Ethiopian Rural Energy Development and Promotion Center

Final Report

Country background information

Solar and Wind Energy Utilization and Project Development Scenarios

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Ethio Resource Group *with* Partners

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Executive Summary

Solar and wind energy resources in Ethiopia have not been given due attention in the past. Some of the primary reasons for under consideration of these resources are lack of awareness of their potential in the country, the role they can have in the overall energy mix and the social benefits associated with them. Knowledge of the exploitable potential of these resources and identification of potential regions for development will help energy planners and developers to incorporate these resources as alternative means of supplying energy by conducting a more accurate techno-economic analysis which leads to more realistic economic projections.

The ultimate objective of this study is to produce a document that comprises country background information on solar and wind energy utilization and project scenarios which present solar and wind energy investment opportunities to investors and decision makers. It is an integrated study with specific objectives of resource documentation including analysis of barriers and policies, identification of potential areas for technology promotion, and nationwide aggregation of potentials and benefits of the resource. The main outputs of the study include estimation of technical and economic potential of the solar and wind resources, regional and woreda level presentation of these resources on GIS maps, a national level energy demand and supply assessment including forecasts to 2030, identification of constraints for wider dissemination of solar and wind resources and financing mechanisms which help facilitate increased market penetration of these technologies.

All analysis in this study is based on the SWERA generated data for the solar and wind resources. Data from other sectors were also collected in order to determine the potential of the resource in various sectors.

The SWERA solar resource data is the first kind of resource assessment conducted in the country at a resolution level of 10 km^2. Solar resource assessment studies were also made by CESEN-ANSALDO group in the 1980s. Comparisons of the solar resource made by SWERA, CESEN-ANSALDO and NASA indicate that the estimation of the resource by SWERA is less by more than 50% of that estimated by CESEN. Estimations of CESEN and NASA provide similar figures for the sites comparisons are made for.

Based on the SWERA data, the mean annual average daily radiation for the country as a whole is 3.74 kWh/m^2/day. The annual average daily radiation for each woreda in the country is indicated using a GIS map.

The potential of the solar resource for power generation and thermal applications is also analyzed for various end users. For grid-based systems, the technical potential for building integrated solar PV (BIPV) from the residential buildings in the country is estimated to be 1.1TWh/year. With availability of data it became possible to estimate BIPV from various sectors for Addis Ababa and it is about 3TWh/year. For off-grid applications technical potential of solar home systems, rural health institutions and rural schools are 4TWh/year, 6.24GWh/year and 15.6GWh/year respectively. For domestic and livestock water pumping in off-grid areas, technical potential is about 36GWh/year.

The SWERA wind resource data was generated from the RISOE Model developed by the Denmark National Laboratory at a resolution of 5 km^2 at 50 m above ground level. Like the wind velocity estimations made by CESEN, the accuracy of the SWERA wind data too suffers from low density of wind measurement stations used for ground verification. A GIS map was also developed indicating the wind resource at regional level. The wind regions of the country were classified into seven categories and the area under each category is calculated and presented at regional level indicating suitable areas for various purposes of

wind development. At a national level the total land area suitable for development of wind energy either for mechanical shaft power or grid based electricity generation is about 166, 100 km^2. The area of wind regions suitable for grid based electricity generation is estimated to be 20,290 km^2. This has a potential to generate 890TWh electricity per year.

In order to realize the full market potential for solar and wind technologies, financing mechanisms based on other countries experiences are also suggested.

The Long-range Energy Alternative Planning model, LEAP, is used to analyse and project energy demand and supply for energy. Scenario analysis is made to determine possible development for energy supplies, i.e. conventional source dominated scenario vs. solar and wind energy friendly scenario.

The energy demand forecast carried out with the model indicates that demand can be expected to grow from 700PJ (194TWh) in 2000 to just over 1900PJ (527TWh) in 2030, a growth rate of 3.5% per year. Sectoral energy shares change where energy demand from the household sector drops from 91% in 2000 to 78% in 2030 with corresponding increases in the other sectors. Fuel shares in the energy balance also change with share of biomass from total demand declining from 93% in 2000 to 82% in 2030.

For the supply side, the Reference scenario shows that the nearly exclusive dependence of the electric grid continues into the future and hydropower plants will contribute 96% to total generation on the grid in 2030. In electrified rural areas supplies are currently mostly from off-grid systems but in the future the contribution of grid electricity will increase and by 2030 grid power will account for 66% of total rural electricity demand.

Supply shortfalls appear for electricity in 2017 for the grid and immediately for off-grid systems. In the Reference scenario, shortfalls are met with the same supply mix as the base case whereas for the Alternative scenarios the shortfalls are met with solar and wind energy. The analysis shows that solar and wind energy may supply the shortfall of 4PJ (1TWh) of grid electricity in 2017 and 46PJ (12.8TWh) in 2030; for off-grid electricity shortfalls appear the year after the base year and solar and wind energy can provide 26.5TJ (7.3GWh) in 2001 and 1075TJ (300 GWh) in 2030; for home systems the potential for solar and wind energy would be in 0.1TJ (28MWh) in 2001 and 48TJ (13GWh) in 2030; and for solar water heaters the potential would be 112TJ (31GWh) in 2001 and 7500TJ (2TWh) in 2030.

1 Introduction

1.1 Overview

Ethiopia is located in the eastern part of Africa between 3^o to 15^o north and 33^o to 48^o east. With a surface area of 1.1 million square kilometers, it is the third largest country in Africa. It is the second most populous country in Sub Saharan Africa with an estimated population of about 71 million, which is mostly distributed in northern, central and southwestern highlands.

Ethiopian economy is predominantly based on agriculture which contributes the lion's share of about 50% to the GDP and over 80% of employment. The agriculture sector is the leading source of foreign exchange for Ethiopia. Coffee distantly followed by hides and skins, oil seeds and recently cut-flower are the major agricultural export commodities. At present the per capita income in Ethiopia is less than USD 100.

With only 6% of households connected and 15%of the population having access to electricity from Ethiopian Electric Power Corporation (EEPCo), access to electricity in Ethiopia is one of the lowest by any standards. Despite the fact that 80% of the population of Ethiopia live in rural areas, electricity supply from the grid is almost entirely concentrated in urban areas. Among other things, dispersed demand and very low consumption level of electricity among rural consumers, limited grid electricity penetration to rural population to less than 1%. Based on the hitherto electricity expansion practices in the country, access to electricity does not seem to be the reality of the near future for the greater percentage of the rural population. However, the recent government's strategy under Universal Electricity Access Program (UEAP) ambitiously plans to increase access to electricity from the current 15% to 50% by the year 2010 by connecting 7500 new towns and villages to the grid. The UEAP does not only aim to increase access, but also aims to raise the level of national per capita consumption of electricity from the current 28 kWh to 128 kWh by the year 2015. In order to realize this, the dependable capacity of the power plants has to be increased to 3GW from the current 0.6GW[1].

The Government of Ethiopia is aware of the fact that the national utility alone through continous grid extension cannot accelerate rural access to electricity. In the struggle to improve rural access to electricity, the government has recently streamlined its strategies and embarked upon removal of barriers and constraints to accelerated off-grid rural electrification. The Rural Electrification Strategy provides opportunities for an increasing participation of the private sector in the supply of electricity to un-electrified rural population. This has included the design of institutional and financing framework[2] for private sector-led rural electrification, which are expected to remove barriers and facilitate private sector participation in the provision of off-grid electricity supply (generation, transmission, distribution and marketing).

This study is part of the Ethiopian Solar and Wind Energy Resource Assessment (SWERA) Project. SWERA is an on going project financed by UNEP/GEF which is being concurrently implemented in 13 developing countries to assess the solar and wind resources potential of each of these countries and to facilitate global shifting to less carbon intensive energy system.

1.2 Objective of the study

This study seeks to produce a document that comprises country background information on solar and wind energy utilization and project scenarios on these technologies. The general objective of the study is to develop and present solar and wind energy investment opportunities to investors and decision makers in reasonable manner. It is an integrated study

[1] Universal Electrification Access Program (UEAP), Main Report, Volume II, EEPCO, April 2005
[2] Rural Electrification Fund (REF), Rural Electrification Board (REB) and Rural Electrification Executive Secretariat (REES) have been formed under the Ministry of Rural Development (MoRD).

with specific objectives of resource documentation including analysis of barriers and policies, identification of potential areas for technology promotion, and nationwide aggregation of potentials and benefits of the resource.

1.3 General Methodology

We suggest breaking the assignment into six distinct tasks. The first three tasks are related to reviews of policies and barriers for solar and wind energy development and a **situational analysis** framework will be used for the reviews.

Task 4 requires that energy demand and supply data be documented for a base year then projected for twenty to thirty years. We shall use the **LEAP model** to document the energy system and also for demand projection. Outputs from this task will be inputs for scenario analysis in Task 6.

Task 5 is the key part in the assignment. Here the technical and market potential for solar and wind energy will be determined. The SWERA developed **GIS database** will be used to graphically select potential S&W development areas in Ethiopia. **Sets of criteria** will be developed for assessment of the technical and market potentials – these selection criteria will be applied on the GIS database. The technical and market potential estimates from this task will be input to scenario analysis in Task 6.

Task 6 will evaluate the national potential of S&W energy. Output from Task 4 will show supply deficits at the national level. Output from Task 5 will show the technical and market potential of S&W energy at the national level. **LEAP** will be used to integrate these two sets of data to determine the potential contribution of S&W in the national energy balance.

Workflow and general outline of methodology

1	Review National Energy Policy	In this task national energy and related policies will be reviewed and their impact on solar and wind energy development in Ethiopia will be assessed.
2	Review of issues for S&W energy	Technical, financial, and institutional issues related to solar and wind energy development will be reviewed. Barriers for wider dissemination of S&W energy will be identified and strategies for their removal will be indicated.
3	Identify financing mechanisms	Accessible finance is one of the critical constraints for S&W dissemination. Appropriate financing mechanisms will be proposed.
4	Assess energy demand and supply	Energy demand and supply will be evaluated at the national level using the LEAP model. Demand will be projected to 2030. The demand-supply gap for the long term will be estimated. Outputs from this task will be inputs for scenario analysis in task 6.
5	Identify regions for S&W development	The SWERA GIS database will be used to estimate the technical and market potential of S&W energy. Potential areas will be identified on the digital map and aggregate S&W energy production potentials will be estimated for these selected sites.
6	Conduct scenario analysis	In this task, the share of the supply gap identified in Task 4 that may be met by S&W energy is estimated. The technical and market potentials estimated in Task 5 will serve to formulate two development scenarios: the Ambitious S&W energy development scenario will be derived from the technical potential; and the Accelerated S&W energy development scenario will be derived from the market potential.

2 Solar Energy Resource

Renewable energy resources in Ethiopia, with the exception of biomass, have not been actively incorporated into the national energy program. Apart from very few donor driven and project-based markets there has been hardly any development in the utilization of renewable energy resources and dissemination of such technologies. Knowledge of the exploitable potential of the solar resource and identification of potential regions for development will help energy planners to incorporate the resource as alternative means of supplying energy by conducting a more accurate techno-economic analysis which leads to more realistic economic projections.

This study seeks to estimate the exploitable potential of solar resource of the country under various scenarios using the SWERA generated solar resource data. Potential areas where there are significant solar resource and corresponding matches of un-served energy demand have been identified and presented using GIS maps.

2.1 Solar Energy Resource Potential

Ethiopia located near the equator its solar resource is obviously of significant potential. The responsible organization for collection and documentation of solar resource data in Ethiopia is the National Meteorological Service Agency (NMSA). Solar resource data including the daily irradiance and sunshine hours for some areas in Ethiopia have been collected and documented by various organizations such as the NMSA, Ethiopian Civil Aviation Authority, and, Food and Agricultural Organization (FAO) of Rome. Further solar resource potential estimation analysis on a national level based on measured data and theoretical methods was carried out by CESEN-ANSALDO Group in the mid 1980s. As an outcome of this study by CESEN, a solar energy map with iso-energy curves for yearly average radiation on a horizontal surface was developed for the first time. Lacking suitable direct measurements, the estimation of solar radiation of Ethiopia by CESEN was limited to measurements of sunshine hours and cloud cover. Data on cloud covers were available only for 12 stations and the instruments used to measure cloud cover (only 20 stations for which data was available) allowed only very course estimates of incident radiation.

In the absence of sufficient data on global radiation and sunshine hours, the total radiation on a particular area is usually estimated based on climatic and geographical analogy of other neighboring areas for which data is available. Following this, the estimation of total radiation by CESEN in areas with a very low density of ground stations, extrapolation was made to cover wider areas leading to uncertainties which can be considerably larger. It is also noted by CESEN that the iso-energy curves in areas with very low density of stations and near the boarders of the country must be considered less reliable [3]. According to CESEN, the annual average daily radiation in Ethiopia reaching the ground is 5.2 kWh/m^2/day. The minimum annual average radiation for the country as a whole is estimated to be 4.5kWh/m^2/day in July to a maximum of 5.55kWh/m^2/day in February and March.

The SWERA solar resource data was developed from the German Aerospace Center, Institute of Technical Thermodynamics (DLR) Model for the area represented by each grid cell in the GIS map. SWERA has developed a national solar resource assessment for Ethiopia at two different resolutions of 40x40km^2 and 10x10km^2. The solar resource data developed by SWERA includes estimates for concentrating solar power (CSP) or direct normal radiation, global radiation on horizontal surface and global radiation on tilted surface. The estimation of CSP analysis utilized direct normal data, which represents concentrating systems that track the sun throughout the day such as trough collectors or dishes. The estimation for radiation on

[3] Solar Energy Resources, Technical Report 3, CESEN 1986

tilted surface analysis used data from the flat plate collector type, typical for a PV panel oriented due south and tilted at an angle from horizontal equal to the latitude of the collector location.

The level of accuracy or certainty of the modeled value in SWERA data for solar resources at $40x40km^2$ resolution is considered to be accurate to 10% of the true measured value within the grid cell. This is because some of the meteorological input parameters to the model (cloud cover, atmospheric water vapour, trace gases, the amount of aerosols in the atmosphere) that are used to calculate the daily total insolation on a horizontal surface are not available at that resolution. The impact of these uncertainties are more exaggerated to CSP applications.[4] The level of accuracy of the modeled value for solar resources at $10x10km^2$ resolution is expected to be higher than the 40 km resolution. All analysis in this study is based on the 10km resolution data.

According to the SWERA solar resource data, the annual average daily radiation on a horizontal surface in Ethiopia is 3.74 kWh/m^2. The minimum annual average radiation for the country as a whole is estimated to be 1.5 kWh/m^2 in July to a maximum of 4.9 kWh/m^2 in February and March. Comparison of the national average radiation estimations by CESEN and SWERA group shows that the estimation by SWERA is less by 39%.

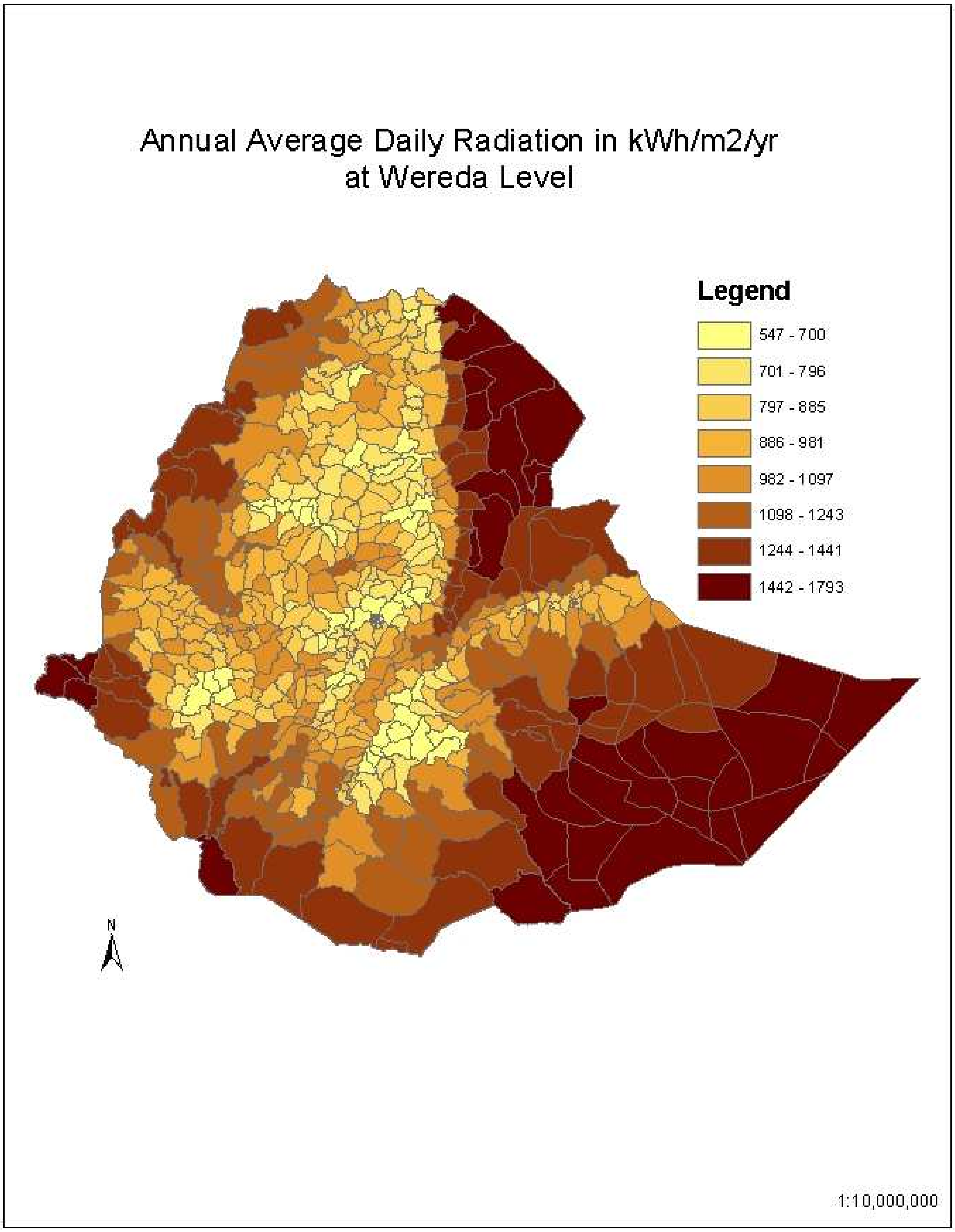
Table 2.1 – Comparison of yearly average daily global radiation ($kWh/m^2/day$) estimations by SWERA, NASA and CESEN for some locations.

			Average Daily Global Radiation on Horizontal Surface ($kWh/m^2/day$)			% Difference		
No.	**Location**	**Lat./Long.**	**SWERA**	**NASA**	**CESEN**	**SWERA vs NASA**	**SWERA vs CESEN**	**NASA vs CESEN**
1	Addis Ababa	9.03/38.7	2.07	5.94	5.54	187%	168%	6.7%
2	Arba Minch	6.08/37.63	3.521	5.49	5.54	56%	57%	1.0%
3	Awassa	7.07/36.95	2.603	5.02	5.59	93%	115%	11.5%
4	BahirDar	11.6/37.4	2.576	5.80	5.39	125%	109%	7.1%
5	Debre Markos	10.03/37.07	2.454	5.69	5.25	132%	114%	7.6%
6	Debre Zeit	8.73/38.95	2.615	5.47	5.82	109%	123%	6.5%
7	Dire Dawa	9.6/41.87	3.214	6.01	5.71	87%	78%	4.9%
8	Gode	8.15/35.53	2.274	5.75	5.55	153%	144%	3.5%
9	Gondar	12.55/37.38	2.145	5.92	5.74	176%	167%	3.1%
10	Gore	8.15/35.53	2.193	5.31	5.22	142%	138%	1.6%
11	Jimma	7.67/36.83	2.6	5.02	5.12	93%	97%	2.2%
12	Kombolcha	11.12/39.73	2.209	5.88	5.38	166%	144%	8.5%
13	Mekele	13.5/39.42	2.27	5.86	6.59	158%	190%	12.4%
14	Metehara	8.87/39.9	3.652	5.83	5.77	60%	58%	1.0%
15	Negele	5.03/39.57	3.393	5.30	5.30	56%	56%	0.0%
16	Nekemte	9.08/36.45	2.303	5.83	5.18	153%	125%	11.2%
17	Robe	7.12/40.0	1.977	5.70	5.58	188%	182%	2.2%

The SWEREA GIS data is used to analyze and assess the potential for photovoltaics (grid based and off-grid applications), solar thermal (Solar water heating for domestic and

[4] Assessing the Potential for Renewable Energy on Federal Lands, Bureau of Land Management, 2002

industrial purposes) and crop drying applications. Concentrating applications are not included in this study as estimation of potential for them require more detail information (regarding the technological aspect and selection of available land area with appropriate size and slop) which could not be gathered during the given period of time. Screening criteria were developed for these solar technologies to produce GIS-based maps and analyses.



