250	1	160	700	200	$862,769	11,388	$999,142	0.327	1		23

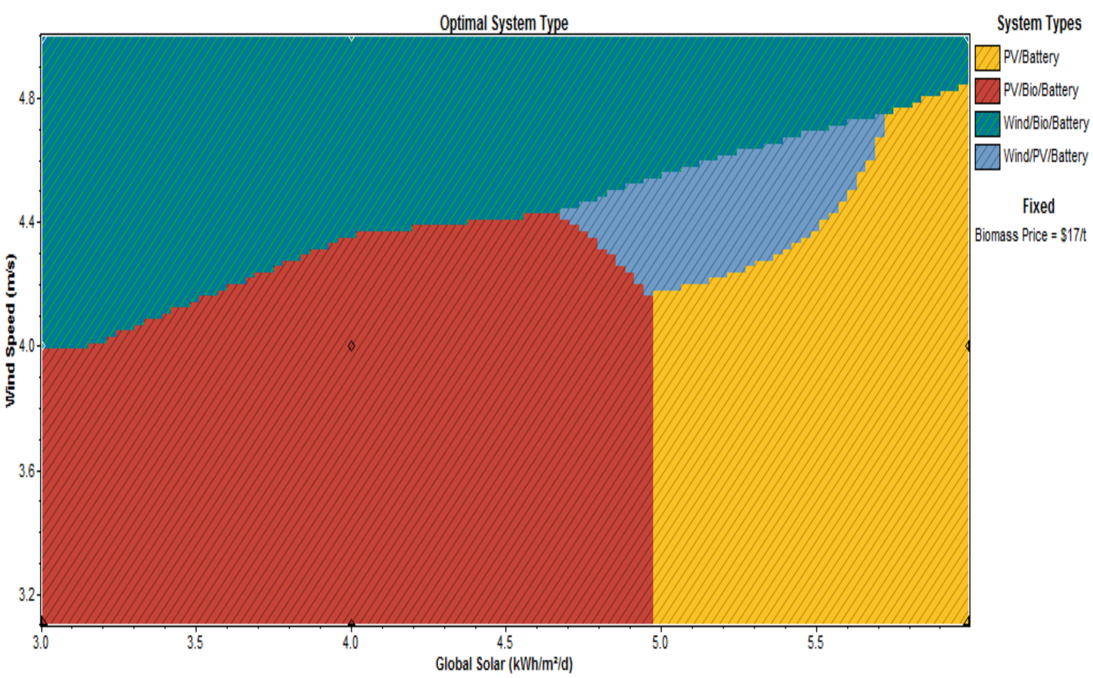

Figure 5-14: Sensitivity result from no diesel syst

The sensitivity input of the cost of diesel is removed in this case and the output of the system is shown below fig 5.12. From the figure we can observe that PV is preferable whenever the solar radiation is increased i.e. if it is above 5kwh/m2/d. At a lower solar radiation the PV/bio/battery system is selected. As the wind speed is increased the wind /Bio/battery system is preferable. Wind/PV/battery combination is preferable for some specific condition i.e. for wind speed between (4.1 -4.7) m/s and for solar radiation (4.7-5.7)kwh/m2/d.

CHAPTER SIX

6 Conclusions, Recommendation and Suggestion for Future works

6.1 Conclusion

In this work, the feasibility study of Solar PV/Wind/Micro-Hydro/Biomass system for the villages Kidusyohanes and Kundab is studied. The Village, Debre, is studied with solar PV/wind/Biomass with and without diesel generator. The areas considered are found in North-West part of the country. The numbers of households (houses) are 184, 162 and 112 for Kundab, kidusyohanes and Debre respectively. HOMER software is used for the modeling and analyzing of the system.

The flow rate at design site is estimated by the help of ArkGIS software i.e. the design flow rate of kidusyohanes is found to be 0.354557m3/s and 0.494437m3/s is for Kundab. This flow rate is less than the actual flow rate in July, Aug, September and October but it is greater in other months. This indicates that the hydro generator with its maximum efficiency in July, Aug, September and October. The head of the river is measured using rope and equivalent in meter is found to be 11m and 23m, for Kundab and kidusyohanes respectively. The micro-hydropower potential is estimated to be 58.4kw for kidusyohanes and 37.8kw for Kundab.

The flow rate data is found from the Ministry of water and energy of Ethiopia. From NASA Monthly average wind speed at 10m is 3.1m/s and solar radiation at horizontal surface is 5.9kwh/m2/d. The biomass data is analyzed from the number of cattle i.e. 0.454ton/day, 2.8179ton/day and 0.7068ton/day for kidusyohanes, Kundab and Debre respectively. This row data is converted to suitable form for the software.

The load is estimated from the experience of the people in the area. If electric access is available in the area the community will use lighting, TV, DVD, Electric stove, “Electric mitad”, refrigerators, and mobile -phone charger for the house hold consumption. The school for the community is considered with Computer, Printer, photocopier, Radio, and lighting loads. The irrigation and well pump is considered as community load in addition the grain mill is also one of the community loads. The peak load is 212,237,155kw for kidusyohanes, Kundab, Debre respectively. The peak deferrable (water wheel pump and Irrigation pump) load is 4kw for kidusyohanes and Kundab and 3.3kw for Debre.

From the study, different combination of feasible result is found with the least cost energy \$0.246/kwh, \$0.218/kwh, \$0.285/kwh for kidusyohanes, Kundab & Debre respectively. 34% (Kidusyohaness), 49.6% (Kundab) and 34.9% (Debre) excess energy is found from the simulation result. For the next 10 years, the load demand will increase to 279.8(23.74%), 307.2(21.8%) and 195.0(17.36%)kw for Kidusyohanes, Kundab and Debre respectively. From this we can conclude that the system will support the load demand for the next 10 years without over loading. We can conclude also that the cost of energy for the system which has hydro power as a generating source is cheaper than the other combination. From the result for kidusyohanes the least cost combination is PV/Micro-hydro and COE is \$0.246/kwh whereas the least cost combination of Kundab is Micro-Hydro/Biomass and COE \$0.218/kwh. As discussed above the model in Debre is not containing the hydro component and the least cost combination is only PV with COE \$0.285/kwh which is more expensive than the other two cases with micro-hydro component.

This cost of energy is expensive than the current COE of the country which is \$0.03056/kwh for domestic tariff. From the daily load profile we can see that the peak load is very high relative to the average load in a day. This is due to the activity of the people early for breakfast and midday for lunch the stove lit and when the sun sets around 18:00, the light will takes place together with the stove for dinner. If we consider the average load the cost of energy will decrease as well as the payback period.

6.2 Recommendations

Currently the attention towards wind and solar energy is increasing worldwide. In case of Ethiopia measured and recorded wind and solar data is not available widely. So the concerned body must give attention to this problem. The gauge is also located at large rivers and the flow rate data for small rivers is not measured. The contribution of small scale hybrid and stand alone power system must not be ignored from the energy package of the country.

6.3 Suggestions for Future Works

Some of the data used in this work is found from the websites. One can obtain the data by measuring the exact data for solar radiation, wind speed and flow rate at the sites. For the case of biomass other resource such as wood, crop residue, human west etc. can be considered and the system may be studied.

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Appendix (A): Flow rate data from ministry of water and energy for Chemoga River with drainage Area 364km^2