2.2 Estimation of Technical Potential for Solar Resource

2.2.1 Methodology of Assessment and Resource Estimation for Solar PV

A) Grid Based Applications

i. Central Generation (PV Power Plants)

Central generation basically refers to solar photovoltaic schemes and the premises of which are primarily designed for electric power generations. These are PV power plants that are connected to electricity distribution lines as embedded generation systems.

It is difficult at this stage to develop a rationale for prediction of potential sites that can be used for central generation. However, marginal lands where distribution lines are available could be potential sites for embedded generation schemes.

ii. Building Integrated PV (BIPV) / Dispersed Systems

Building integrated PV refers to isolated generation of electricity from solar PV that is laid out on available space in individual buildings to feed to local distribution lines.

Potential for power generation from BIPV from both residential and non-residential sectors is commonly estimated by the amount of space available on roof tops (and building facades) that would be appropriate to lay out PV panels. If, however, information is not available to indicate the total size of available space on roof tops estimation of technical potential will be purely hypothetical and too course to be useful. For lack of data, the potential of BIPV for non-residential sector cannot be estimated at national level in any crude form. For residential sector the following screening criteria and methodology is used for the estimation.

Methodology

Box 2.1: - BIPV potential estimation methodology

1. All buildings must be in electrified areas as system has to be integrated to the local distribution lines.

2. Total number of residential buildings is assumed to be equal to 90% of total number of households (considering residences in apartments sharing same roof tops, more than one family per household unit- Source: CSA-1.1 household per household unit).

3. It is conservatively assumed that there will be at least 10m^2 roof top area available for laying out PV modules for power generation. Technical potential, therefore, is estimated as: total number of connected residential buildings in the woreda * 10m^2 area of roof top * annual average daily radiation of for the woreda * 365 days * 14% module efficiency * 90% system efficiency. This approach could be used to estimate BIPV potential at woreda level if number of connected residential buildings were known.

   National level BIPV technical potential in residential buildings is estimated as: total number of residential connections in the counrty * 10m^2* national annual average daily radiation*365 days * 14% efficiency*90% system efficiency.

According to data obtained from EEPCO, there are 700,000 residential connections[5]. The national annual average daily irradiation is 3.74kWh/m^2/day. Therefore, the BIPV technical potential in residential buildings is about 1.1TWh per year. Since domestic loads and PV generations do not match well, a lesser percentage of domestic buildings could be considered.

Larger potential can be obtained if larger area of roof tops and building facades, and efficiency of PV modules more than 14% is assumed.

BIPV technical potential in Region 14 was calculated per purpose of building based on tenure information obtained from the Region's Administration office. The total potential estimation is summarized in Table 2 below. Only 50% of total built up area is considered for spaces used to lay out PV modules as there will be unsuitable spaces due to slop, orientation and set aside for other purposes like placing water tanks, water heaters, etc.

Table 2.2: Built up areas per land service and potential for total yearly power generation

Land Service/ Purpose of Building	**Total No. of houses**	**Total Built up Area (m^2)**	**Technical Potential (GWh/yr)**
Residence[a]	321114	35843701.96	2390
Government Offices	395	516458.45	34
Institutions[b]	30815	4206850.21	281
Diplomat & Int. Organizations	89	37747.08	3
Defence	39	568549.87	38
Others[c]	8299	1393481.08	93
Total	**360751**	**42566788.65**	2839

a - includes facilities used for residential purpose and commercial activities together
b - includes businesses and industries
c - includes facilities used for purposes of recreation, religious activities, sport, etc.

(Source: Region 14 Administration)

The total BIPV technical potential for Region 14 at annual average daily radiation of 3.0kWh/m^2/day is about 2.8TWh per year[6]. This almost equals EEPCO's existing power plants firm energy generation capacity (3.4TWh/year). This estimation of potential can change depending on the assumptions taken and as the city develops and more buildings are put in place.

B) Off-grid Applications (Small Decentralized Systems)

a) Solar Home Systems (SHS) /Scattered Systems

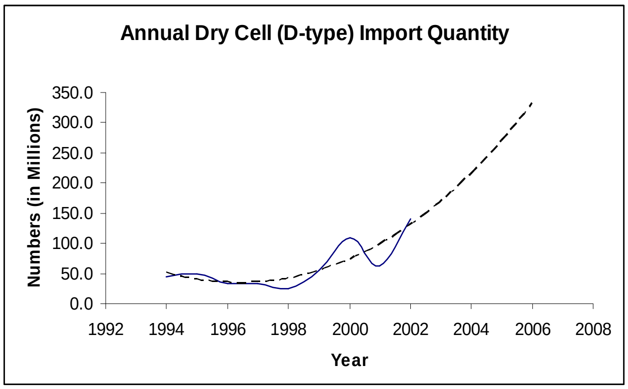
Solar Home Systems usually refer to individual PV systems which provide power to a single consumer (i.e. a household or a commercial establishment). Often, SHSs are used to generate small amount of electric power to meet the basic electric power needs of individual users in rural areas.

[5] Source: EEPCO, Facts in Brief, 2004

[6] Higher technical potential of about 5TWh per year is obtained with CESEN resource estimation of annual average daily radiation of 5.2kWh/m^2/day.

Non-cooking energy consumption among rural households is very low in Ethiopia. In rural and non electrified households, lighting and entertainment devices such as radio/ cassette players are end uses that such type of energy sources are needed for. For lighting, kerosene is the major source of fuel among all rural households and businesses. Of the total amount of kerosene imports in the country, a significant portion of about 20%[7] will be used for lighting by rural households in kerosene based lighting devices like pressure lamps, lanterns, and wick lamps.

Fig. 2.1: Estimated dry cell consumption in the country
(Source: Custom's Office)



Dry cells are also another most important source of energy in rural areas. It is primarily used to power light-torches and radio/cassette players. Annual dry cell consumption of the country for the years between 1998 and 2000 is indicated in Figure 2.1. It can be perhaps argued that over 300 million dry cell batteries would be consumed and disposed of by the end of 2006 if similar trend of consumption continues8.

On average, the basic non-cooking energy needs of a rural household in a non-electrified rural area is estimated to be 178 Wh per day9. If this were to be supplied with solar PV, a 70Wp SHS would provide enough power to meet the minimum electrical requirement. The assumption is that a 70Wp SHS would generate sufficient power at a yearly average daily radiation of 3.74kWh/m2/day. Depending on the solar resource available in a given area, the yearly power that any household obtains may vary from place to place. The daily load for a typical rural household is indicated in Annex 1.

As the percentage of electrification coverage in rural Ethiopia is very low (less than 1%), all rural households are considered for the estimation of the SHS technical potential. All urban households are excluded as many of them are already electrified and the remaining ones will be connected in the coming few years by EEPCO as part of its Universal Electrification Access Program.

Methodology

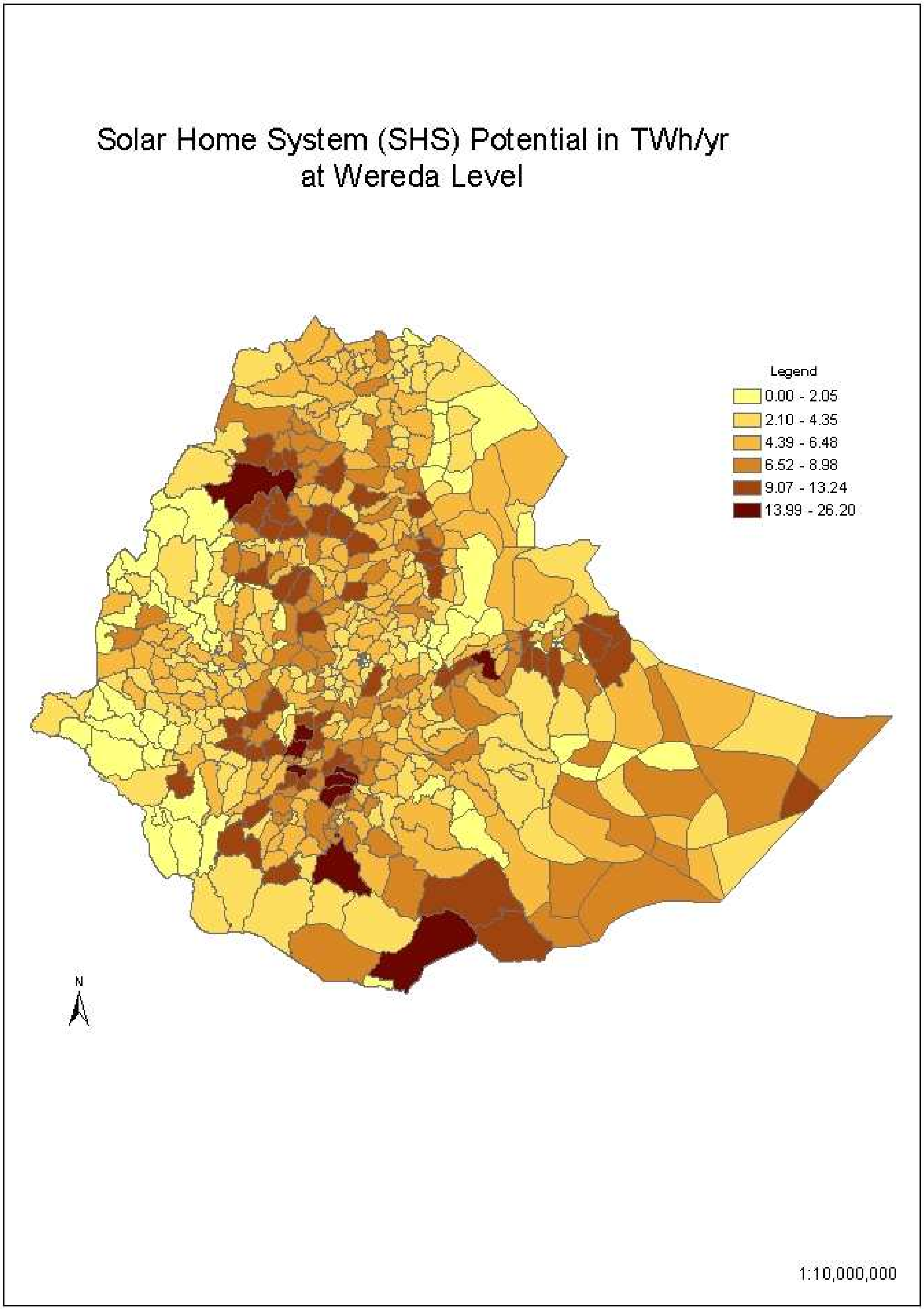
Box 2.2:- SHS technical potential estimation methodology

The technical potential for solar home systems in rural households is estimated by multiplying the size of the SHS for individual household (i.e. 70Wp system) by the number of non-electrified households times the solar resource expressed in terms of kWh/kWp/year

(i.e. Wp * non-electrified rural households * kWh/kWp/year * efficiency).

[7] Own estimation based on anecdotal information
[8] Projection of dry cells consumption of year 2006 is made by the author
[9] More explanation for the estimation is given in section that deals with economic/ market potential estimation for off grid applications.

The technical potential for SHS in the country as a whole is estimated to be 3.9 TWh/year. However, in order to bring about a more significant development impact, other options of energy supply systems which provide wider access to electricity could be more appropriate and economical in areas where households are more clustered. Application of solar home systems is more appropriate for widely dispersed households. Estimations of technical potential for all woredas in the country are indicated on the GIS map.



b) Health Institutions

Health service in Ethiopia particularly in rural areas is one of the lowest in the world. Quality and magnitude of health service provision is directly related to availability and consumption of electrical energy. However, availability of electrical power to support health services is nil in almost all rural health institutions.

Rural health institutions include health posts and health clinics/stations. Facilities in health posts include only the most basic items such as communications equipment, lights, and occasionally, a vaccine refrigerator. A health clinic is with a somewhat larger facility than a health post. A health clinic offers a wider service than a health post. It may have items such as vaccine refrigerators, laboratory equipments such as centrifuge and microscopes, and lights for a one or two bed ward for more seriously ill patients. Additional power may include lights and entertainment instruments like a radio/cassette player and a TV set for the staff.

An average daily electrical energy requirement for rural health institutions is indicated in the following table.

Table 2.3: Daily energy requirement for health posts and health clinics[10].

Appliance	*Health post*		*Health clinic/station*	
	Loads	*Wh*	*Loads*	*Wh*
Lights - compact fluorescent	2*11W*4h	88	5*11W*4h	220
Vaccine refrigerator	1*60W*5h	300	1*60W*5h	300
Microscope			1*15W*1h	15
Centrifuge nebulizer			150W*0.5h	75
Communication VHF radio	2W*12h+ 30W*1h	54		54
TV Color for staff			60W*4h	240
Radio Cassette player			15W*3h	45
Total per clinic per day		442		949
Assuming 20% system lose (Wh/d)		88		190
Total per clinic per day (Wh)		**530**		**1139**
Total per clinic per year (kWh)*		193		416
PV size needed (Wp) @ anuual daily average radiation of 3.74kWh/m^2/day		196		423

[10] Antonio C.J and Ken Olson, Renewable Energy for Rural Clinics, NREL, September 1998

Methodology

Box 2.3:- Methodology for estimation of scattered solar PV systems for health institutions

Option 1:
The total solar potential for PV systems will be the size of the module needed to meet the yearly energy requirement multiplied by the number of health institutions at woreda scale times the solar energy potential for the given place expressed in terms of kWh/kWp/year.

(i.e., Wp * number of health institution in a given woreda * kWh/kWp/year)

This will give the solar energy potential that should be harnessed to meet the current electrical power needs from solar PV in rural health institutions.

In absence of information on number and type of rural health institutions at woreda level, Option 2 can be used in anticipation of future potential rather.

Option 2:
Wp* potential health services needed per size of population * kWh/kWp/year
Since distribution of these health institutions in non-electrified areas is not known, percentage of all rural population is considered as potential (i.e., 85% of the population in woredas are considered for the estimation)

Capacity of health institutions –

- 1 health center for 25,000 people
- 1 health post for 5,000 people
- 1 health station for 10,000 people

(Source: Ministry of Health based on 2002/03 statistics)

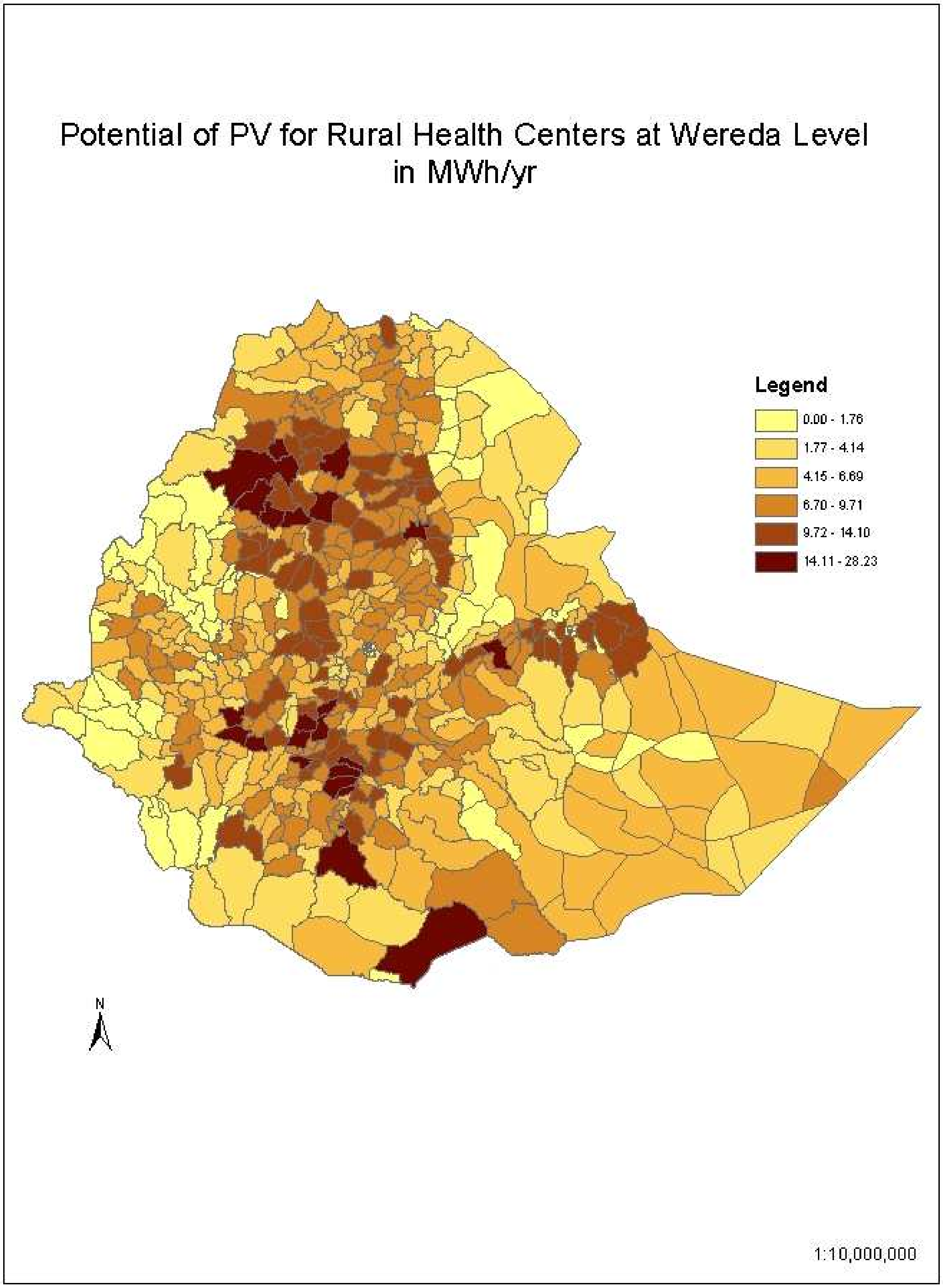
Since information on the number and type of health institutions at woreda level is not obtained, technical potential of scattered solar PV systems for rural health institution is estimated using the methodology indicated in Option 2 in Box 2.3 which considers number of potential health services needed per size of population[11].