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1992	Mean	0.284	0.663	0.713	0.502	0.385	0.53	8.391	22.293	23.302	3.659	1.855	-
	Maximum	0.375	1.074	0.921	0.737	0.493	1.894	17.881	47.365	63.567	6.431	2.373	-
	Minimum	0.207	0.209	0.593	0.353	0.284	0.356	2.053	3.089	4.378	1.39	0.794	-
	Runoff (mm)	2.088	4.567	5.244	3.576	2.835	3.771	61.741	164.038	165.934	26.923	13.211	-
1993	Mean	0.472	0.455	0.185	1.83	4.511	9.321	21.091	39.129	28.57	6.207	1.538	0.563
	Maximum	0.525	0.593	0.474	3.271	12.551	19.575	71.535	65.412	72.17	19.133	2.26	0.706
	Minimum	0.378	0.353	0.133	0.311	0.791	5.469	9.365	19.926	17.694	1.822	0.742	0.402
	Runoff (mm)	3.474	3.023	1.363	13.033	33.195	66.372	155.193	287.922	203.444	45.675	10.952	4.145
1994	Mean	0.237	0.132	0.031	0.106	0.314	0.495	7.691	19.826	0.799	0.361	0.044	0
	Maximum	0.378	0.133	0.078	0.19	2.697	1.136	27.256	68.046	2.881	0.705	0.136	0
	Minimum	0.133	0.115	0.011	0.056	0.049	0.05	0.88	3.236	0.093	0.149	0	0
	Runoff (mm)	1.744	0.877	0.232	0.751	2.311	3.525	56.59	145.883	5.692	2.654	0.31	0
1995	Mean	0.002	0.056	0.072	0.316	0.939	0.434	9.91	21.032	10.098	1.363	0.347	0.763
	Maximum	0.005	0.098	0.319	0.955	2.679	1.602	43.715	39.045	20.376	3.834	0.447	3.258
	Minimum	0	0.005	0.029	0.025	0.252	0.212	0.839	13.053	4.11	0.425	0.25	0.198
	Runoff (mm)	0.017	0.372	0.531	2.251	6.906	3.091	72.921	154.761	71.91	10.028	2.474	5.611
1996	Mean	0.935	0.43	0.301	2.173	3.915	5.673	17.31	21.877	10.954	1.843	0.863	0.506
	Maximum	1.858	1.305	1.117	6.842	11.057	12.914	37.25	38.907	31.959	7.266	1.94	0.829
	Minimum	0.33	0.082	0.061	0.72	0.908	1.63	2.523	8.601	4.59	0.481	0.298	0.281
	Runoff (mm)	6.881	2.959	2.213	15.471	28.806	40.398	127.372	160.977	77.999	13.56	6.144	3.721
1997	Mean	0.3	0.051	0.052	0.177	0.227	1.449	12.047	20.955	7.466	3.924	2.893	0.952
	Maximum	0.707	0.18	0.098	0.622	1.865	3.398	37.431	42.912	18.222	12.034	4.62	2.166
	Minimum	0.207	0.011	0.02	0.017	0.028	0.336	4.078	6.566	2.768	0.521	1.382	0.371
	Runoff (mm)	2.207	0.342	0.381	1.262	1.67	10.317	88.645	154.195	53.164	28.876	20.6	7.002
1998	Mean	0.523	0.2	0.197	0.032	0.892	1.386	14.611	17.442	13.358	13.25	1.24	0.287
	Maximum	1.112	0.644	0.66	0.097	2.7	6.348	28.48	35.722	32.358	53.136	2.446	0.447
	Minimum	0.205	0.045	0.078	0.01	0.027	0.332	3.037	11.053	4.652	2.749	0.408	0.194
	Runoff (mm)	3.846	1.328	1.45	0.225	6.563	9.87	107.509	128.346	95.123	97.496	8.827	2.108
1999	Mean	0.208	0.058	0.01	0.008	0.046	1.023	15.183	29.173	12.429	13.343	0.999	0.359
	Maximum	0.452	0.122	0.016	0.042	0.248	7.561	47.334	65.385	26.167	42.879	3.402	0.474
	Minimum	0.137	0.012	0.005	0.001	0.001	0.069	2.658	12.939	2.219	2.941	0.399	0.273
	Runoff (mm)	1.528	0.386	0.072	0.058	0.336	7.285	111.721	214.661	88.506	98.181	7.112	2.639
2000	Mean	0.168	0.052	0.018	0.094	-	-	-	-	-	11.011	4.022	0.67
	Maximum	0.27	0.089	0.04	0.257	-	-	-	-	-	53.859	12.577	1.074
	Minimum	0.097	0.029	0.007	0.009	-	-	-	-	-	4.461	0.918	0.394
	Runoff (mm)	1.239	0.355	0.134	0.671	-	-	-	-	-	81.024	28.643	4.934
2001	Mean	0.243	0.182	0.224	0.155	0.405	2.451	21.552	33.995	6.24	1.654	0.471	0.28
	Maximum	0.391	0.486	0.546	0.353	3.146	8.859	62.566	111.379	23.428	3.601	1.988	1.384

	Minimum	0.149	0.089	0.07	0.032	0.076	0.233	5.915	12.643	1.739	0.58	0.278	0.149
	Runoff (mm)	1.787	1.211	1.646	1.107	2.978	17.454	158.582	250.142	44.436	12.174	3.354	2.059
2002	Mean	0.594	0.113	0.47	0.447	0.07	0.925	-	-	-	-	-	-
	Maximum	2.142	0.162	3.979	1.556	0.557	5.125	-	-	-	-	-	-
	Minimum	0.165	0.063	0.032	0.025	0.014	0.016	-	-	-	-	-	-
	Runoff (mm)	4.37	0.751	3.455	3.182	0.511	6.584	-	-	-	-	-	-
2003	Mean	0.08	0.212	-	-	-	-	10.888	21.88	15.602	2.255	0.329	0.191
	Maximum	0.112	4.412	-	-	-	-	33.914	51.117	42.681	12.958	0.477	0.304
	Minimum	0.06	0.011	-	-	-	-	4.434	10.514	5.038	0.481	0.181	0.111
	Runoff (mm)	0.59	1.408	-	-	-	-	80.119	161.001	111.097	16.592	2.345	1.406
2004	Mean	0.094	0.053	0.105	0.349	0.48	0.938	13.5	22.735	8.906	4.363	0.482	0.345
	Maximum	0.11	0.088	0.705	2.212	3.415	2.496	32.115	53.339	20.831	18.53	0.773	0.672
	Minimum	0.088	0.025	0.011	0.017	0.005	0.014	1.45	9.25	2.434	0.811	0.292	0.24
	Runoff (mm)	0.691	0.362	0.773	2.489	3.531	6.679	99.339	167.288	63.42	32.103	3.435	2.535
2005	Mean	0.214	0.093	0.383	0.211	0.223	2.068	12.882	12.389	12.497	2.046	0.448	0.229
	Maximum	0.44	0.123	2.894	1.346	1.02	13.562	26.027	21.826	28.762	5.83	0.872	0.304
	Minimum	0.133	0.053	0.02	0.061	0.046	0.045	4.152	7.203	5.098	0.682	0.295	0.165
	Runoff (mm)	1.578	0.62	2.815	1.5	1.644	14.723	94.792	91.162	88.992	15.057	3.193	1.682
2006	Mean	0.132	0.087	0.153	0.566	0.255	1.214	14.062	-	14.371	1.117	0.406	0.282
	Maximum	0.164	0.147	0.836	2.113	0.525	3.048	41.758	-	31.395	3.454	0.694	0.404
	Minimum	0.098	0.045	0.016	0.164	0.098	0.346	1.48	-	2.787	0.47	0.298	0.196
	Runoff (mm)	0.975	0.58	1.123	4.029	1.878	8.645	103.47	-	102.334	8.217	2.894	2.073
2007	Mean	0.296	-	-	-	-	-	12.256	17.197	12.419	4.464	0.356	0.186
	Maximum	0.51	-	-	-	-	-	33.808	30.418	34.916	35.551	0.513	0.273
	Minimum	0.179	-	-	-	-	-	5.112	7.354	4.269	0.521	0.252	0.147
	Runoff (mm)	2.177	-	-	-	-	-	90.182	126.543	88.433	32.85	2.536	1.368
2008	Mean	0.105	0.031	-	-	0.664	1.965	8.392	15.594	8.3	0.869	1.488	0.317
	Maximum	0.135	0.067	-	-	5.29	5.625	24.577	32.646	24.901	2.701	9.008	0.625
	Minimum	0.069	0.003	-	-	0.125	0.573	0.989	4.589	1.325	0.295	0.281	0.151
	Runoff (mm)	0.769	0.216	-	-	4.887	13.989	61.752	114.742	59.102	6.397	10.595	2.331
2009	Mean	0.099	0.043	0.08	-	-	-	6.185	20.381	4.645	2.877	0.104	0.124
	Maximum	0.166	0.177	0.599	-	-	-	16.984	50.211	23.484	17.294	0.259	0.246
	Minimum	0.051	0.015	0.006	-	-	-	0.425	7.264	0.252	0.105	0.061	0.027
	Runoff (mm)	0.728	0.286	0.586	-	-	-	45.513	149.968	33.076	21.172	0.737	0.912
	Mean= Monthly average Flow rate m3/s Maximum=Maximum flow rate m3/s							Minimum = minimum flow rate m3/s Runoff(mm)=Monthly Run off in million m3					