Table 2.4: Technical potential of scattered solar PV systems in health institutions at national level

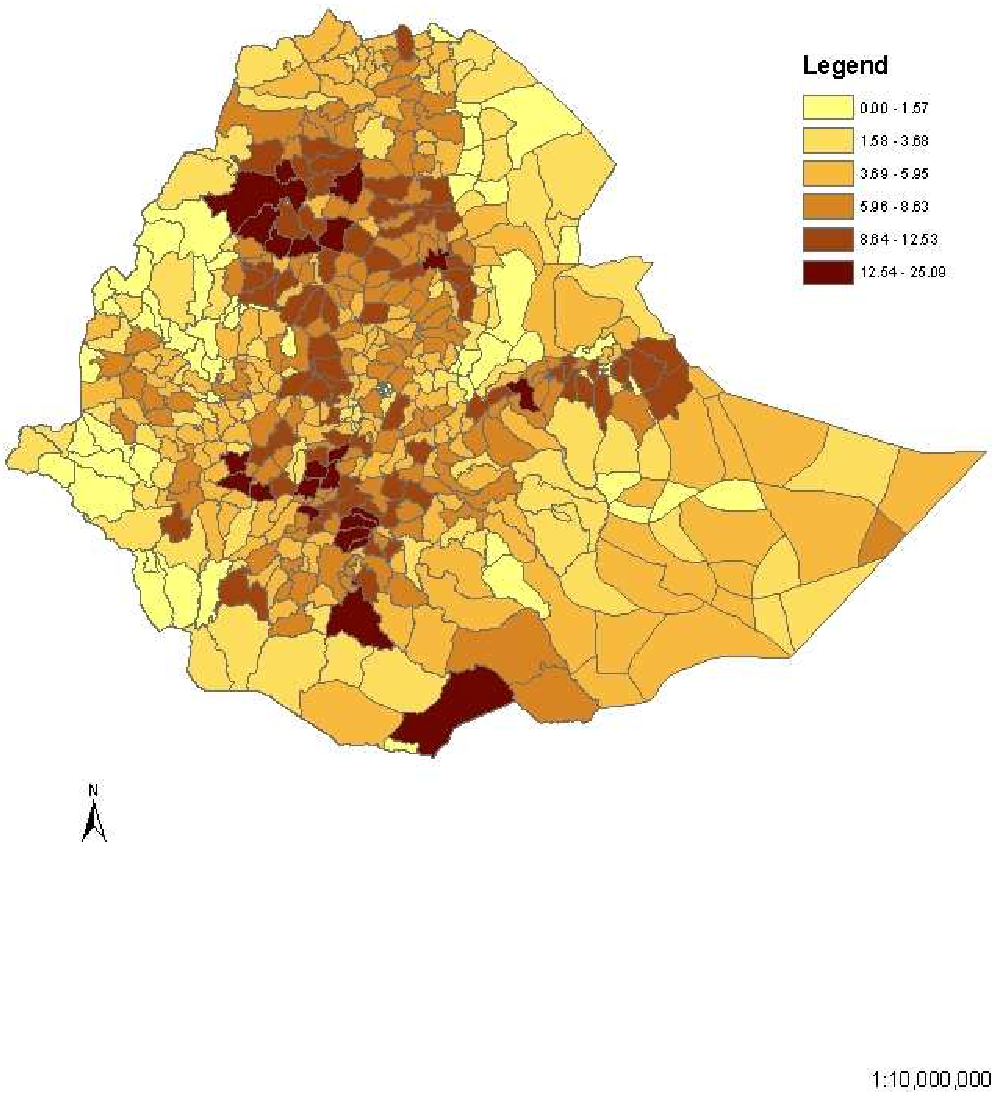
Potential Health Service Coverage (number)		Technical Potential for scattered PV systems in rural health Institutions (GWh/year)		
Health Clinics	Health Posts	Health Clinics	Health Posts	Total
5614	11228	3.24	3.0	6.24

The national potential of solar resource for PV systems for rural health institutions is estimated to be 6.24GWh/year. Technical potential estimation in each woreda is indicated on the GIS map attached.

[11] Health and Health Related Indicators, Ministry of Health, February 2004.


Potential of PV for Rural Health Centers at Wereda Level
in MWh/yr
Legend
0.00 - 1.76
1.77 - 4.14
4.15 - 6.69
6.70 - 9.71
9.72 - 14.10
14.11 - 28.23
N
1:10,000,000

Potential of PV for Rural Health Posts at Wereda Level in MWh/yr



c) Schools

Electric energy to support education is of paramount importance. However, just like rural health institutions, availability of power in rural schools too is almost nil. Typical power requirements for a rural school electrical applications include lighting for evening classes and staff's quarters, study rooms such as libraries, teaching aid equipments like TV sets and signal receivers, VCR and radio/cassette players. One should note that this estimation could vary as the size and number of electrical equipments in use, students and staffs significantly differ from one school to another.

Electricity requirements for a primary school and a high/technical school are adopted from "Renewable Energy for Rural Schools" and summarized as shown in the following table. Annual electricity requirements are 177 kWh for elementary schools and 490 kWh for high schools and technical institutions.

Table 2.5: Electrical energy requirements for a typical rural school

Appliance	*Primary school*		*High/technical school*	
	Loads	*Wh*	*Loads*	*Wh*
Lights – compact fluorescent	5*20W*4h	400	5*20W*4h	400
Teaching aids				
Radio	2*15W*4h	120	4*15W*4h	240
TV (21" B&W)				
TV (21" color)	1*100W*40	400	2*100W*4h	800
VCR/Satellite receiver			1*30W*4h	120
Refrigerator/Lab. Equip.				500
Power tools/Workshop				500
Total per school per day		920		2,560
Assuming 20% lose (Wh/d)		184		512
Total per school per day (Wh)		**1104**		**3072**
Total per school per year (kWh)*		177		490
PV size needed (Wp) @ annual daily average radiation of 3.74kWh/m^2/day		409		1140
* Total energy requirements for the year computed as daily demand times 160 days per year (8 months per year and 20 days per month).				

Methodology

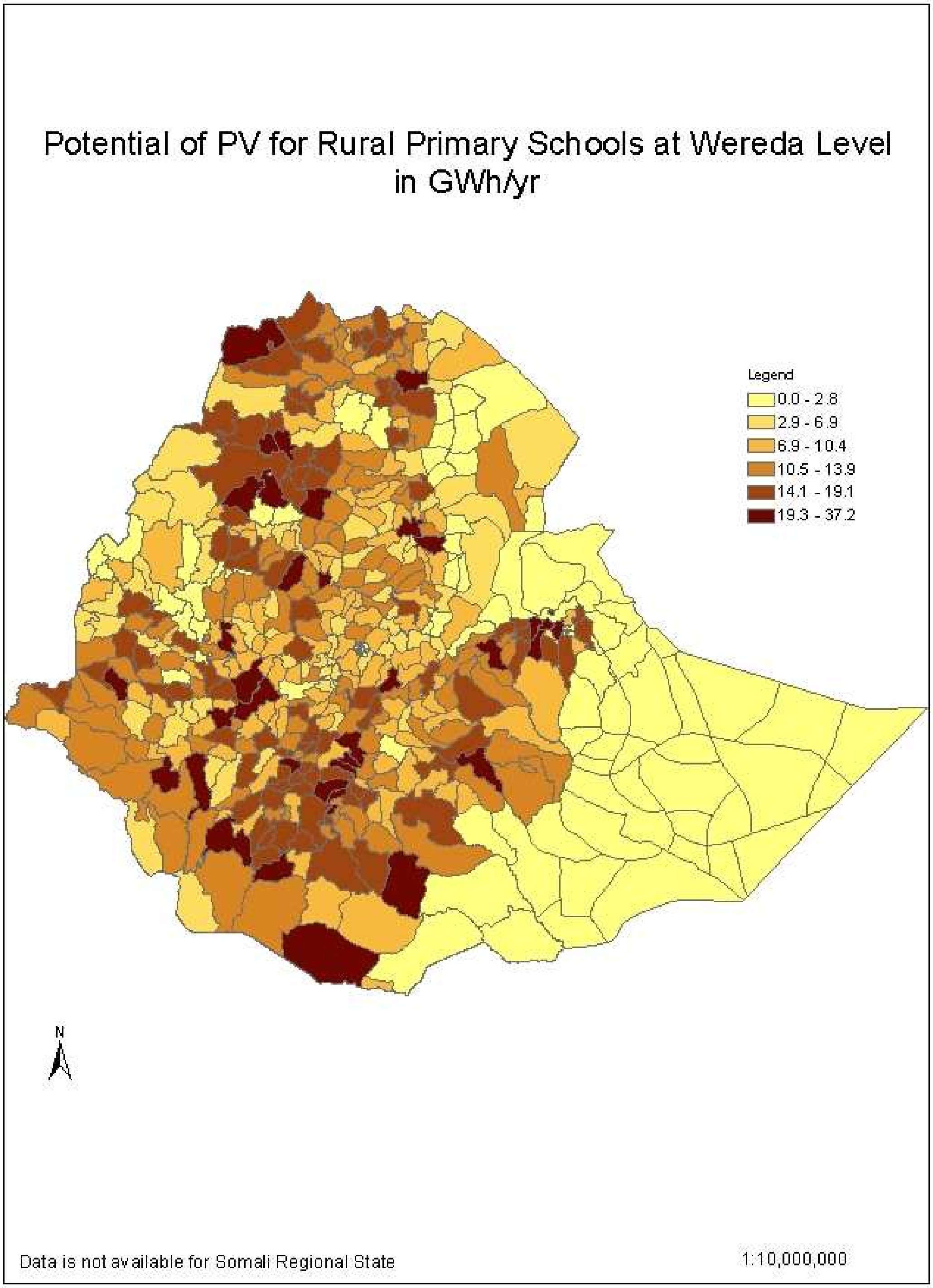
Box 2.4:- Methodology for estimation of technical potential of PV systems for rural schools

Assumptions:

- Only rural primary schools are potentials for PV systems as almost all secondary schools are in electrified areas
- Only one section for each grade (from grade 1 to 8)
- 50 students in each section
- Only 400 students per school

Wp* number of primary schools needed for school age rural population * kWh/kWp/year

In order to supply enough power for these end uses from solar PV in an area with a yearly average daily irradiation of 3.74kWh/m^2/day is about 400Wp and 1140Wp for primary and high schools respectively. The solar potential for PV systems in the country as a whole for powering rural primary schools is estimated to be 15.6GWh/year. Since data on number of primary schools in Somali Regional State is not available, the potential of PV for rural primary schools in the region is not indicated on the map.



d) Religious Institutions

Significant portion of PV systems are being sold to religious institutions in Ethiopia at present. Main items that power is required for includes lights, loud speakers, and musical instruments. Data on the number and distribution of religious institutions in the country are not available to estimate the resource potential in the sector.

e) Water Pumping

Water is the source and sustainer of life. A sustainable supply of water both for domestic use and agricultural purposes can be ensured by pumping out water from subsurface sources whenever available. In most rural areas humans and animals obtain drinking water from unprotected and contaminated surface waters usually traveling quite a long distance daily. Still in many rural areas even contaminated surface waters are hardly available within a day long journey. Supply of water for irrigation purposes is mostly powered by the earth's gravitational force. In cases where pumped irrigation is feasible solar pumps could be considered up to a certain scale beyond which the upfront cost will be too high.

The power required to pump water either from surface or subsurface water depends on the depth and amount of water delivered per unit of time. Average water requirements for humans, livestock and irrigation purposes are known with small variations depending on the condition of the local environment. However, the head from which water is pumped from varies from one place to another very greatly. Because of lack of data regarding the depth and distance of water sources the solar potential for water pumping purpose can be indicated on the GIS map only in terms of yearly energy per meter of head.

For Domestic Use

Clean potable water is available only for 36% of the population in Ethiopia[12]. The remaining 64% of the population does not have access to clean water. The minimum World Health Organization (WHO) standard for human water requirement is 30 liters per day[13]. This includes the amount used for self consumption and personal hygiene. Accessibility of water either from bore holes or surface water body should be known prior to determination of the power required.

Methodology

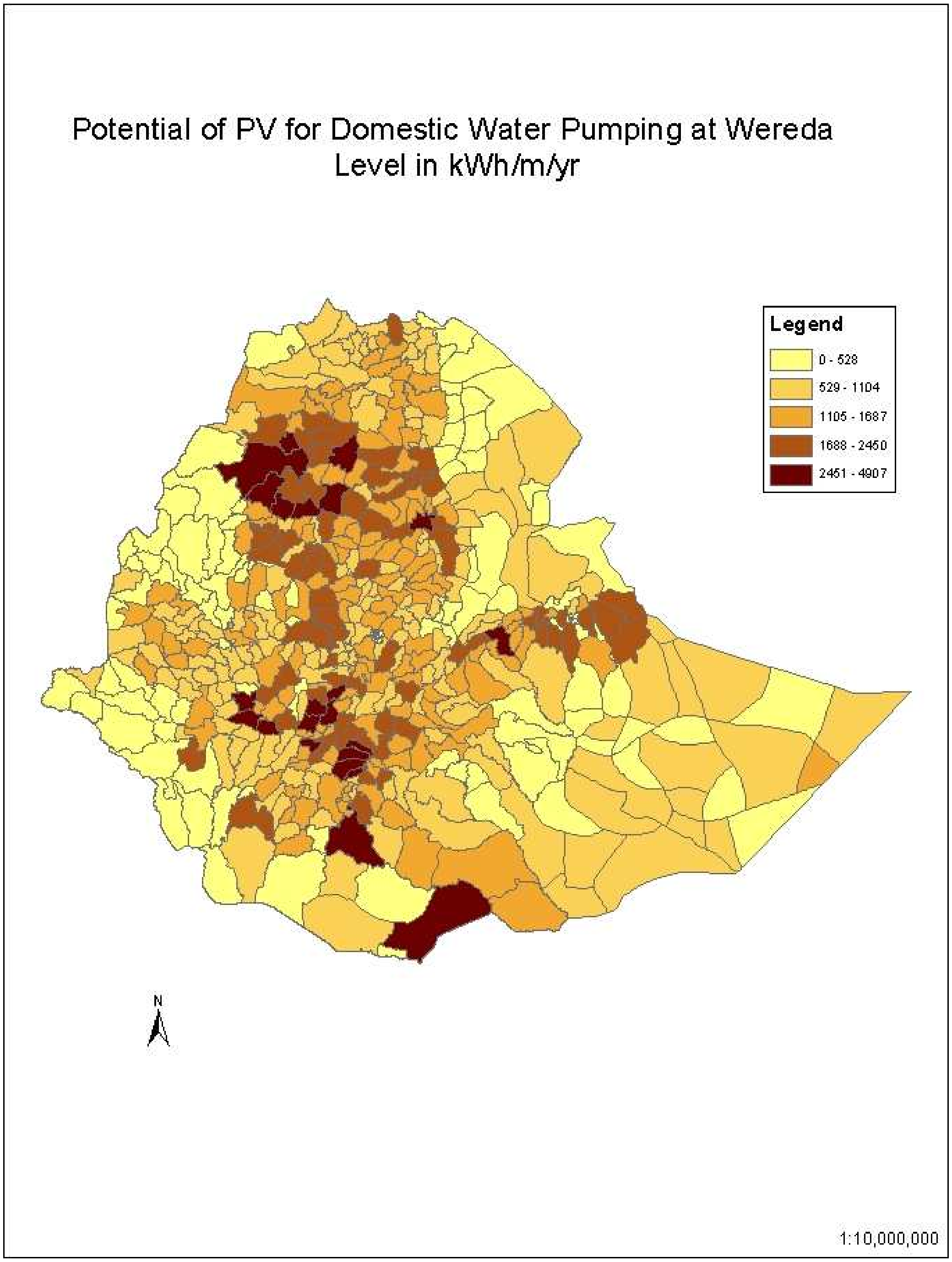
Box 2.5:- Methodology for estimation of technical potential of solar PV for domestic water pumping

The solar resource potential per meter head for domestic water pumping is estimated by multiplying the size of population (currently with no access to clean water supply) in non-electrified areas by the volume of water per person times the useful power. An average efficiency factor of 50% is used for the whole pumping system. The following formula is used (64%*woreda population *Water requirement (11 m^3/person/year) * Useful power (2.72Wh/m^4) * system efficiency of 50%) (or 73% * population *0.015 kWh/m/year).

The estimation of the potential resource at a national level is calculated using: 64% *71 million * 11m^3/person/year) * 2.72 Wh/m^4 * 50%.

[12] Walfare Monitoring Survey, CSA, 2004.
[13] Minimum WHO standard human water requirement is 30liter/person/day (for consumption and personal hygiene).

The potential of the solar resource for domestic water supply is about 680 MWh/m/year. If an average of 50m pumping head is assumed, the technical potential will be 34 GWh/year for the whole country. The potential in each woreda is indicated on GIS map.



For Livestock

Daily average water consumption per tropical livestock unit (TLU) is bout 40 liters/TLU/day. This consumption level may vary depending on local environmental conditions and distance that livestock travel in a day.

Methodology

Box 2.6:- Methodology for estimation of technical potential of solar PV for livestock water pumping

Solar potential per meter of water head is calculated as:

Total number of TLU * 14.6m^3/TLU/year*Useful power (2.72Wh/m^4)*system efficiency of 50%) or in short (total TLU*0.02 kWh/m/year).

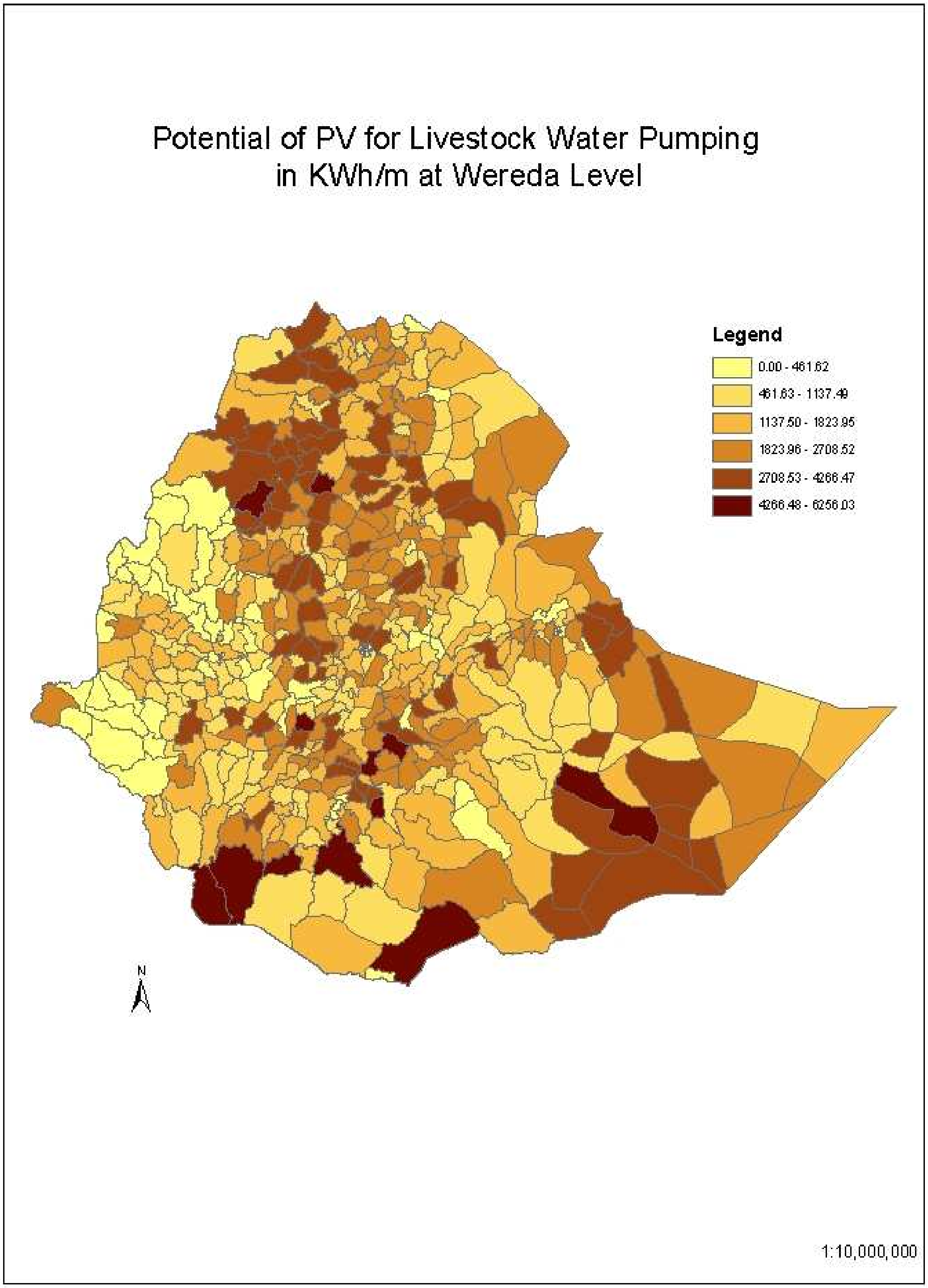
This is calculated at woreda level and is indicated in the GIS map. This estimation assumes delivering of water to livestock in their vicinity. It avoids daily travel of long distance to the water place.

For the country as a whole, the total solar energy potential for livestock water pumping is about 56 MWh/m/year. If an average of 50m head is assumed, the solar energy potential for water pumping becomes about 0.3 GWh/year for livestock consumption.

Table 2.6: Typical drinking water requirements[14].

Type	Water Consumption
Domestic (People)	
WHO recommended minimum	30 L/d
Average Use (Africa/ Asia)	45 to 85 L/d
Average Use (Europe/ South America)	250 L/d
Average Use (North America)	450 L/d
Livestock	
Cow	40 L/d
Sheep and goat	5 L/d
Horse	40 L/d
Donkey	20 L/d
Camel	20 L/d
Irrigation	
Market gardening	60 m^3/d/ha
Rice	100 m^3/d/ha
Cereal	45 m^3/d/ha
Sugar cane	65 m^3/d/ha
Cotton	55 m^3/d/ha

[14] Antonio C.J et al.


Potential of PV for Livestock Water Pumping
in KWh/m at Wereda Level
Legend
0.00 - 461.62
461.63 - 1137.49
1137.50 - 1823.95
1823.96 - 2708.52
2708.53 - 4266.47
4266.48 - 6256.03
N
1:10,000,000

2.2.2 Methodology of Assessment and Resource Estimation for Solar Thermal Applications

A) Solar Water Heating (SWH)

Application of solar water heaters is cross sectoral. They can be applicable in any kind of processing which involves water heating, boiling and steam generation.

i. SWH-Domestic Applications

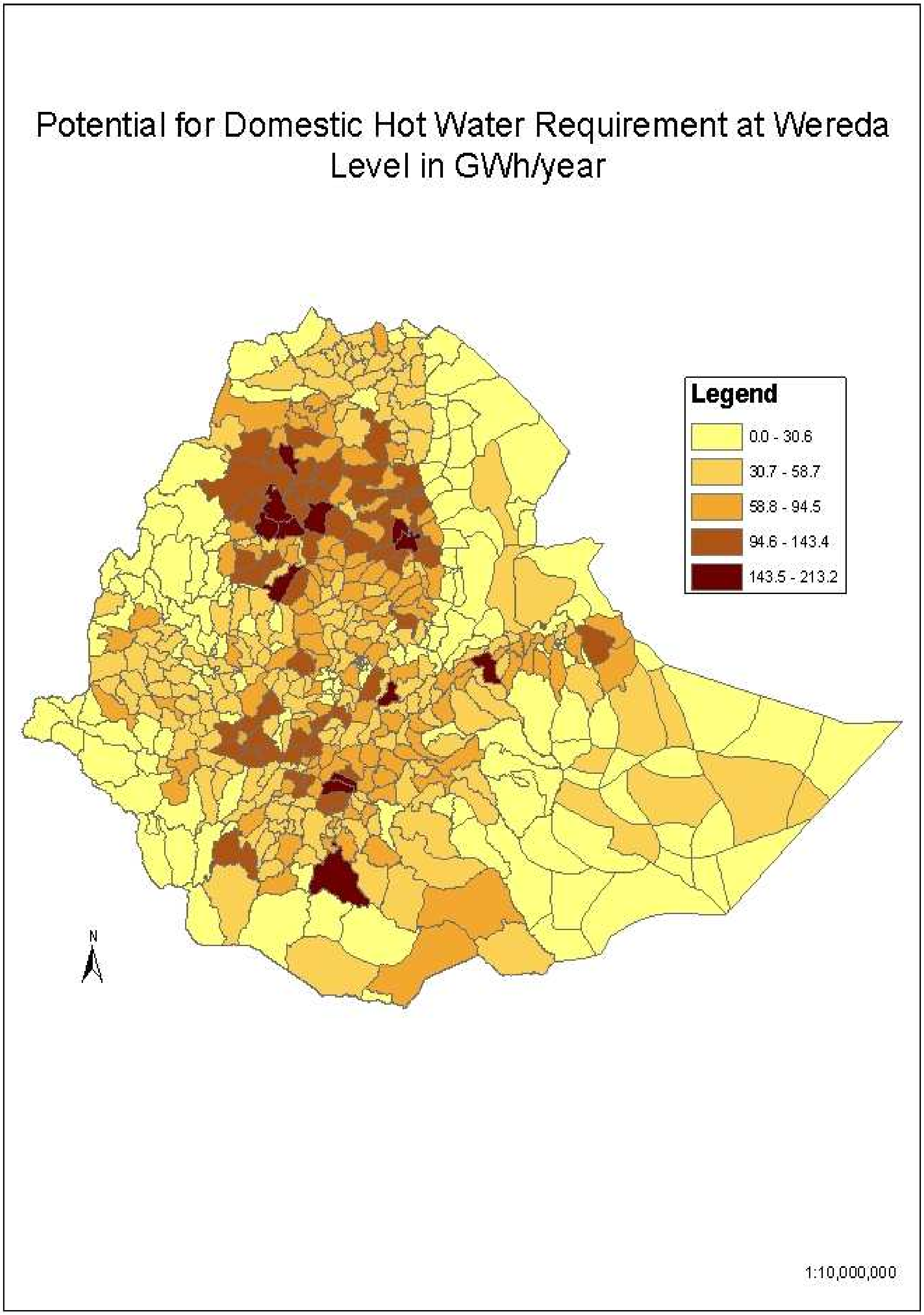
The domestic application of SWH is basically for heating water for hygienic applications. It can be for bathing or washing.

Methodology[15]

> **Box 2.7:- Methodology for estimation of technical potential for SWH for domestic applications**
>
> 1. Hot water requirement for bathing (shower) is estimated to be 20 to 25 liters per person per day at 40^oC.(Source: SIDA)
>
> 2. Assuming a family size of 5, the thermal energy required to provide 125 liter of hot water per day for bathing is about $3.5kWh_{th}$/hh/day ($1270kWh_{th}$/hh/yr).
>
> 3. All rural and urban households are considered for estimation of total technical potential.
>
> 4. Assuming 50% for system efficiency, the solar resource potential is calculated as: Total number of households multiplied by $2540kWh_{th}$/hh/year.

Total technical potential for domestic solar water heating is indicated at woreda scale on the GIS map. The solar potential for domestic water heating for the country as a whole is estimated to be 36TWh/year.

[15] Source: SIDA


Potential for Domestic Hot Water Requirement at Wereda Level in GWh/year
Legend
0.0 - 30.6
30.7 - 58.7
58.8 - 94.5
94.6 - 143.4
143.5 - 213.2
N
1:10,000,000

ii. SWH-Commercial/Business and Institutional Applications

Commercial establishments where SWH could be applicable include hotels, restaurants, bathing or shower service providers, and laundries. Hot water requirement for commercial applications varies greatly depending on the size and type of businesses. Solar water heaters do also have applications in health and educational institutions to providing hot water for cooking (pre-heated water) and for hygienic purposes. The technical potential includes all commercial establishments, health and educational institution particularly those with boarding facilities. Since data on the number, size and type of services provided by these institutions is not obtained, it is difficult to estimate the solar resource potential for water heating applications.

iii. SWH-Industrial Application

There is quite high potential for solar thermal applications in the industrial sector. Often, industrial processing mechanisms utilize energy for steam generation, or heating air for convective driers that will be used for range of applications. In some cases greater percentage of thermal energy requirements of industries can be replaced by solar energy. In food and beverage industries, most processes such as heating, drying, washing happen at low to medium temperature ranges (i.e. 30 to 90^{o}C) which almost totally can be replaced by solar. Textile and chemical industries, Tanneries and others use hot water and high temperature steam. Solar water heater can be used to heat up water to the required temperature or pre-heat boiler make up water for steam generation. Thermal energy requirements of industries and temperature ranges of the applications should be known in order to assess the potential for solar thermal applications. The following table indicates industries with high potential of solar thermal applications.

Table 2.7: Industrial sectors and processes with the greatest potential for solar thermal uses[16].

Industrial Sectors	Processes	Temperature Range (^{o}C)
Food and beverages	drying	30-90
	washing	40-80
	pasteurizing	80-100
	boiling	95-105
	sterilizing	140-150
	heat treatment	40-60
Textile industry	washing	40-80
	bleaching	60-100
	dyeing	100-160
Chemical industry	boiling	95-105
	distilling	110-300
	various chemical processes	120-180
All sectors	pre-heating of boiler feed water	30-100
	heating of production halls	30-80
Tannery	Pre-heating of boiler feed water	100 or above

[16] Untapped Potential, Werner Weiss

B) Solar Dryer and Cookers – For crop drying, food preservation and preparation

Solar dryers do have applications in industries as well as in agriculture. Drying is a common process in most industries. Electricity or direct combustion systems are commonly used to heat up air which will then be blown on to materials that need to be dried up. Solar dryers can partly replace the energy requirements of such systems providing the required result. In the agricultural sector, literally all farmers use solar energy in its natural form to dry up their harvests (usually cereals) before taking them to storage. Drying can be made before or after harvesting. However, for the most perishable products like vegetables and fruits, drying is less widely used as a means of preservation for later consumption. Hence, significant portion of farm produce spoils every year because of lack of preservation techniques. A solar drier can be used for preservation of surplus products while maintain the nutrition as it avoids direct exposure of the food staff from the radiation.

Application of solar cookers is more appropriate for food stuffs that do not need frequent tending. They can be highly applicable for boiling beans, root type foods such as cassava and potato, and variety of vegetables.

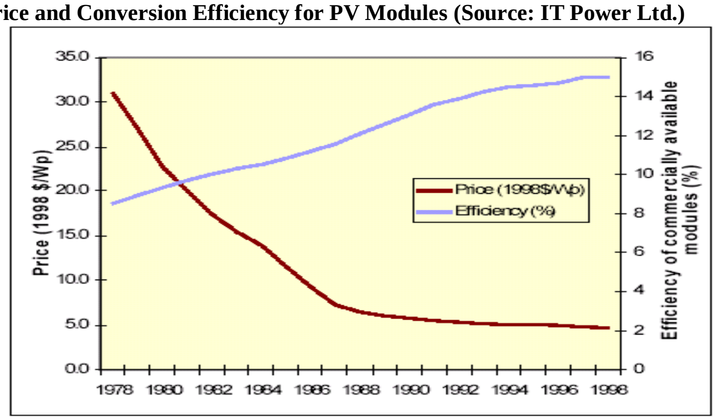
2.3 Estimation of Economic Potential of Solar Resource

2.3.1 Solar PV

A) Grid Based Applications (Central Generation and BIPV)

In terms of price, electricity from PV currently is far from being competitive to electricity from the grid[17]. Comparison of electricity price from PV and the grid is not imaginable at this stage. This, however, should not prohibit consideration of grid based systems as a strategy of laying the ground work for future applications. Comparisons based on economic costs rather indicate a different situation. Based on current international price of PV modules and balance of systems, for embedded generation the economic cost of electricity from PV will be around ETB 6.28/kWh[18] as compared to the economic cost of ETB 1.37/kWh for grid (ICS) electricity from EEPCO[19]. Total cost of system (for modules and grid connected inverters) about ETB 14 per peak watt is required for PV to compete with the economic cost of grid electricity[20]. Perhaps this is a price which could never be achieved. However, it is believed that large scale production of modules and system components, efficiency improvement and a major break through in technological innovation in future generation PV modules, a significant cost reduction could be realized in the coming couple of decades.

Fig. 2.2: Price and Conversion Efficiency for PV Modules (Source: IT Power Ltd.)



Historical facts, current situations and recent discoveries very much support continuation of cost reduction as a consequence of technological improvement and economy of scale in production and sales. As PV technology improves efficiency increases and hence there will be cost reduction. Historical trends indicate that the cost of PV modules have dropped down from several hundred dollars per watt peak (Wp) in the 1970s to about 4 dollars at present.

---

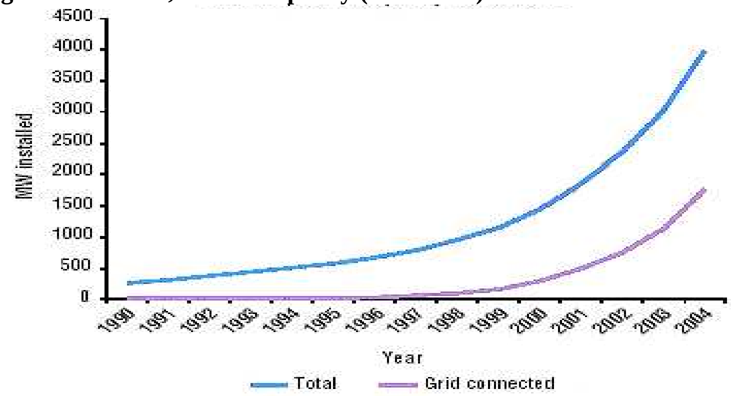
[17] Financial cost (levelized electricity cost) of electricity from PV is about ETB 15.53/kWh and ETB 8.71/kWh for scattered (individual solar home systems) and embedded generations respectively while the average price of grid electricity for domestic customers for consumptions up to the first 100 kWh is ETB 0.28/kWh.

[18] SWERA generated solar energy resources are used for calculation of costs throughout this document unless specifically expressed. In this analysis a national annual average daily radiation of 3.74kWh/m2/day is used.

[19] EEPC, Electric Tariff Study, Nov. 2005.

[20] The current financial cost for a complete PV system for grid based application is above ETB 88.70 per peak watt which makes the cost of PV electricity ETB 8.71/kWh (for embedded generation). Market price for a module only (size above 60Wp) currently is about ETB 65 per peak watt. Lifting all duties and taxes from PV systems will help much to reduce the cost per kWh but it will still be much higher than economic cost of grid electricity. In this case, the cost per peak watt for the complete PV system will be reduced to ETB 64/Wp, making cost of grid based PV electricity a little bit above ETB 6.28/kWh which is higher than economic cost of grid electricity by about 350%.

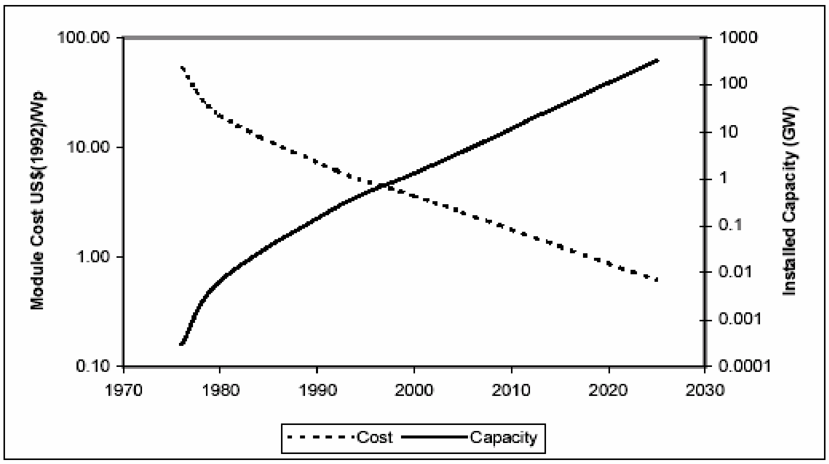
Fig. 2.3: Solar PV, World Capacity (1990-2004) Source: REW



Production and sales of solar PV has been increasing dramatically since the late eighties. The PV industry reached its first gigawatt of world cumulative production in 1999. By the end of 2004 total cummulative production had quadrupled to over 4 giga watt with an annual production exeeding 1.1 GW.

Plans announced by major manufacturers for 2005 included at least a 400 MW increase in production capacity and several hundred megawatts further capacity in the 2006-2008 period. Production expansion is continuing aggressively around the world and price too is reducing considerablly.

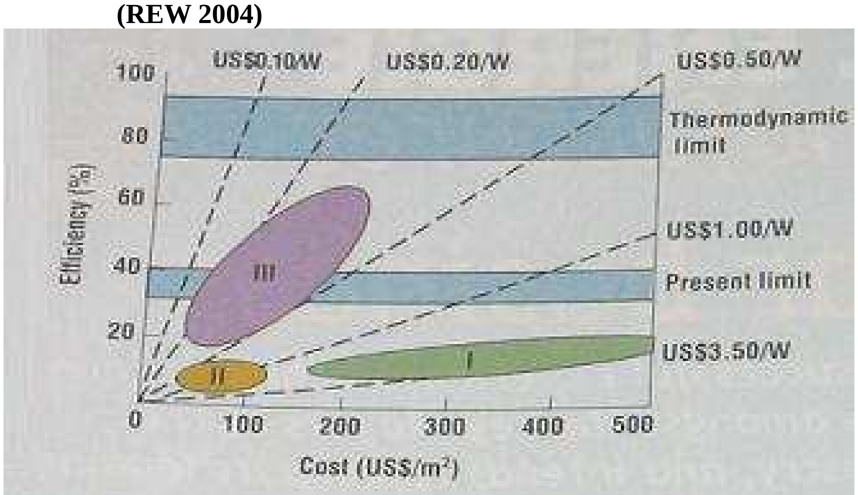
Fig. 2.4: Projection of grow in capacity and reduction in cost for solar PV (Source PIU 2001a, Rob Gross and Jake Chapman)



It is believed that this trend of cost reduction will continue as the technology has not yet reached its maturity limits in terms of technological development. Projection of capacity growth and cost reduction based on trends from the early seventies, indicate that cost of PV will fall down below $0.50/Wp around 2025.

Current innovations with third generation PV are highly promising for cost reduction. With the third generation advanced thin film structure, costs below USD 0.5 per peak watt would be likely; making PV compete head-on with conventional electricity generation options. Figure 5 shows the cost and efficiency domains for the three generation of solar PV technology: (I) wafer-based, (II) thin film, (III) advanced thin film[21]. Having seen the world trend for grid based solar PV systems and the hope with the technological innovation that price will in a couple of decades become competitive with the current economic cost of grid electricity, ETB 1.37/kWh[22]. It is not, therefore, too early to think about grid based PV systems now.

Fig. 2.5: Cost/efficiency domain for three generation PV technology (REW 2004)



Allowing for a modest increase in efficiency to 16% for modules available in the market with a life time of 20 years and at discounting rate of 10%, grid based solar PV could deliver electricity at an economic cost of ETB 6.28/kWh considering the SWERA estimation of the national annual average daily radiation of 3.74kWh/m^2/day (1365kWh/kWp/year). It is notable that the economic cost of electricity generation from grid based PV could be as low as ETB 4.52/kWh with a solar resource of 5.2kWh/m^2/day (1900 kWh/kWp/year), estimation by CESEN. If cost reduction trend of modules and system components continues in the future as expected, embedded generation with PV could compete with economic cost of grid electricity.

B) Off-grid application

a) Scattered Systems (Home Systems, Institutional PV, Water pumping, etc)

Off-grid applications of PV systems considered in this section are scattered systems. Scattered systems refer to individual systems that are not delivering electricity for clustered groups such as households that are fairly close together in a certain community or town. It rather means individual systems that deliver power to a single end user; it can be a household, an institution or a community water pumping unit. Cost of electricity generation from PV (with a battery storage) does not compete price wise to electricity generated from a diesel genset which delivers power to a community or town where end users are clustered within a given area. A well designed diesel genset system with a standard low voltage mini-grid distribution system

[21] Source: REW 2004
[22] If price of modules reduced to $0.5/Wp, grid electricity could be reduced to ETB2.39/kWh at annual average daily radiation of 3.74kWh/m2/day for the country. With estimation of CESEN, 5.2kWh/m2/day for national average annual daily radiation, economic cost of electricity from grid based PV could be as low as ETB1.70/kWh (Annex 3 for cost comparison of grid based PV).

can deliver electricity at a levelized electricity cost of ETB 5.67/kWh[23]. This cost, however, is affected by the price of diesel at duty point. At current price of PV modules and balance of systems, PV SHS provides power at a cost of ETB 15.53/kWh.

The electricity price from diesel genset will be somewhat higher than the generation cost as there will be additional profit margin and other taxes. Electricity from PV, however, is not affected by such factors and hence its price for its life time is already determined when it is yet installed. Though a predicted price from PV could sometimes be considered as an advantage, its current price per kWh is far from being competitive to electricity from diesel gensets. It has to be remembered that gensets for scattered generation, like powering a single rural household, never competes with PV alternatives as even the smallest genset would be over sized by several folds.

The amount of power and energy required by scattered end users (i.e. rural households) is usually very little. In the case of rural households, non-cooking energy is required to meet basic needs like lighting and powering entertainment devises such as radio/cassette players and sometimes B&W TV sets only for few hours a day. The total monthly energy needed to power this will not exceed 5 kWh (or less than 10kWh) in most cases. Several studies conducted in different parts of the country confirm this as well. Survey results under the Ethiopian PV Commercialization Project (EPVCOM) indicate that the monthly expenditure for lighting and entertainment on the average is about ETB50 and ETB 30 for the surveyed households[24]. This is very much in line with the finding of the study concurrently conducted, the baseline survey, which indicates the ability to pay ETB 47 per month for lighting for the surveyed group[25]. A recent study on PV market potential study conducted in Jimma under GEF-UNEP funded project also came up with monthly expenditure figure of ETB 75 per month for lighting and entertainment for households. Moreover, it also confirms that most households (nearly 90%) do possess two lighting points[26]. The conclusions that can be drawn from each of these studies is that the pre-electrification energy consumption level of scattered rural households is less than 5 kWh per month as the amount expended could not buy more energy with the technology available locally at present (kerosene lanterns, dry cell, etc). The off-grid master plan study also indicates that for about 85% of the households studied the current daily energy demand does not exceed 70W supplied for 4 to 5 hours a day[27]; the overall average in fact is nearly 50W. Powering such small scattered individual demands with gensets could by no standard be price competitive to PV alternatives. PV systems are ideal solutions for such applications. Hence, comparison of PV has to be with traditional sources of power, the ability and willingness to pay of the end users. PV in fact is complementary in that it fills the gap between traditional power sources (like kerosene, wood, etc) and grid electricity. Customers ones started consuming modern energy sources using SHS, their demand will grow through time and their consumption level could justify the high cost of infrastructure for future grid connection.