Appendix (B): components costs from different source

TABLE I
HYBRID SYSTEM COMPONENTS

Diesel generator set	***Wind turbine***
Size : 250kW	*Size : 3kW*
Capital cost : 25700$	*Capital cost : 5950 $*
Replacement cost : 17400$	*Replacement cost : 4485 $*
Bio diesel generator set	***Batteries***
Size : 250kW	*Model: surrette 4KS25P*
Capital cost : 68750$	*Capital cost : 782$*
Replacement cost : 48750$	*Replacement cost : 456 $*
PV module	***Converters***
Size : 150kW	*Size : 200kW*
Capital cost : 225000$	*Capital cost : 142800$*
Replacement cost : 161625 $	*Replacement cost : 107400$*

TABLE II
SIMULATION RESULT

Source: J. K. Maherchandani, Chitranjan Agarwal, Mukesh Sahi, "Economic Feasibility of Hybrid Biomass/PV/ Wind System for Remote Villages Using HOMER" Vol. 1, Issue 2, August 2012.

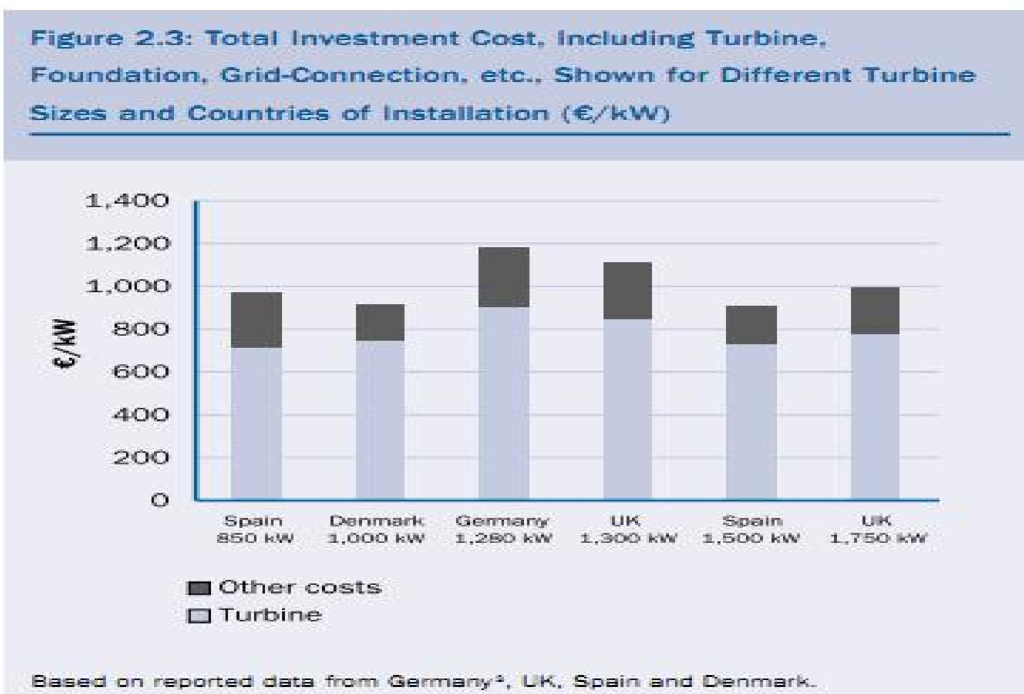
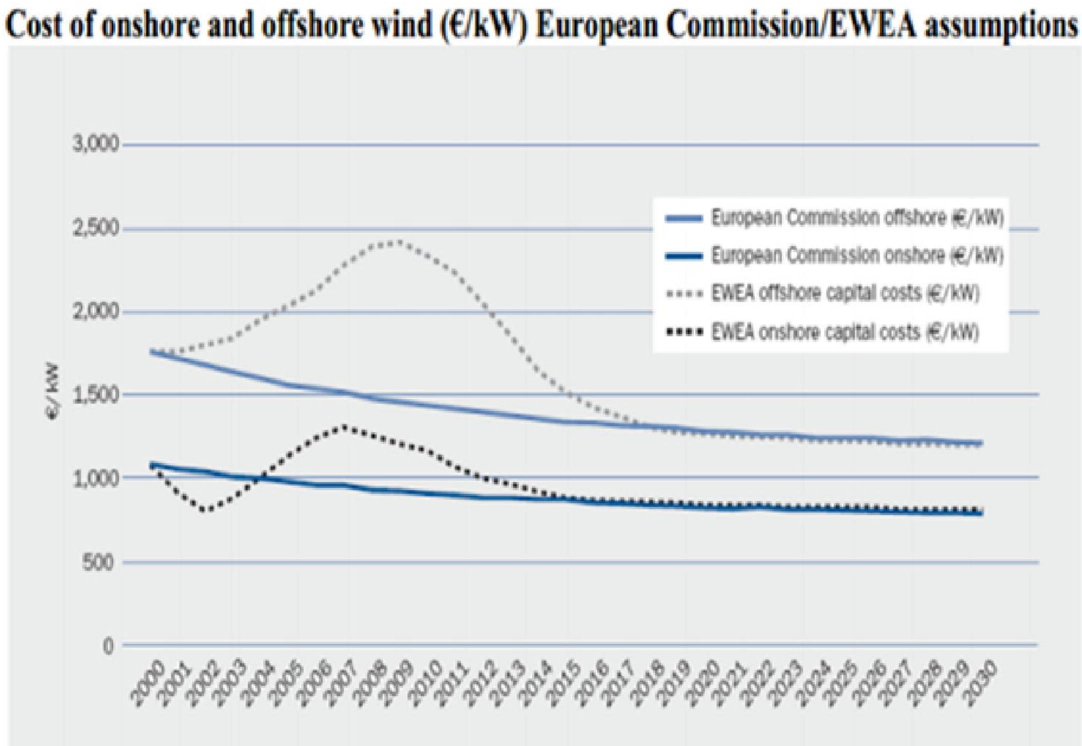