On average, if a certain household consumes about 5 kWh per month using a SHS for powering a couple of lights, a B&W TV set and radio/cassette players for 4 hours a day and

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[23] Diesel price of ETB 4.78/liter is considered. This is deduced from a case study presented in Annex 2 where a diesel genset supplies power to a hypothetical community of 200 households.
[24] Ethiopian PV Commercialization Project, Ethiopian Electric Agency, Draft Final Report, Mark Hankins and Melessew Shako, October 2004
[25] Baseline Survey
[26] Market Assessment for Solar PV Home Systems Commercialization in Jimma, Hilawe Lakew, August 2005.
[27] OFF-Grid Rural Electrification Master Plant, Draft Final Report, Rural Electrification Executing Secretariat, IED, 29 March 2006

30 days a month, the monthly payment would be about ETB78/month[28]. This is within the range that upper-middle class households are paying for lighting and entertainment devices as indicated by various studies. End users in fact would be willing to pay more for better quality services[29]. If the economic cost of electricity generation form PV is considered (i.e. ETB11.80/kWh) the monthly payment that a household would be paying is about ETB 60 per month for a monthly consumption of 5 kWh[30].

Table 8 below shows estimation of households' ability to pay for various sizes of solar PV electricity generation systems based on income and expenditure for lighting (Central Statistics Authority)[31].

Table 2.8: Comparison of current expenditure for lighting by income and size of PV systems

Income Group (ETB/year)	Less than 600	G1-(1000- 1400) Low	G2(1400-4000) Lower Middle	G3(4001-9000) Upper Middle	G4(9001 and above) High
% of expenditure for lighting + entertainments	15	14	12	10	8
Current expenditure for lighting +entertainments (ETB/month)	Less than 8	12-16	20-30	50-80	100-133
Replacing PV system (Wp)	--	Lantern (10Wp)	2 lights + radio (20Wp)	2 lights +B&W TV+ Radio/cassette (70Wp)	4 lights+ color TV + radio/cassette + video deck (150Wp)
Average cost of system (ETB)	--	1,200	4,000	7,500	16,000
Expected life time of system (years)	--	10	20	20	20
Electricity cost (ETB/kWh)	--	19.0	20	15.50	11.30
Expected monthly Consumption (kWh/month)	--	0.84	2.10	5.34	13.60
Expected monthly payment (ETB/month)	--	16.30	42	83	153

The values in Table 2.8 are generated using the national annual average daily radiation and the current average installed price for PV systems available in the market place. If economic cost of PV systems is considered, there could be further cost reduction between 20 to 30%.

---

28 Using solar resource estimation made by CESEN (5.2kWh/m2/day as national figure for annual average daily radiation), cost of electricity would be ETB13/kWh leading to a monthly payments of ETB65.

29 Study conducted by EEPCoIn dicates that customers are willing to pay more (up to 10%) for better services.

30 With a solar resource of 5.2kWh/m2/day, economic cost of electricity from SHS will be reduced to ETB10/kWh making the monthly payment for a 5kWh/month consumption ETB50/month.

31 Source: CSA, Revised report on the 1995/96 household income, consumption and expenditure survey, 1998

The cash market for SHS could be very limited but the market size could include income groups who spend as small as ETB 15 per month if credit facilities are put in place.

Cost of electricity generation from various sources is indicated in table below.

Table 2.9: Electricity Cost from Genset, Solar PV and Grid

Electricity Source	Levelized Electricity Cost	
	Financial	Economic
Diesel Genset*	5.67	5.68
PV - Solar Home System	15.53	11.80
PV – Embedded Generation	8.71	6.28
EEPCO (ICS)		1.3739
EEPCP (SCS)		2.2767
*analyzed at diesel price of 4.78ETB/liter		

Table 2.10 shows variation of cost of electricity generation using a diesel genset.

Table 2.10: Cost of electricity generation against price of diesel (Annex 2)

Diesel Price (ETB/L)	Electricity Cost (ETB/kWh)
4.78	5.67
5.00	5.77
5.25	5.88
5.50	6.00
6.00	6.22
6.50	6.44
7.00	6.67
8.00	7.12
9.00	7.51

Rural Institutions

The consumption level of rural institutions like health posts, health clinics and schools is still too low to use a generator set as part load operation will not be economical. As indicated in the section which deals with the solar PV potential in this sector, the monthly energy requirement of these rural institutions is around 13.3kWh, 28.5kWh, 27.6kWh and 76.8kWh for health posts, health clinic, primary schools and high schools respectively. It is not only such low level of energy consumption that makes use of diesel gensets uneconomical but also the rate at which it is consumed is also very low as it is distributed through out the day. The choice of genset to provide such low power will be a gasoline genset which actually means more fuel consumption, high fuel cost, frequent engine maintenance and short life time. Unless there are other electricity energy demands in the vicinity which can also be supplied from same source to justify economical use of larger gensets, solar PV will still remain to be the most economical choice.

Water Pumping

Solar pumps are increasingly used for domestic and livestock water pumping in rural areas. Cost of water pumping using solar can be cost competitive to diesel pumps depending on the solar resource available in the location, price of fuel and the power required for pumping. Price of diesel gensets reduces per kW as the capacity of the genset increases. Moreover, high capacity gensets perform at higher efficiency than smaller ones. These two conditions give advantage to diesel gensets in reducing costs if the power required for pumping is high. In such cases solar pumps could cost more than diesel pumps per volume of water delivered.

Considering an average price of diesel gensets, operating at very good performance in a well designed system, diesel pump can deliver water at less cost than a solar pump. Table 10 below compares cost of delivering 54m^3 of water per day with a total head of 58m at two different fuel prices and solar resources.

Table 2.11: Cost comparison between diesel and solar pumps[32]

Cost of Water Pumping	Source of Energy			
	Diesel		Solar	
	ETB4.78/L	ETB6.00/L	3.74kWh/m^2/day	5.2kWh/m^2/day
Financial Cost (ETB/m^3)	1.38	1.54	1.70	1.35
Economic Cost (ETB/m^3)	1.39	1.58	1.37	1.02

For solar pumping to compete with a diesel pump at irradiance of 3.74/m^2/day, diesel price at point of service must be higher than ETB7.20 per liter. Solar pump can deliver at less cost if the solar resource in the location is higher. If comparison is made in terms of economic costs, solar pump can deliver water at less cost for a very wide range of applications.

2.3.2 Solar -Thermal

Solar Water Heating (SWH)

Well manufactured solar water heaters last for 20 years without needing much maintenance. Cost of water heating using SWH is the most economical means of water heating.

Table 2.12:- Cost of water heating with solar water heater and electric boiler[33]

Wood* (ETB/kWh)	Solar Water Heater (ETB/kWh)				Electric Boiler (ETB/kWh)			
	@ 3.74 kWh/m^2/day		@ 5.2kWh/m^2/day		Domestic		Commercial	
Financial	Financial	Economic	Financial	Economic	Financial	Economic	Financial	Economic
0.88	0.56	0.43	0.40	0.31	1.05	3.02	1.20	2.46
* Institutional wood stove with an overall efficiency of 50% is considered								

The cost of water heating obviously is less in areas with high solar resources. For household use and commercial applications, solar water heaters are cost competitive and the market size is basically the technical potential.

In general, the market potential for solar PV for off grid applications and solar water heaters is quite high. The problem is that PV and SWHs are capital intensive while gensets and traditional power sources are operating expense intensive. Even though the cost per service delivered (i.e. kWh or cubic meter of water) seems very attractive, these technologies at this stage are beyond the reach of many potential users. The primary reason for this is the requirement of 100% upfront payment before acquiring the system - not dispersed in the life time of the system. Therefore, the barrier partly is financial. With appropriate and effective financing mechanisms put in place, solar PV and SWH will indeed be cost competitive with traditional and conventional means of energy sources. Various types of financing mechanisms and experiences of other countries that are successful in dissemination of PV systems is discussed in another section in this document. Similar financing mechanism can be applied for SWHs as well.

[32] Analyzed for a system which pumps 54m3 of water daily from at 58m head (See Annex-5)
[33] See Annex 4

3 Wind Energy Resource

Until recently, wind energy resource development was perhaps the least of all renewable energy resources that were given any attention in Ethiopia. This is partly due to lack of focus for development of renewables in general, and also due to the difficulty of locating an appropriate wind site in a country with low wind resource. Therefore, information on the wind resource potential and location of promising wind regimes will help energy planners and developers to consider the resource as alternative means of supplying energy.

This study seeks to estimate the practicable potential of wind resource of the country under various scenarios using the SWERA generated wind resource data. Potential areas where there are promising and accessible wind resource have been identified and presented using GIS maps. Wind energy potentials for the electricity grid connection were also estimated at regional level.

3.1 Wind Energy Resource Potential

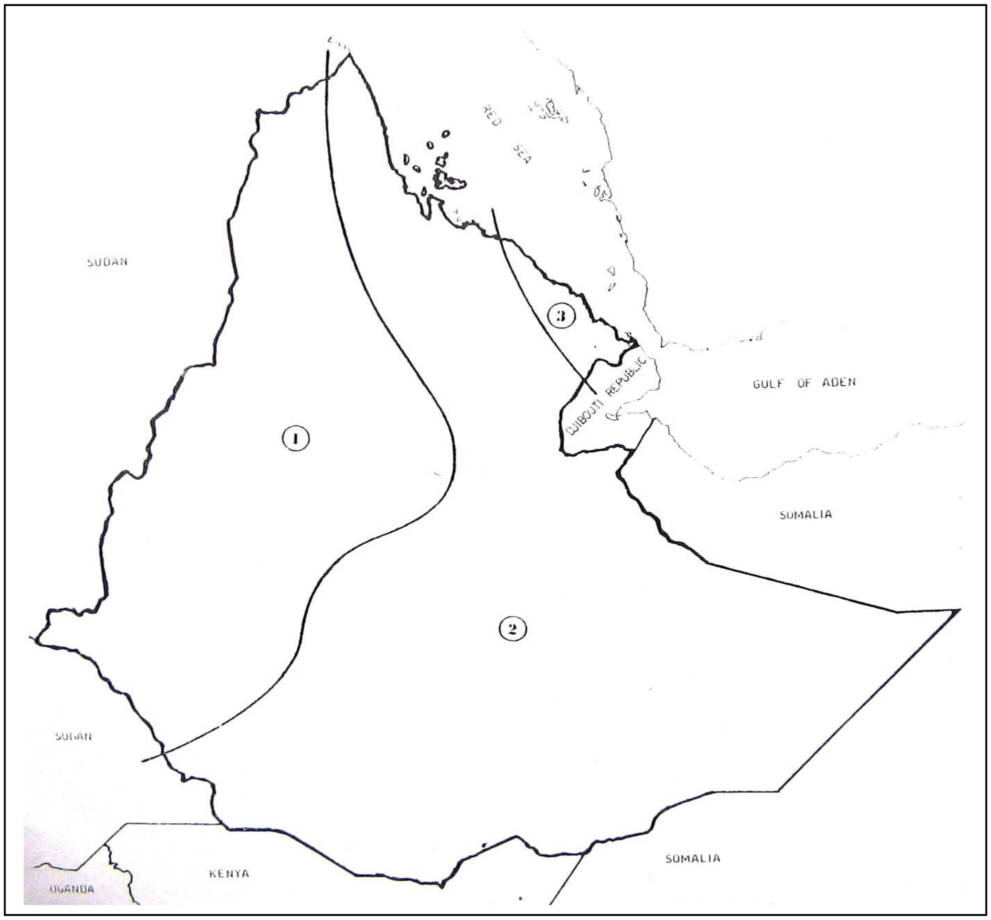
Wind speed generally decreases as one moves from higher latitudes towards the equator. The energy transported to a higher altitude gets stronger as the latitude increases (i.e. as the area decreases flow of energy density increases). However, the local effects might be quite important - presence of geographic structures such mountains, valleys and costal areas may enhance wind speed. Ethiopia being located near the equator, its wind resource potential is very much limited. There are few promising windy areas in Ethiopia located along side the main east African Rift Valley, the North Eastern escarpment of the country near Tigray regional state and the eastern part of the country (near North east of the Somali regional state).

Wind data has been collected and documented by National Meteorological Service Agency (NMSA) primarily for a purpose of aviation. This data is not of much use for estimation of the resource as most of the met-stations do not qualify the required standard for wind speed measurements. Most of the met station measurements for wind speed were taken at heights lower than the accepted standard of 10 m and over half were taken at just 2 m above ground level. A national level wind resource potential estimation has been done for the first time by CESEN-ANSALDO Group in mid 1980s. This estimation was purely based on theoretical analysis with only very few ground data verification. Low density of station measurements could not allow a greater geographical resolution and hence the estimation categorized the wind regions in Ethiopia only in three very broad groups – an increasing gradient in wind speed from west to east with maximum concentration near Djibouti boarder on the Red Sea Coast[34].

The figure below shows the regions with annual mean wind speed (and annual mean wind energy density) estimated at 10 meters above ground level.

[34] CESEN-ANSALDO, Wind Energy Resources, Technical Report 4, Ethiopian Nation Energy Committee, 1986.

Fig. 1: – Wind Regions of Ethiopia as estimated by CESEN-ANSALDO Group.



Region 1 :- less than 3.5 m/s (< 63W/m^2)
Region 2 :- 3.5 – 5.5 m/s (63 – 190 W/m^2)
Region 3 :- greater than 5.5 m/s (> 190 W/m^2)
(Note that this map includes Eritrea)

The SWERA wind resource data was generated from the RISOE Model developed by the Denmark National Laboratory at a resolution of 5km^2 at 50 m above ground level. Like the wind velocity estimations made by CESEN, the accuracy of the SWERA wind data too suffers from low density of wind measurement stations used for ground verification.

Based on the SWERA wind resource data, a GIS map was generated to indicate the annual mean wind power density of any particular location in Ethiopia. The wind atlas also helps to spot locations with good-to-excellent wind resources as a first estimation. Further ground measurements might be necessary for verification of the estimation when planning a deployment of wind generators on a site.

3.2 Estimation of Technical Potential for Wind Resource

The energy output from wind is very much dependent on wind speed. Estimation of the resource is however not a precise art. Identification of locations for wind energy generation depends on several factors other than the speed of the wind. Physical accessibility of locations, proximity to electricity grid, exclusion of designated areas such as national parks and visual impacts on areas of outstanding beauty are some of the factors that need to be taken into consideration while estimating the potential of the resource.

3.2.1 Methodology of Assessment and Wind Resource Estimation

For the estimation of the wind resource the method used was a hierarchical approach to the resource where unsuitable areas are gradually eliminated. Starting with identification of the resource at various wind categories, from poor to excellent wind regimes, land areas available under these categories were mapped irrespective of their land use. Further screening was applied by eliminating designated and inaccessible areas, applying environmental and economic considerations, and taking areas with wind speed estimates above a threshold value.

The wind resource was categorized into seven wind classes as Poor, Marginal, Moderate, Good and Excellent based on the mean annual wind speeds (or the corresponding wind power density) at 50m above ground level[35]. The wind classes range from poor to excellent wind regimes identifying the land area of the country that fall under these categories. Areas with wind resources below annual mean wind speed of 3.5m/s (mean power density < 50W/m^2) measured at 50m above ground level are not considered as they are not economically viable with current technologies.

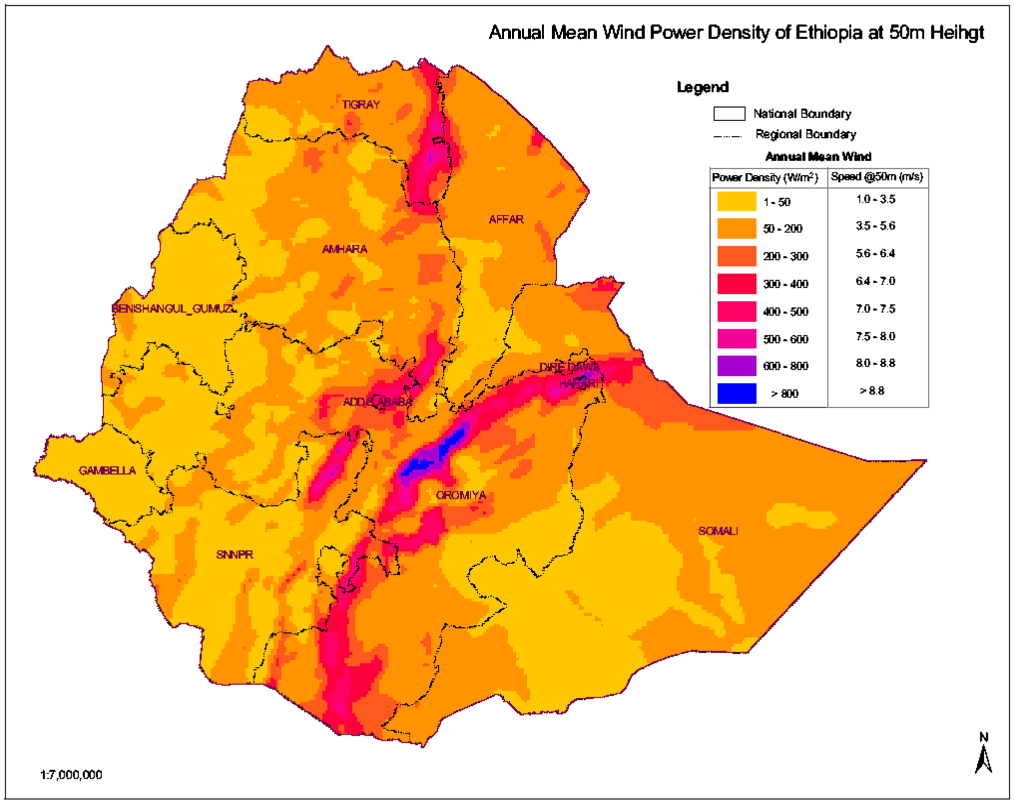
i. First Estimation

The first estimation considers the whole land area of the country that practically fall under various wind resource categories without excluding land areas that could possible be eliminated for reasons of accessibility, economics or environmental. This first estimation provides the bigger picture of the country in terms of locating windy areas. The practicable potential is certainly lower than the first estimation as more land will be eliminated with further screening.

Areas estimated to have Moderate and higher (Class 3 and above) wind resource are primarily located in the highlands featuring a sudden change in altitude from the neighboring land masses. These areas are basically the escarpments along the Great Rift Valley extending to the Southern, Eastern, North Eastern parts of the country, and the Central highlands. The strongest wind resource with energy density above 800 W/m^2 are located on the ridge of the highlands in the central part of the rift valley.

[35] Note that there are three Classes of Excellent wind categories (i.e. Class 5, 6 and 7).

Fig. 2:- A GIS map showing wind resources of Ethiopia (without excluding designated areas)



The wind resource classifications, Class 1 to Class 7, are indicated by color-codes as indicated in the GIS map above[36] – Class 7 indicating the strongest wind regions. Each color-code has an assigned range of values to represent annual wind power density in W/m^2.

Table 1: – Classification of wind resource and extent of associated land areas

Wind resource category	**Wind Class**	**Wind power density (W/m^2)**	**Wind speed @ 50m (m/s)**	**Total Area (km^2)**
Poor	1	50 - 200	3.5 – 5.6	564,606
Marginal	2	200 – 300	5.6 – 6.4	96,801
Moderate	3	300 – 400	6.4 – 7.0	42,935
Good	4	400 – 500	7.0 – 7.5	23,975
Excellent	5	500 – 600	7.5 – 8.0	6,529
Excellent	6	600 - 800	8.0 – 8.8	3,814
Excellent	7	Above 800	Above 8.8	1,715
Total area covered by Marginal-to-Excellent wind regions				**740,376**

The classification of the wind resource in terms of annual mean wind speed and power density corresponding to those shown in the resource map are presented in Table 1 above. Table 1 also shows the land areas of the country that fall under these wind resource classifications. The land areas indicated in the table below are gross areas without excluding preserved areas. They include all land and water masses including towns, national parks, wood lands and priority areas of outstanding beauty.

[36] The map also includes regions below Class 1 category (i.e. regions below 3.5m/s).

The wind resource of Ethiopia is generally low. About 35% of the total area of the country is even below Class 1 wind category (note that Table 1 above does not include wind regions below Class 1 wind category). Poor wind regions account nearly 50% of the total land area. It can be concluded from this that it is only about 15% of the total land area of the country that has promising wind resource. The land area with Moderate-to-Excellent wind region is nearly 7% of the total land area, of which the practicable potential will be less due to exclusion of areas designated for other purposes. Distribution of wind resource areas by regions is shown in Table 2 below.

Table 2: – Regional distribution of wind resources under various wind categories.

Region	**Wind Resource Category and Land Area Under Category (km^2)**							
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Total**
Addis Ababa	--	42	277	207	--	--	--	**526**
Afar	67340	6,331	1,550	545	--	--	--	**75,766**
Amhara	88659	12,578	2,357	1,687	328	--	--	**105,609**
Benshagul	4528	--	--	--	--	--	--	**4,528**
Dire Dawa	552	665	286	--	--	--	--	**1,503**
Gambela	359	--	--	--	--	--	--	**359**
Harar	--	2	32	109	108	143	--	**394**
Oromia	131865	45,257	26,832	14,794	3,352	3,492	1,715	**227,307**
SNNPR	40857	6,190	3,305	2,562	1,509	103	--	**54,526**
Somali	196571	18,946	3,209	524	80	--	--	**219,330**
Tigray	33877	6,790	5,087	3,547	1,152	77	--	**50,530**
Total	**564,606**	**96,801**	**42,935**	**23,975**	**6,529**	**3,815**	**1,715**	**740,376**

The majority of land area with Good-to-Excellent wind resource region falls in Oromia followed by Tigray and SNNPR. Wind resource potential of Class 7 category is found only in Oromia.

ii. Second Estimation

This second approach is basically an application of further screening criteria on the first estimation by eliminating preserved areas such as National Parks, sanctuaries and wild life reserves, forest lands and water bodies.

Table 3:- Areas covered by forest lands, protected areas and water bodies

Land Use	**Area**		**As % of total area of the country**
	Km^2	**%**	
Forest Land			
Highland Bamboo	5,241	27%	0.5%
Natural Forest	11,524	59%	1%
Plantation	2,831	14%	0.3%
Total forest land	**19,595**	**100%**	1.7%
Protected Area			
Controlled Hunting Areas	148,065	76%	13%
National Park	20,096	10%	1.8%
Sanctuary	2,197	1%	0.2%
Wildlife Reserve	23,399	12%	2%
Total of Protected Areas	**193,757**	100%	17%
Water bodies			
Lakes	7,431		0.7%
Total of All[37]	**220,783**		**19.5%**

[37] It should be noted that some of these eliminated areas may overlap and the total eliminated area might be less than the sum of each individual area.

Controlled Hunting Areas are not primarily designated for their landscape values nor for protection of wildlife - therefore may not very likely be particularly sensitive to the visual and noise impact of wind farms. Hence, Controlled Hunting Areas are not eliminated as it does not seem reasonable to leave out such significantly large portion of the country's resourceful region. For lack of appropriate data in GIS format, towns, settlements, historic sites and monasteries could not be excluded. Regions under Poor wind resource category (Class 1) are excluded as they are not technically and economically feasible with current technologies.

Table 3:- Estimation of wind resource excluding designated and poor wind regions.

Wind resource category	Wind Class	Wind power density (W/m^2)	Wind speed @ 50m (m/s)	Total Area (km^2)
Poor	1	50 - 200	3.5 – 5.6	538,810
Marginal	2	200 – 300	5.5 – 6.0	92,019
Moderate	3	300 – 400	6.0 – 7.0	40,304
Good	4	400 – 500	7.0 – 7.5	22,279
Excellent	5	500 – 600	7.5 – 8.0	6,454
Excellent	6	600 - 800	8.0 – 8.8	3,646
Excellent	7	Above 8	Above 8.8	1,392
Total area covered by Marginal-to-Excellent wind regions				**166,094**

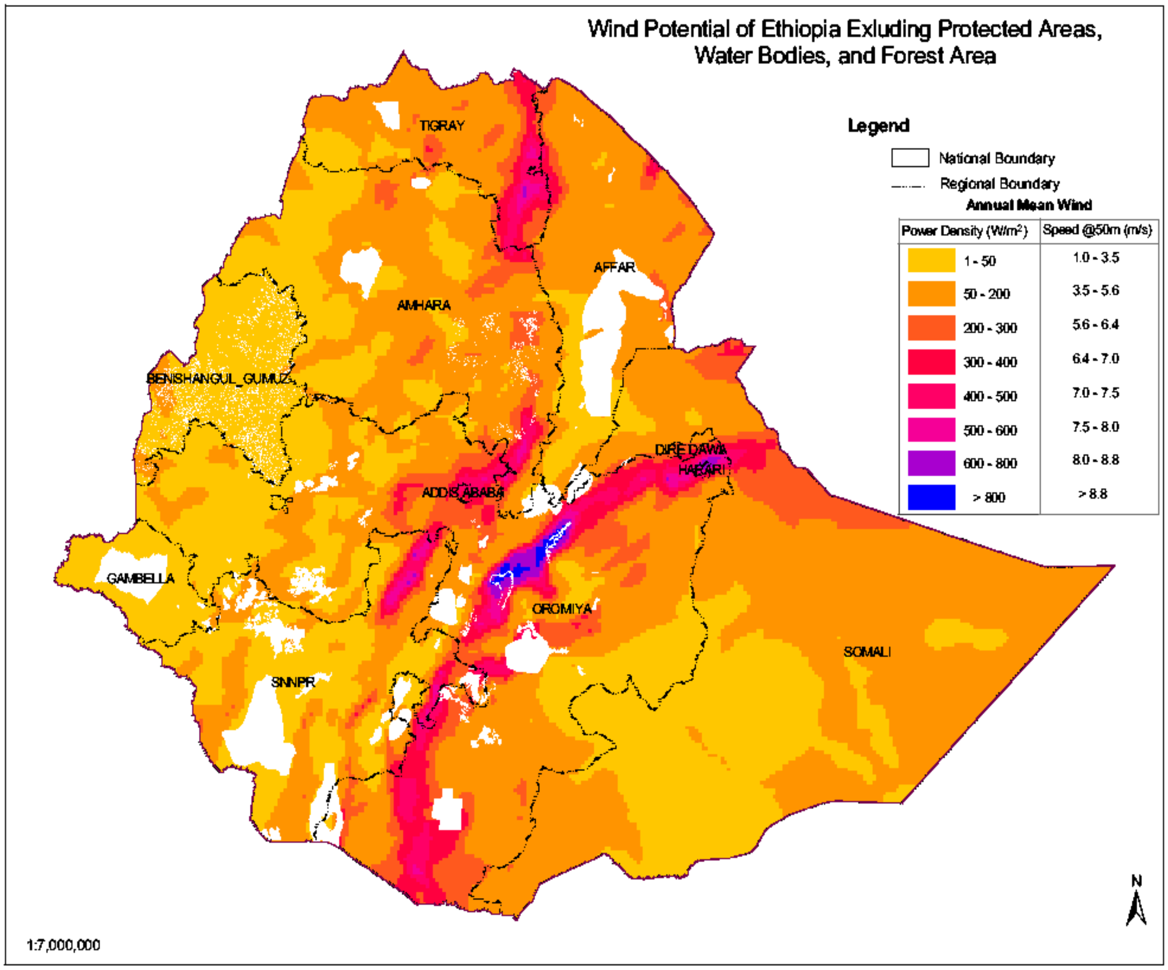
After eliminating designated areas and regions of Poor wind category, the wind resource classified under Marginal-to-Excellent categories are estimated to cover a total amount of 166,094 km^2 of land. Exclusion of designated areas reduces the useable potential areas (i.e. classified under Class 2 to 7) by 5.5%.

Table 4: – Regional distribution of wind resources under various wind categories.

Region	**Wind Resource Category and Land Area Under Category (km^2)**							
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Total**
Addis Ababa	--	42	277	207	--	--	--	**526**
Afar	57,318	5,948	1,553	546	--	--	--	**8,047**
Amhara	84,881	11,966	2,322	1,678	328	--	--	**16,294**
Benshagul	3,996	--	--	--	--	--	--	**0**
Dire Dawa	553	667	287	--	--	--	--	**954**
Gambela	317	--	--	--	--	--	--	**0**
Harar	--	2	32	109	108	143	--	**394**
Oromia	124,838	41,911	24,626	13,142	3,274	3,323	1,392	**87,668**
SNNPR	37,439	5,823	2,950	2,519	1,510	103	--	**12,905**
Somali	196,734	18,862	3,163	526	80	--	--	**22,631**
Tigray	32,734	6,798	5,094	3,552	1,154	77	--	**16,675**
Total	**538,810**	**92,019**	**40,304**	**22,279**	**6,454**	**3,646**	**1,392**	**166,094**

Regional distribution of wind resources in terms of land area coverage is presented in Table 4 above. The column for the total figures in Table 4 represents wind regions with Class 2 and above categories. Benshangul Gumuz and Gambela Regions do not have a wind resource that can be harnessed with current wind technologies.

Fig. 3:- A GIS map showing geographic distribution of wind resources of Ethiopia (excluding designated areas)



White areas in Fig. 3 above represent excluded areas. It can be seen from this wind atlas that Good-to-Excellent wind regions are located on the ridges of the highlands along the rift valley. The wind resource potential in the western part of the country is almost nil.

The actual practicable potential will still be less than the second estimation as areas unsuitable for development for physical reasons (i.e., settlements, road sides, air ports, etc.) should be further eliminated. Depending on the local condition a buffer zone of about 100m around roads, rivers, railway might be needed for safety reasons so that there is minimum risk of anything falling from the turbine hitting travelers. A 400m buffer zone around settlements might be left so that the noise levels at the nearest dwelling places are likely acceptable. Near airports a 6km clearance for radar could be satisfactory.

In reality, presence of infrastructure like access roads and electricity grid-network coverage, and availability of heavy duty cranes and trucks for transportation and erection of big size turbines, etc determines the actual feasible wind potential. In general, areas including the 200 W/m^2 up to maximum are suitable for wind water pumping, areas from 300 W/m^2 up to maximum is suitable for small home-size wind power systems, and areas with wind power density greater than 400 W/m^2 would be quite competitive for grid connected wind power.

iii. Estimation of Wind Resource for Grid-based electricity generation

Electricity generation from wind for grid-based system basically refers to wind farms. For technical and economic reasons appropriate wind regions for grid-based electricity generation are those with wind density of 400W/m^2 (wind speed 7m/s) and above. Such wind regions primarily occur on high terrains such as ridges and mountain tops which are mainly located at the edge of the highlands that form the great east African rift valley.

The second estimation of the wind resource described above does not take account of the restrictions due to the availability of infrastructure such as electricity grid and road networks. Grid-based wind electricity generation usually entails wind farms of considerably big size turbines. This requires availability of electricity grid network for connection and access roads for transporting equipment to site to a reasonably closer distance. Therefore, potential wind regions for grid based system should be the intersection of regions with Class 4 and above wind categories, a certain buffer zone around the existing and anticipated high transmission lines and all weather road networks. The overlapping of transmission lines, road networks and wind resources will restrict the wind resource further, particularly in the short term.

Buffering roads and high voltage transmission lines in 25 km and overlapping them with wind regions in Good-to-Excellent categories in the second estimation will give the total wind resource regions for grid based electricity generation.

Table 5:- Categories of wind resource favorable for grid based wind electricity generation.

Wind resource category	Wind Class	Wind power density (W/m^2)	Wind speed @ 50m (m/s)	Total Area (km^2)	Percent windy land	Potential for Installed Capacity (MW)
Good	4	400 – 500	7.0 – 7.5	15,175	1.3	75,875
Excellent	5	500 – 600	7.5 – 8.0	3,729	0.3	18,645
Excellent	6	600 - 800	8.0 – 8.8	985	0.1	4,925
Excellent	7	Above 8	Above 8.8	401	0.04	2,005
Total				**20,290**	**1.8**	**101,450**

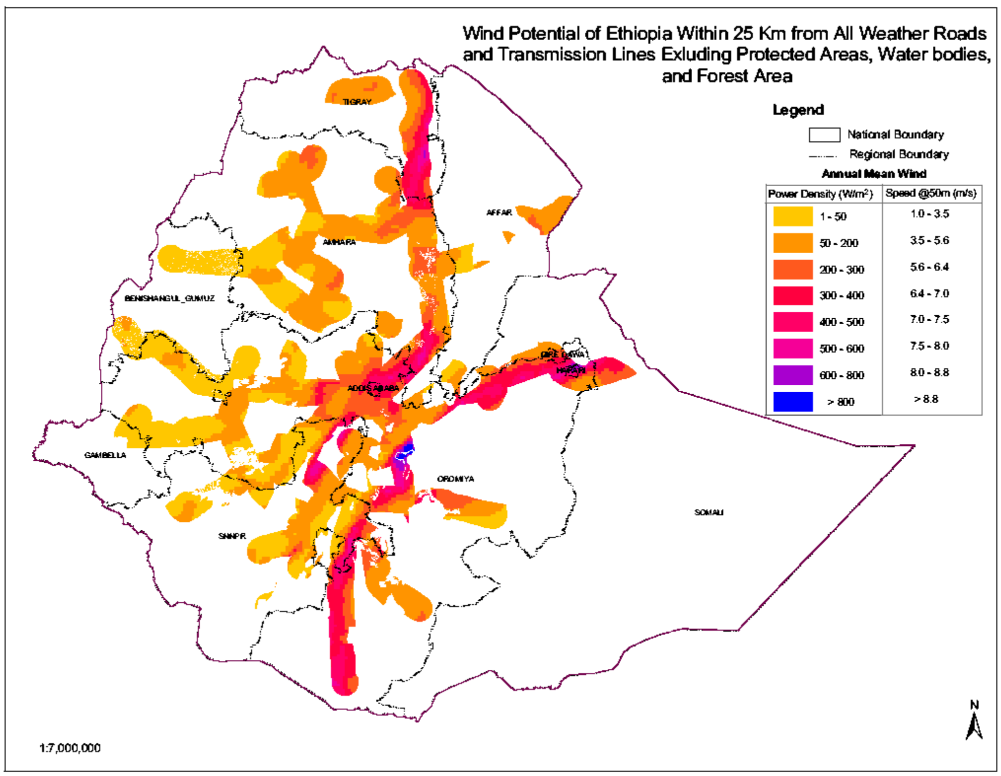
At a national level, the estimation of land area suitable for grid based wind electricity generation adds up to be a little bit over 20,000 square kilometers. In terms of generation capacity assuming an installed capacity of 5MW per square kilometer[38], the total national potential for grid base wind electricity system will be about 100 GW. Assuming 80% operating time for the turbines (i.e. the time the turbines should be producing some power), the total wind resource potential for wind regions with Good-to-Excellent categories is estimated to be 10.6 million Tcal per year (890TWh per year). There are too many site-specific features which such a method of resource estimation cannot take into account. However the estimates can give a range of what may be possible.

[38] This is a recommendation by SWERA international team

Table 6:- Regional distribution of wind resources favorable for grid based wind electricity generation.

Region	Wind Resource Category and Land Area Under Category (km^2)				
	Class 4	**Class 5**	**Class 6**	**Class 7**	**Total**
Addis Ababa	207	--	--	--	**207**
Afar	12	--	--	--	12
Amhara	1614	328	--	--	1942
Benshangul	--	--	--	--	--
Dire Dawa	--	--	--	--	--
Gambela	--	--	--	--	--
Harar	109	108	143	--	360
Oromiya	9074	1726	754	401	11955
SNNPR	1589	819	10	--	2418
Somali	271	19	--	--	290
Tigray	2299	729	77	--	3105
Total	**15175**	**3729**	**985**	**401**	**20290**

Fig. 4:- Geographic distribution of wind resources favorable for grid based wind electricity generation.



The wind map above shows all wind regions that overlap with a buffer zone of existing and planned high voltage transmission lines and all weather roads excluding protected areas, forest lands and water bodies as discussed above in Second Estimation. The map also shows that the grid and road networks matches well with the high wind resource areas.

3.3 Estimation of the Economic Potential of Wind Resources

3.3.1 Mechanical Water Pumping Applications

Regions with Marginal and above wind categories are suitable for development of mechanical wind power for water pumping. The applications of mechanical wind pumps are primarily to lift surface and underground water for small scale irrigation, domestic use and livestock watering.

The total land area suitable for mechanical water pumping applications amounts 166,094 square kilometers. The demand however may not match with the wind resource area. This will further reduce the resource that can possible be developed.

3.3.2 Small Home-sized Wind Electricity Generators

Rated power output with home-sized wind turbines ranges between few hundred watts to 10s of kilo watts. Moderate-to-Excellent categories of wind regions are suitable for generation of electricity using such wind turbines. This corresponds to wind regions with annual mean wind speed starting from 6.5m/s measured at 50m height. The tower economics for small wind generators usually makes sense when the height of the turbine hub is between 15m to 25m. Any additional gain of electricity by increasing the hub height above this range would not be economical. Therefore, wind generators can be considered if the available wind speed at hub height is around 5m/s. Recent wind technologies make generation of power possible even with wind speeds as low as 3.5m/s (Cut-in wind speed) at the hub height. Power generated at such low wind speed only overcomes the power loses caused by a long wire run or the internal voltage drop of the system. Operating wind speeds at low annual wind speeds does not make electricity generation competitive with the alternatives.

Based on the wind resource estimation made in section 1.2.1 (ii-Second Estimation), the land area suitable for home-sized wind electricity generation includes regions with Moderate-to-Excellent wind categories. This amounts to 74,075 square kilometers of land.

The price per kWh of electricity from wind cannot compete to that of grid electricity. In good wind regimes wind electricity could be a cheaper alternative to solar PV or diesel genset in terms of investment cost as well as the cost of electricity generation.

The graph below shows a cost comparison of a 1kW wind turbine (BWC XL.1)[39], solar PV system and a diesel genset generating equal amount of electricity per year. It shows what the Life Cycle Cost of the systems would look like if equal amount of electric power is generated. The comparison assumes standalone systems. A simple Spread Sheet Model[40] was developed to determine the annual power that can be generated from the BWC XL.1 wind generator at various annual mean wind speeds[41]. The cost of Solar PV systems and diesel gensets were calculated for the corresponding equal energy output.

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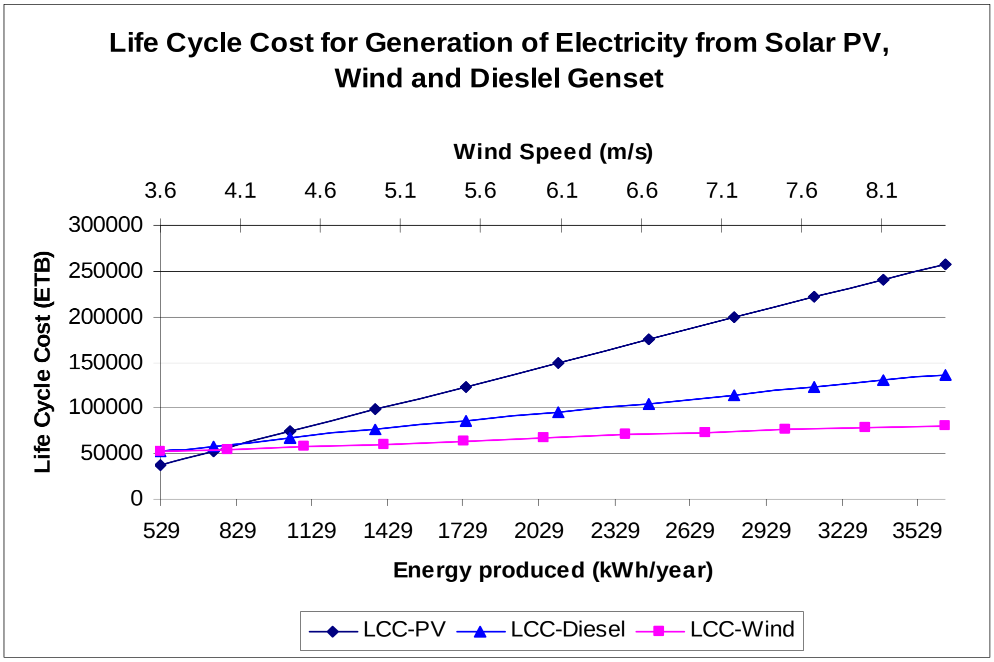
[39] BWC XL.1 is a 1kW home-sized wind generator manufactured by Bergey Windpower. See manufacturer's information for the power curve (performance at various wind speeds) in Annex 6.
[40] Annex 7 provides a guide on how to develop and use an Excel spread sheet model for Analytical Calculation of Wind Turbines Performance using annual mean wind speed and the power curve of a wind turbine.
[41] See Annex 8 for the calculation of annual energy output.