Figure 2.3: Total Investment Cost, Including Turbine, Foundation, Grid-Connection, etc., Shown for Different Turbine Sizes and Countries of Installation (€/kW)

Source:Poul Erik"Wind Energy the facts Volum2 costs &prices "Risø National Laboratory,Denmark,2003.



Source: EWEA (European wind Energy association), 2007.

Appendix(C): Penstocks Diameter selection graphs

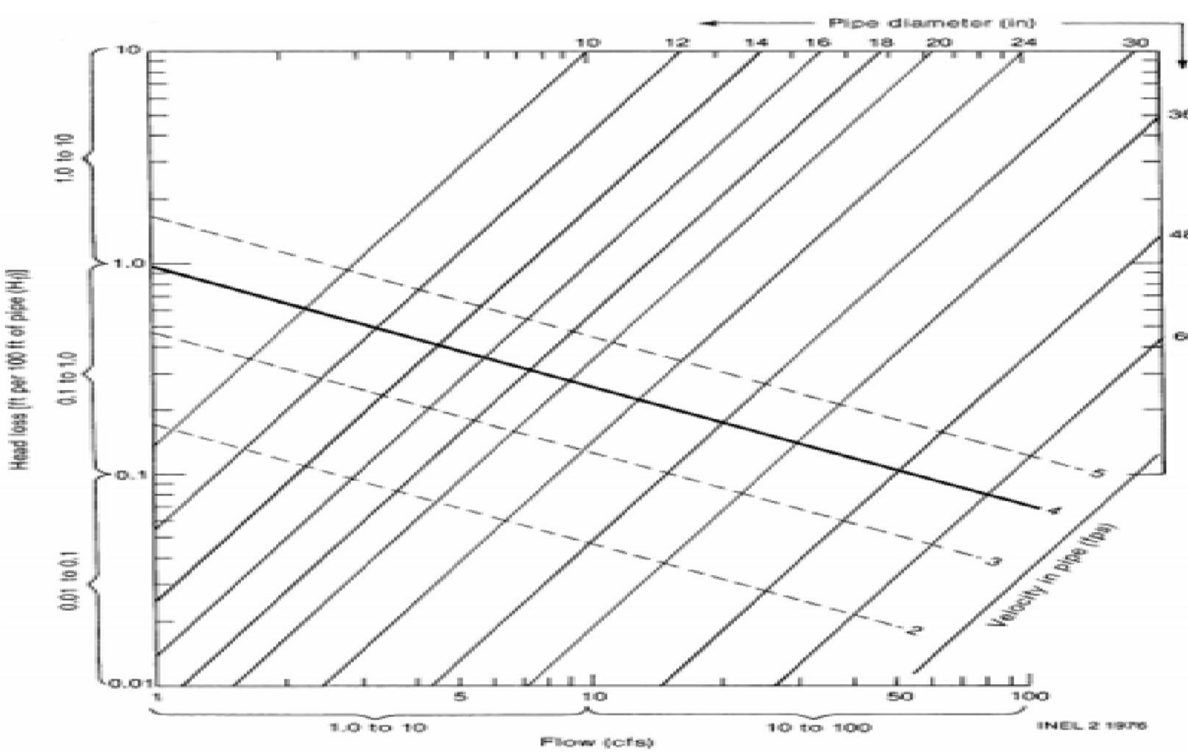


Table C-1: Lists of the wall thickness (t_w), pressure rating (P_R),and surge allowance factor (S_A) for several sizes of commonly available pipe materials.

Pipe size → / Pipe material ↓	4 in.			6 in.			8 in.			10 in.			12 in.		
	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A
Steel	0.24	1400	57	0.28	1200	56	0.25	800	54	0.25	640	52	0.25	540	51
							0.32	1100	56	0.37	1030	55	1.38	890	54
													0.41	1000	55
PVC (polyvinyl chloride)	0.11	100	12	0.16	100	12	0.21	100	12	0.26	100	12	0.31	100	12
	0.17	160	15	0.25	160	15	0.33	160	15	0.41	160	15	0.49	160	15
	0.26	250	18	0.39	250	18	0.51	250	18	0.63	250	18	0.75	250	18
PE (polyethylene)	0.265	100	9	0.39	100	9	0.51	100	9	0.63	100	9	0.75	100	9
	0.41	160	11	0.60	160	11	0.78	160	11	0.98	160	11	1.16	160	11
	0.62	250	13	0.91	250	13	1.18	250	13	1.47	250	13	1.75	250	13