Fig.5:- Life Cycle Cost (LCC) for generation electricity from solar PV, wind and diesel genset.



The above graph corresponds to BCW XL.1 wind generator performance, solar PV modules and a 3 kW capacity diesel genest (the smallest available in the market). These sizes are selected to represent small stand alone home system. Energy generation with the Solar PV system assumes 5 peak sunshine hours per day while diesel price of ETB7/liter was considered as a reasonable price in remote off grid areas[42].

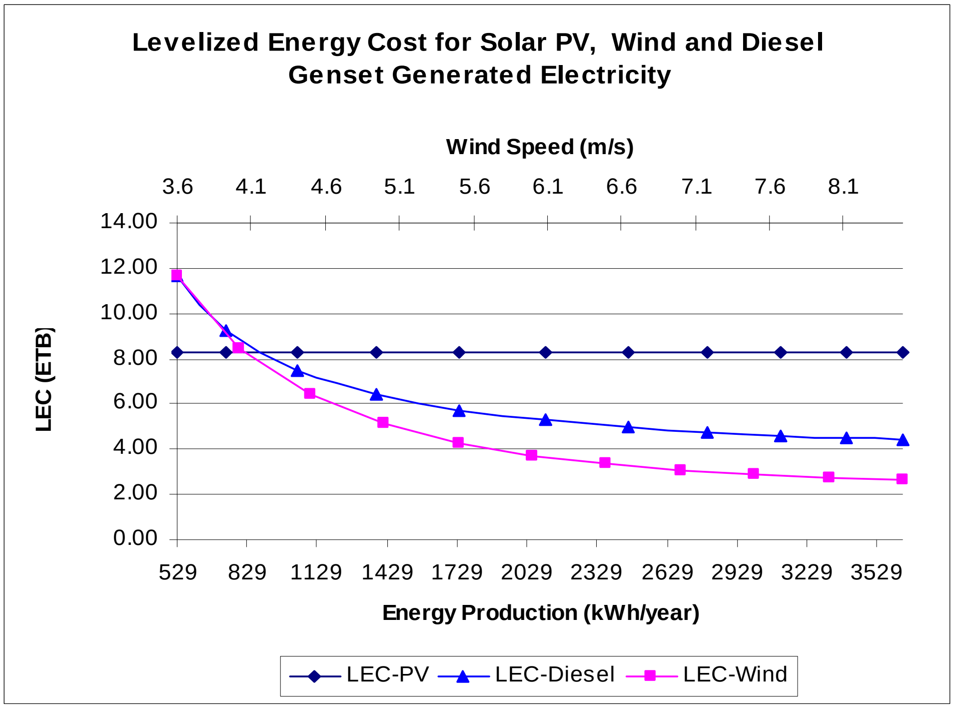
In the above example, the LCC for the wind generator does no change much for various output levels. Subject to the available annual mean wind speeds the annual energy that can be generated from a wind turbine varies. The same wind generator can generator more energy at high wind speeds without incurring much cost on the system. Since this is a standalone system, it is the cost of the battery bank that makes the change in the LCC.

Fig. 5 above provides an indication to the required capital and investment cost in the life time of a wind generator, solar PV and diesel genset. LCC of wind electricity generation system can be the most capital intensive means of electricity generation if operated in low wind regions. It can also be the cheapest alternative in high wind areas.

The Levelized Energy Cost (LEC) for the above example is presented in Fig. 6 below. Operating in annual mean wind speeds less than 4.5m/s, BWC XL.1 wind generator costs more for kWh of electricity generated compared to other alternatives such as solar PV or diesel gensets. At higher wind speeds, wind electricity becomes the most attractive means of power generation.

[42] See Annex XXXX for calculation of LCC and LEC

Fig.6:- Levelized Energy Cost for Solar PV, Wind and Diesel Generated Electricity.



3.3.3 Grid based Wind Electricity Generation – Wind Farms

This section primarily refers to the wind resource available for development of wind farms. The size of individual wind generators that are usually considered for medium to large size wind farms have rated power outputs that range from few hundred kilo watts to mega watts. Optimal size of each individual turbine is determined according to factors such as access road, crane capacity, and local experiences for routine O&M.

The land area with a wind resource that is suitable for wind farm development in Ethiopia amounts to 20,290 square kilometers. As described in Section 1.2.1.iii above the total wind resource potential for grid based electricity generation is estimated to be 10.6 million Tcal per year (890TWh per year).

Financial analysis was developed for a hypothetical wind farm composed of 20 turbines using RETScreen software. The size of turbine units was determined using the suggestions made by Lahmeyer International, from their experience in the feasibility study conducted for Wind Park Development in Ethiopia[43]. Enercone-48 model wind turbine with 800kW rated power, 50m hub height and 48m rotor diameter was assumed in this example. The total plant capacity is 16MW with expected life time of 25 years. The site is assumed to have an annual mean wind speed of 7.5m/s (i.e. 500W/m^2). Based on Rayleigh wind distribution (i.e. shape factor, k=2) the annual energy that can be delivered from the wind plant is 32,872MWh. The energy generated by the wind farm would help reduce the energy cost that thermal generators would have consumed to generate same amount of electricity. The model further assumes an 75% match for displacing use of thermal generators. In other words, the avoided energy cost is 75% of the energy generated by the wind turbines that would have been produced otherwise

[43] Feasibility Study for Wind Park Development in Ethiopia and Capacity Building, Mesobo-Harena Wind Park Site, Part I & II, Final Draft Report, Lahmeyer International, June 2006

by thermal generators. See detail inputs such as cost assumption, dept/equity ratio, inflation, etc. in Annex 9.
The table below shows the output of RETScreen model for financial feasibility indicators for the project.

Table 7:- Summary of Financial Indicators

Financial Feasibility		
Plant Capacity	kW	16,000
Energy generated	MWh/yr	36,872
Initial Plant Cost	ETB	246,801,052
Cost per installed Capacity	ETB/kW	15,425
Energy production cost	ETB/kWh	0.638
IRR	%	13.5%
Simple Payback	yr	11.4
Year-to-positive cash flow	yr	11.4
Net Present Value - NPV	ETB	40,216,613
Annual Life Cycle Saving	ETB	4,430,588
Benefit-Cost (B-C) ratio	-	1.54
GHG emission reduction cost	ETB/t_{CO2}	-4,723

In this example the firm energy production cost from wind is ETB0.64/kWh. Compared to the generation cost of electricity from hydro based systems, ETB 0.36/kWh, wind electricity is not financially feasible[44]. However, if the wind plant is considered to displace certain percentage of electricity generation from the thermal plant whose energy production cost is ETB 0.96/kWh, wind electricity can be considered as a feasible alternative. The benefit from carbon financing is actually a loss as the net balance for the up-front and periodic cost exceeds the revenue that can be obtained from sales of certified emission reductions.

[44] Average firm energy generation cost for hydropower and thermal systems are ETB 0.36/kWh (EEPCO) and ETB 0.96/kWh respectively. (Source: EEPCO)

4 Potential barriers for wide-scale dissemination of solar and wind energy technologies

About ninety nine percent of rural households in Ethiopia are still without access to electricity. These households depend on inefficient and polluting energy sources such as biomass for cooking, kerosene and wax-wick for lighting. Renewable energy technologies could have bigger roles to play if proper consideration is given to them. In spite of high upfront costs and absence of a market infrastructure, Solar Home Systems have become increasingly attractive in terms of providing reliable and high quality service compared to the traditional sources of energy. The market for renewable technologies is huge but the market infrastructure needs to be developed if this huge potential is to be addressed. Currently there are a number of market barriers that deter a wide-scale dissemination of solar and wind energy technologies in Ethiopia. The major barriers are technical, capacity, information, economic/ financial, institutional, and policy.

Technical barriers:

- Lack of locally developed adapted technologies that fit with local conditions
- Lack of training facilities
- Lack of maintenance facilities
- Absence of national standards for solar and wind energy

Capacity barriers

- Inadequate technology development and adaptation capacity
- Weak technical expertise
- Limited participation of private sector

Information barriers

- Lack of successful pilot projects that can show the benefits of solar and wind energy technologies to be replicated
- Lack of awareness about the positive economic (on the long-run) and environmental impacts of solar and wind energy technologies
- Lack of awareness media programs
- Inadequate dissemination efforts
- Missing or inadequate feed back mechanism

Economic/financial barriers

- Abject poverty and therefore lack of affordability
- High product cost (due to lack of scale)
- High cost compared to competing technologies
- High payback period
- Financing difficulties due to the absence of targeted credit facilities for supplier, end-users
- Absence of development activities to reduce prices of such technologies
- High interest rate

Institutional barrier

- Lack of horizontal and vertical cooperation among institutions
- Institutional inadequacies at all levels

Policy Barriers

- Absence of solar and wind energy development strategy

- Absence of national direct and indirect support programs
- Competing products subsidized
- Environmental laws not strictly applied

These barriers not only reduce the size of the market but also reduce the economic potential by swelling the cost of the technology. The actual size of the market for renewable technologies to a greater extent depends on how well these barriers are addressed. Awareness of the benefits and impacts of solar and wind energy technologies by final consumers and promoters, building technical capacity of local technicians and the market infrastructure, putting appropriate financing mechanism in place and providing an integrated barrier removal approaches through policy supports will have a vital impact in realization of the full size of the market for these technologies.

5 Review of national energy policies and strategies

Energy is a key input for economic and social development. This means the development of energy policy must be guided first by the principles of the national economic policy and then it has to be consistent with sectoral and multi-sectoral policies. Policies that have direct impact or that are directly impacted by energy policy include policy on national resources and environment, policy on science and technology, policy on water resource management, and policies on health and education.

The National Economic Policy, *November 1991*

The National Economic Policy was issued in 1991. This policy set the principles for all sectoral and multi-sectoral policies drafted since. Although the Economic policy is fourteen years old and its contents may need revision, its basic principles still apply. The policy shifted the role of government in the economy from one of centrally planned and executed to one that is market based and private sector led.

- The policy also gave stress to peoples' participation in development. This indirectly brings the issue of decentralization in the development process (which was later taken up as a key development strategy and democratization process).
- Mobilization of external resources was also addressed in the policy. This stemmed from the recognition that internal resources would not suffice to bring the required rapid and sustained development.

The Rural Development Strategy*, November 2001*

The Ethiopian economy is based on agriculture.[45] Productivity and outputs in agriculture are low. These two basic facts lead to the conclusion that productivity in agriculture must be increased rapidly to ensure then enhance the livelihood of millions. Rapid transformation of the agriculture sector will also benefit the industrial and service sectors through direct linkages to them.

The goal of the Rural Development Strategy (RDS) is therefore enhanced productivity in agriculture. The following are the main strategies identified to achieve this goal:

- Agricultural intensification,
- Agricultural diversification,
- Agro-ecologically optimized land use,
- Irrigation, and
- Application of labor-intensive technologies

The strategy recognizes productivity and outputs depend on inputs and markets. This recognition has led to the formulation of strategies for development of the physical infrastructure and to improving access to finance (to improve access to agricultural inputs and to markets).

Energy is recognized to be an essential rural infrastructure. The strategy explicitly addresses the issue of rural electrification and proposes RE implementation by both the public and private sectors. **Solar and wind energy are specifically addressed in the strategy as potential alternatives for rural electrification (p. 231)**. The strategy pointed out that the

[45] Agriculture constitutes 50 percent of GDP and is the base for the industry and service sectors. More importantly, 85 percent of the population derives its livelihood from agriculture.

participation of the non-government sector would be crucial in the application of solar and wind energy in rural areas.

- The strategy also underlined the fact that the proposed communication and information infrastructure cannot be run without electricity. This means that in many cases electricity infrastructure may have first priority.
- For the traditional energy sector, the strategy proposes sustainable resource management and utilization.

The Natural Resources and Environment Policy (1994)

In relation to the energy sector, this policy raises the issue of biomass energy sustainability. The policy assessment has identified non-sustainable exploitation of biomass resources as one of the key issues for policy. Non sustainable exploitation of forests for fuel is indicated to have contributed to erosion, degradation of water quality and loss of biodiversity.

The inter dependence of the biomass energy system and the agricultural production system is recognized. The negative manifestations of the use of agricultural residues and animal dung for energy are indicated as contributing to soil nutrient loss and declining productivity.

The policy recommendations for mitigation of the non-sustainable biomass energy use include:

- Production of woody biomass on farm and homestead, and on private wood lots,
- Distribution of improved biomass stoves,
- Provision of substitute fuels for biomass,

Science and Technology policy, 1993

The objective of the policy is capacity building in generation, development, use and dissemination of appropriate technologies to contribute towards national development goals.

Rationale and efficient utilization of natural resources (with respect to biomass energy utilization) is addressed in the policy. Wider dissemination of renewable energy technologies is also recommended.

The amended Investment Proclamation (No. 116/1998)

The Investment Proclamation governs internal and external investment in Ethiopia. The general investment regulations apply also for the energy sector. However, the power sector is dealt with particularly in the Proclamation where foreign investment is limited for certain power generation facilities:

- Electricity generation from sources other than hydropower is reserved for the government and local developers. Development of non-hydro plants larger than 25MW is left to the government while those below this are left for the local private sector.
- The government remains the sole operator of the national grid
- Electricity generation from hydropower is open to both local and external developers without limit on capacity.

The National Energy Policy, 1994

The goal of the energy policy is the provision of reliable and affordable energy for national development. The link between energy and development and the issue of environmental sustainability were recognized by the policy. *The general policy direction was towards a least-cost, indigenous resource based and environmentally sustainable development for the energy sector.*

The policy has addressed issues of energy resource development, energy supply, energy conservation, environmental sustainability, research and development, and institutions. The following ten policies are the core on which sectoral policies were based:

1. To enhance and expand the development and utilization of hydrological resources for power generation with emphasis on mini hydropower development.
2. To promote and strengthen the development and exploration for natural gas and oil;
3. To greatly expand and strengthen agro-forestry programs;
4. **To provide <u>alternative</u> energy sources for the household, industry, agriculture, transport and other sectors;**
5. To introduce energy conservation and energy saving measures in all sectors;
6. To ensure the compatibility of energy resources development and utilization with ecologically and environmentally sound practices;
7. To promote self-reliance in the fields of technological and scientific development of energy resources;
8. To ensure community participation, especially the participation of women, in all aspects of energy resources development and encourage the participation of the private sector in the development of the energy sector.
9. To stage popularization campaign through mass media using various national languages to create awareness among the general public and decision makers regarding energy issues; and,
10. To create appropriate institutional and legal frameworks to handle all energy issues.

The policy priorities were hydropower development for the power sector, energy efficiency, and transition to modern energy services for the household sector. These objectives were to be met through wider private sector participation and within the principles of environmental sustainability.

Policies on solar and wind energy are addressed in the policy under “Energy Resource Development.” Two policies were stated:

- Solar and geothermal energy will be used, wherever possible, for process heat and power generation [6.1.3 (1)]
- Ethiopia's wind energy resources will be developed to provide shaft power for water pumping and irrigation [6.1.3 (2)]

The rural electrification strategy, 2002

The strategic goal (development goal) of the strategy is stated as reducing poverty. This is to be effected with the delivery of rural electrification by stimulating economic activity and improving access to better social services. Rural electrification is expected to

- Improve the productivity of rural productivity activities,
- Improve access to better social services (communication, water health, and education),

- Reduce environmental impacts,
- Promote private sector participation,
- Extend services to previously under served nomadic and pastoralist population.

The strategy proposed three basic rural electrification approaches: grid extension by the public utility (EEPCO), private sector led off-grid electrification, and **promotion of new energy sources**.

Photovoltaic based electrification is recommended for isolated and dispersed electricity requirements. It is recognized that PV can meet energy requirements from the household, commercial and social sectors cost effectively. The strategy underlines that for successful dissemination of the new energy sources three basic factors have to be fulfilled: capacity building for promotion of these sources, affordable finance, and cost recovery tariffs.

A new institutional framework is recommended for effective implementation of the strategy. The main recommendation was the setting up of a new Rural Electrification Fund (REF) to direct the operation of the off-grid part of the strategy. The functions of the REF would be promotion, financing and technical assistance of off-grid rural electrification projects.

Rural Electrification Fund Establishment Proclamation (Proclamation no. 317/2003)

The Rural Electrification Fund (REF) was established based on recommendations of the Rural Electrification Strategy. The non-government sector is recognized to be the main actor for off-grid rural electrification. The Fund is established to promote private sector participation through the provision of accessible finance and technical assistance.

The Fund is overseen by a Rural Electrification Board (REB) and its day to day activities are carried out by the Rural Electrification Secretariat (RES). The Fund will be financed partly from the Ethiopian government and partly by external donors and lenders.

The REF proclamation states that **priority will be given to electrification through renewable energy sources**.

The Draft Rural Energy Strategy, 2004 (not in effect since not approved by the government)

A rural energy strategy has been drafted by the EREDPC in 2004. This is an example of a sectoral strategy only partially based on the energy policy. This strategy analyzed development policies and strategies, including the Rural Development Strategy, and other cross-sectoral policies in some detail. There was some stakeholder consultation on the strategy as well.

For Rural Electrification, the strategy recommends solar and wind energy for “decentralized mini-grid” and “auto-generation or home” systems. It recommends

- Helpful regulations for the import and distribution of solar and wind energy technologies, and
- Technology transfer for production of solar and wind energy technologies

Shortcomings of the energy policy

The rural sector is omitted in the policy. The greatest drawback of the policy is its total disregard to the rural sector. Rural areas are mentioned only once in the policy document and only in relation to "appropriate rural transport technologies." This flaw has made the policy analysis overlook resources and technologies that would be suitable in the rural setting. If the rural energy sector was analyzed in some detail, the roles of solar and wind energy in delivering key services would have been brought out.

The policy was not based on detailed needs analysis. The policy makers seem to have followed a top down approach where little demand analysis was made at sub sector level (for example the rural sub-sector). Such analysis would have shown the specific demands that would be best served with small decentralized solar and wind systems.

Some policy statements are imprecise where "alternative" encompasses diverse resources and technologies. The policy considers solar energy for thermal and power uses. However, this policy statement seems more related to geothermal than to solar: process heat (unless as pre-heating) is not usually considered feasible with solar energy; and the term "power generation" is usually applied for large-scale power projects.

The policy was formulated based on inadequate information. Wind energy is proposed for mechanical applications only. The role of wind energy was limited to mechanical power because the available data at the time indicated wind speeds to be below 5m/s for all parts of Ethiopia. This is an example of policy made on inadequate information; had some of the information available now was available at the time wind energy would have been proposed for electrical power as well.

No strategies were set for private sector participation. Another failure of the policy is its lack of strategies for its policy statements (at least as indications). For instance, although private sector participation (and incentives) is stated as a major policy there is no indication in the document how this may be achieved. This issue and the next, that of financing, are interrelated: the main reason for private sector participation is to mobilize private resources to reduce government budgetary burdens.

Financing was overlooked. Resource mobilization, and specifically finance mobilization, is a critical issue for any sector development. This issue has however not been addressed at all in the policy.

The international context was overlooked. Issues such as oil supply, foreign investment, globalization, and regional trade have not been adequately addressed. These international issues change constantly and there is a need for revision of the policy to address current realities.

Current concerns were not reflected. Poverty eradication is the single most important agenda for action for the government. The role of energy in poverty reduction should be addressed in some depth. However, at the drafting of the policy the issue had not come to the forefront.

There was no comprehensive framework for policy. A full assessment of policy issues requires a good framework for analysis. This seems to have not been in place when the policy was drafted. Policy is the outcome of policy analysis, stakeholder consultations, and policy formulation. Policy analysis in particular requires problem definition, demand and supply forecasting, scanning of external environment, identification of alternative courses of action and systematic evaluation of alternatives. The Ethiopian energy policy seems to have not followed such a systematic framework for analysis.