A-C (transite—asbestos cement)	0.32	100	41	0.46	100	41	0.56	100	40	0.62	100	39	0.72	100	38
	0.41	150	44	0.53	150	43	0.63	150	41	0.83	150	42	0.96	150	41
	0.41	200	44	0.66	200	45	0.81	200	45	1.02	200	45	1.18	200	44
FRP (fiber reinforced epoxy)	0.07	225	17	1.11	250	16	0.14	225	16	0.18	225	15	0.21	225	15

Pipe size → / Pipe material ↓	14 in.			16 in.			18 in.			20 in.			24 in.[a]		
	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A
Steel	0.25	490	50	0.25	430	49	0.25	380	48	0.25	340	47	0.25	280	45
	0.38	810	54	0.38	710	52	0.38	630	52	0.38	570	51	0.38	470	
	0.44	970	55	0.50	990	55	0.50	880	54	0.50	790	53	0.50	660	
										0.59	950	54	0.69	940	54
PVC (polyvinyl chloride)	← PVC pressure pipe not available →														
PE (polyethylene)	0.82	100	9	0.94	100	9	1.06	100	9	1.12	100	9	1.41	100	9
	1.27	160	11	1.46	160	11	1.64	160	11	1.81	160	11			
	1.92	250	13												
A-C (transite—asbestos cement)	0.74	100	38	0.83	100	37	0.95	100	37	1.06	100	37	1.24	100	
	1.11	150	41	1.23	150	41	1.47	150	42	1.64	150	42	1.98	150	
	1.38	200	44	1.57	200	44	2.09	200	45	1.98	200	45	2.81	200	45
FRP (fiber reinforced epoxy)	0.26	225	15	0.29	225	15									

a. Above 24 inches, see manufacturer.

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