Strategies for policy implementation were not developed after the policy. Policies are formulated with certain assumptions and expectations of the future (both internal and external). However internal and external factors may develop in ways not foreseen by policy makers at the time of policy formulation. This means policies have to be revised when significant changes occur on their basic assumptions. In regard to the Ethiopian energy policy, a number of important changes have occurred since 1994 including poverty reduction as the main goal of government, political and economic decentralization.

Renewable energy strategy

The discussion above clearly shows that there is need for a new energy policy. The new policy must go through the complete policy management process: policy process design, analysis, formulation, stakeholder consultation, implementation, and monitoring and evaluation. The policy analysis must address:

- Energy demands separately for rural and urban areas,
- All available sources of energy including solar and wind energy,
- The external environment (energy security and macro-economic stability, regional trade)
- The role of energy in poverty reduction, and
- Resource needs, including finance, for policy implementation.

Sectoral strategies usually stem from energy policies since the rationale for a sectoral strategy depends on its potential contribution to meeting policy goals. In the Ethiopian context, since there are serious gaps in the Energy Policy the Renewable Energy Strategy cannot be based on the existing policy. On the other hand, since the policy process from initiation to implementation can take over two years, the drafting of the strategy cannot wait for the revision of the Energy Policy either. **For this reason a compromise solution would be to draft an interim renewable energy strategy now.** Solar and wind energy will have a central role in this Renewable Energy Strategy.

Development of a renewable energy strategy is outside the scope of this assignment. A brief outline of the goals, rationale, challenges for the strategy are provided below.

Goals for the revised energy policy

The goal of the existing energy policy is *a least-cost, indigenous resource based and environmentally sustainable development for the energy sector.* The policy goals for the revised energy policy may be summarized with the following:

a. Poverty reduction
    - Economic and social development
b. Energy security (macroeconomic stability)
c. Sustainability
d. Governance (including decentralization)
e. Economic efficiency
f. Effective energy institutions

Rationale for the renewable energy strategy

The rationale for the Renewable Energy Strategy (and solar and wind energy) is that renewables will contribute directly and significantly to five of the six policy goals: poverty reduction, energy security, sustainability, governance, and economic efficiency.

Solar and wind energy vs. poverty reduction. In dispersed rural settlements solar and wind energy will be the only viable (physically and economically) options for delivery of essential services. These services include electricity for water pumping, health institutions, schools, and for the home[46].

Solar and wind energy vs. energy security. Solar and wind are indigenous resources. They lower vulnerability to adverse external changes. Changing priorities at the international stage where renewables are now in the forefront means countries have to build their capacity to produce and use these technologies effectively.

Inclusion of solar and wind energy in significant scale into the national energy supply mix will ameliorate unpredictable shortfalls in supply to environmental and other factors. For example, in the case of the power grid exclusive reliance on hydropower will result in shortfalls during particularly dry seasons.

Solar and wind energy vs. sustainability. Solar and wind energy have considerably lower negative environmental impacts than the conventional sources they replace. Replacement of kerosene lamps with PV home systems remove indoor pollutants from the home, reduce fire hazards and GHG, replacing diesel engines for electricity generation and water pumping reduce GHG.

Critical rural services such as water supply, inputs for health clinics and schools are vulnerable to unreliable energy supplies due to poor physical infrastructure. Roads are impassable during the wet season, this means fuel delivery cannot be relied on. Decentralized energy service technologies like solar and wind surmount this problem.

Solar and wind energy vs. decentralization. Solar and wind energy technologies are particularly suited for decentralized application therefore decentralized management.

Solar and wind energy vs. economic efficiency. Solar and wind energy technologies are the least-cost options for scattered rural settlements and communities. Replacement of petroleum with solar and wind energy can save households and commercial establishments resources they would use in other productive undertakings.

Challenges and actions for the renewable energy sector

The issues that need addressing in the renewable energy strategy (and for solar and wind energy) may be grouped into two:

a. <u>Development challenges</u> relate to two of the six policy goals: that of improving access to energy to reduce poverty and to ensuring energy security through a balanced supply mix with renewables.

   In terms of poverty reduction impacts, the priority areas for solar and wind energy application will be the social sectors of water, health, education and communication in rural areas. Solar and wind energy are the least-cost options for these services in many of the scattered rural settlements in Ethiopia.

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[46] These services are related to three of the Millennium Development Goals (MDGs): reducing child mortality, improving maternal health, and universal primary education.

- The government should promote PV and wind energy for water pumping, PV for solar water heating for health and education sectors, and PV for rural communication facilities.

Improving access to electric lighting and audio-visual media in the home extends the working hour for adults and the time for learning and information for both adults and children. This increases the productivity of the current generation and builds the capacity of the next generation.

- *The government should work towards mass dissemination of PV for rural lighting and audio-visuals.*

In regard to the issue of a balanced supply mix the issues may be looked at the centralized system level (the electric grid) and the decentralized level. Large-scale deployment of solar and wind energy in rural areas improves supply diversity at national level.

Supply diversity must also be ensured for the electric grid. The generation mix for the grid must be diversified to include solar and wind energy (and other conventional and non-conventional sources). Generation costs for solar and wind energy are declining while that for oil is increasing. Grid connected wind may be competitive to oil based systems at present, and grid connected PV will become competitive within 20 years.

- *The government should carry out feasibility studies for grid connected wind and PV.*
- *The government should pilot projects for grid connected wind and PV to collect resource and technology data as well as to build human and institutional capacity in planning, building, and operating of such systems.*

b. The <u>institutional challenges</u> relate to dealing with the *information, financing, capacity, and policy* barriers. Effective energy institutions will resolve the capacity barrier (of people, systems and institutions); the information barrier (information gathering, analysis and dissemination); the financing barrier (rationale pricing, incentives, affordable supplier and user finance).

Capacity building is key to any undertaking. For the development of solar and wind energy as well institutional and human capacity must be built in policy and strategy formulation, information management, planning, development, operation and management of systems.

- *The government should build the capacity of one institution to manage renewable energy development in the country.*
- *The government should work to enhance the capability of this institution in information management for solar and wind energy resources and technologies.*
- *The government should build the capacity of stakeholders in the planning, development, operation, and management of solar and wind energy systems.*

Inadequate **information** leads to inappropriate policies, plans and actions (see discussion of the energy policy). For this reason an adequate information base must be set up for the energy sector as a whole.

- *The government should systematically acquire and analyze solar and wind energy resource data for potential sites in the country.*
- *The government should continuously document the state of the art in solar and wind energy technology.*
- *The government should disseminate information about the benefits and costs of solar and wind energy.*

Large-scale deployment of solar and wind energy is justified in economic terms (for certain applications and areas, of course). However, their high initial costs are a barrier for a large section of potential users for using them and a barrier for suppliers to produce or import them in economic volumes. The challenge is therefore to provide affordable finance for both suppliers and users of solar and wind energy.

- *The government should provide affordable finance for suppliers.*
- *The government should facilitate the provision of affordable finance for users.*

6 Financing Mechanisms for Wide Scale Dissemination of Solar Energy Technologies

In the initial stage of renewable energy technology development and dissemination, information barriers (lack of awareness of new technologies at all levels), and technical (technology know-how) barriers dominate. Following that, financial, institutional and policy barriers become major limitation in realizing the full market potential by hindering the market penetration of the technologies. A sound strategy for a wide-scale dissemination of solar and wind energy technologies will need to address all these barriers.

The most important barrier to a high market penetration of solar and wind technologies is the cost of the technologies. Renewable energy technologies in general are considered to be more expensive than conventional source of energy that they are competing against – such as genset and grid electricity. This is mainly because renewables are competing with conventional energy sources in unleveled field. Solar and wind technologies are not fortunate enough to get the support mechanisms including subsidy and well-developed infrastructure that conventional energy sources are obtaining. Externalities such as cost of environmental impacts are not included in the pricing of energy from conventional fuels and technologies that solar and wide technologies are competing against. Upfront cost of solar and wind energy technologies in addition to the public perception towards these technologies make access to finance difficult.

In order to address finance as a barrier for developing solar and wind technologies, several financial support mechanisms have been developed and tried in many countries.

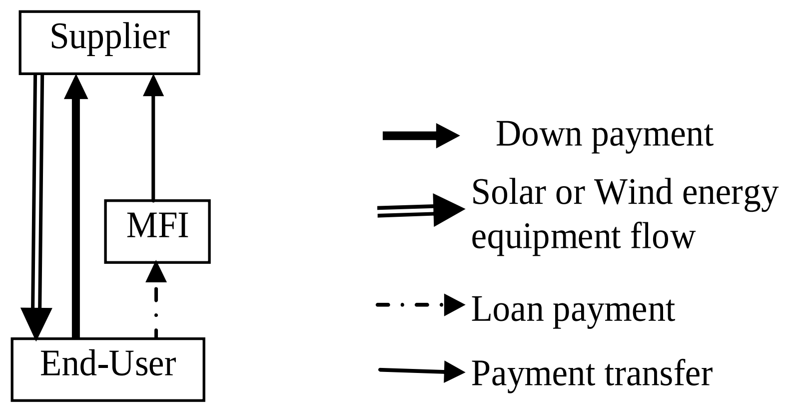
End-User Financing

The rationale behind end-user financing is to enable the large percentage of rural households and business to access modern energy sources through credit schemes. It should be noted that only very few percentage of rural end-users afford solar and wind energy technologies through cash payment of the full upfront cost.

End-user financing discussed in this section is basically to address financial barriers for decentralized individual systems. It includes use of individual solar or wind home systems for residence or business without excluding commercial and cottage industrial application. Financial support mechanisms in this case can be provided by making credit facilities available for the capital cost of equipment or through providing services for fee.

Traditionally, equipment suppliers provide credit for their customers and it is the responsibility of suppliers to supply a reliable technology as well as to ensure the collection of the credit. Such method of credit scheme is called Hire-Purchase. Taking advantage of the experience and strategic position of Micro Finance Institutions (MFIs) in rural communities, a third-party financing approach allows an end-user to purchase a solar or wind technology equipment from a supplier through credit provided by a MFI. If credit is provided by the supplier itself, collection of loan can be effected through MFI as an intermediate institution for agreed amount of charges.

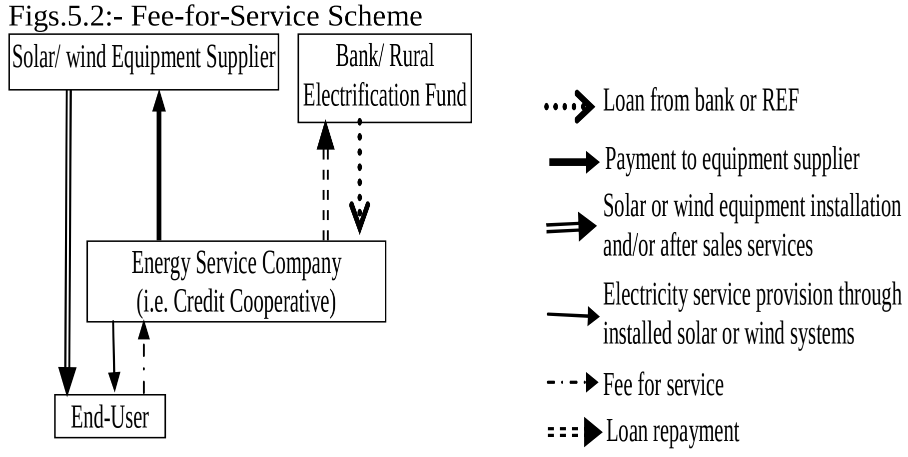
Fig. 5.1: Hire Purchase Scheme



In hire purchase schemes, solar or wind energy technology user takes loan from a MFI (or supplier) to purchase a system which he/she becomes owner of the system after paying off the disbursed loan. The main role of MFI in this case is disbursement of credit for pre-financing of the systems and administration of the collection. This should be seen by MFIs as an opportunity for diversification of new loan portfolio.

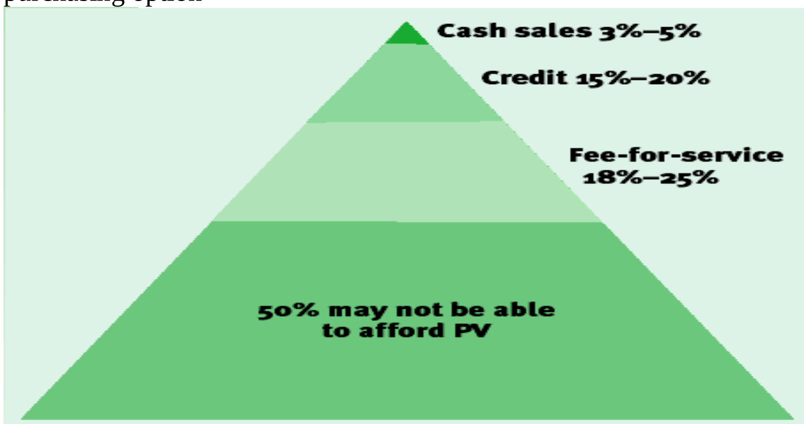
In a fee-for-service scheme the solar or wind energy technology user will only pay for the electricity service. The user will not be owner of the system and hence does not need to worry about the high upfront cost of investment (capital cost) on the system. Energy Service Companies (ESCO) can be electricity suppliers by installing systems and charging the user only an agreed amount of fee for the electricity service provided. Microentrepreneurs, service cooperative or even MIFs can be ESCOs.

Figs.5.2:- Fee-for-Service Scheme



Experiences of Asian and Latin American countries indicate that availability of credit facilities increase market size of solar and wind energy technologies. Studies made in Indonesia estimated that a fee-for-service option would expand the market from less than 30% for cash market to at least 70%. Figure xx below shows estimation made by PV developers in one Latin American market. The proportion of end users that can afford solar PV under different purchasing options suggests a tenfold increase over the cash market[47].

Fig. 5.3: Proportion of end users that can afford solar PV under different purchasing option



MFIs in Ethiopia are mostly financing income generating business in areas which they are familiar with. Most MFIs are not familiar with energy technologies though few have some experience in financing diesel-engine driven grain milling businesses. Solar and wind technologies are still unknown to MFIs and are hesitant to finance them. Moreover, interest rates to loan from MFIs are usually discouragingly high for solar and wind energy technology adopters. MFIs in Ethiopia should reconsider their lending policies diversifying loan portfolios to include renewable energy systems. It is also an opportunity to make use of funds available from government and other international organizations for environmental and rural electrification where by loans with special interest rates (i.e. loan subsidy) could be available for renewables. Lessons must be learned form MFIs in other countries that are successful in wide-dissemination of solar and wind technologies by addressing finance barriers.

Capital Subsidy

One reason for the seemingly high cost of renewable energy technologies are subsidies that are available for conventional energy sources and un-paid costs for traditional fuels. Solar and wind energy technologies should also get subsidy benefits in order to be cost competitive to conventional fuels and achieve an increased market penetration. If subsidies, however, are not appropriately disbursed they may distort the market and could deter the commercial dissemination of the technologies.

[47] Renewable Energy for Micro-enterprise, NREL, November 2000

Indian Experience

India has one of the most comprehensive renewable energy program, which includes promotion of SHS. The support has been through capital subsidy. In the initial stage of the program the SHSs enjoyed a relatively high take off. But the market was limited to the sales through the program as the budget available for the subsidy was limited. The credit market could not also develop as capital subsidy distorted the market. In addition to this, very long and tiresome processes to claim subsidy delays the disbursement which in turn retards the dissemination rate.(Source: J.P.Painuly)

Subsidies linked to credit schemes available from financing institutions like Micro-Finances or Credit Cooperatives, could advance the commercialization and dissemination of solar and wind technologies.

Sri Lankan Experience:

Uva Provincial Council, the least electrified province in Sri Lanka, set a precedent in 2001 by re-allocating funds for rural grid extension to subsidize solar PV systems. The Province found it more economical to subsidize solar PV systems in partnership with the private sector rather than funding the Ceylon Electricity Board, Sri Lankan electricity utility, to extend the grid. The Province offered a subsidy to off-grid households to purchase a SHS. The companies signed an agreement with the Province to receive these funds once the systems were sold for the subsidized amount and proof of installation was submitted. In most of these sales there was an involvement of an MFI to provide micro financing. Over 5000 systems were installed in 6 months in the province under this scheme. Other provinces in Sri Lanka adopted this initiative to follow on. With all these initiatives a total of about 25,000 SHS were sold in Sri Lanka.(Source: Gunaratne)

7 National Demand and Supply Assessment

7.1 Assessment of demand and supply

The objective of this sub task is to estimate current and projected demand for energy at the national level for the long term (30 years). Three energy sector development scenarios were developed to illustrate the Reference development path and alternative sector developments where solar and wind energy will play significant roles.

This task required assessment of demands and supplies at aggregate national level. A single framework of analysis is required for projection of demand, supply capacities, resource flows and GHG abatement potentials. The Long-range Energy Alternative Planning (LEAP) model is used to make the demand and supply assessment.

Overview of the LEAP model

Energy models are generally classified into three: accounting models, optimisation models, and general equilibrium models. The difference among the models lies in how they deal with energy prices. In accounting models, the effect of energy prices in market allocation for fuels is considered outside the model while in the others energy prices are considered inside the models.

- In accounting models market shares for energy carriers is determined externally from the system. The analyst determines the potential effect of relative prices among energy carriers and he inputs this information into the system.
- In optimization models, energy prices determine market allocation for energy. In fact, the objective function for optimization is often formulated as a search for the least-cost option among alternatives.
- General equilibrium means equilibrium in product as well as capital markets. This means demand equals supply, i.e. product and service markets clear (all producers provide their products at the prices consumers offer). General equilibrium energy models are used to determine market-clearing prices for energy.

LEAP is an Accounting Model. It is a tool for energy data management as well as analysis. LEAP uses process analysis to represent the energy system. In process analysis energy demand, supply, and resource processes are represented in detail in the system.

LEAP variables & modules	*Description*
Basic parameters	Basic parameters set the scope in which the model operates. Basic parameters include • Base year for analysis • The projection period • Energy units • Currency
Key variables	Key variables are demographic and economic variables used for analysis of the energy system (such as Population, Household size, GDP). Instead of putting values for these variables inside demand or transformation branches, the variables and their values are set once in

	Key Variables. These variables are then referred to in the demand and transformation branches by name. This serves two purposes: first it enforces consistency (for example, users won't set different values for the same variable in the same scenario) and second it simplifies analysis.
Demand	In the Demand module energy demand is broken down into sectors, sub-sectors, end uses, and end use devices. At each branch, *Activity levels (which are social and economic variables)* are specified and for the last branch (end use/technology level) final energy intensities are specified. An example is shown below for the Household sector Households (sector) = 14 million Urban (sub sector) = 15% of Households Cooking (end use) = 95% of Urban Households Fuelwood stove = 18%, energy intensity = 26 GJ/H-H Charcoal stove = 25% , energy intensity = 7.4 GJ/H-H Kerosene stove = 55%, energy intensity = 5.8 GJ/H-H
Transformation	Transformation represents energy conversion, transmission and distribution technologies in the system. Transformation analysis involves grouping conversion and transportation systems into Modules. Modules are energy conversion sectors in the energy system such as power stations in the grid, oil refining or charcoal production. Each of these Modules may consist of several conversion technologies: for example, the Electricity Generation module may consist of Hydropower plants, diesel plants or geothermal plants. These conversion technologies are called Processes in LEAP.
Resources	Resources are divided into Primary resources and Secondary fuels. The requirements for resources is automatically generated by LEAP from fuels consumed in the Demand branches and produced in Transformation. The type of data entered by the analyst in Resources include Reserves (for fossil fuels), annual yields (for renewables), costs of indigenous production, imports and exports.

Basic parameters

The first task in energy system analysis is LEAP is to set the scope and units of analysis for the study. As indicated in section 7.1, the main parameters to be set are the base year, the projection period, energy unit, and the currency.

a. Base year

The base year (the Current Accounts Year) is the year for which demand, transformation and resource data is input into the model by the analyst. The data and structure of the energy system in Current Accounts serves as the initial point for all subsequent scenario analysis.

The base year must has as complete a dataset as possible. For Ethiopia, the year 1998/99 is chosen to be the base year since that is the year for the latest National Energy Balance. The year is also far back in the past for any additional data that may be required yet recent enough to reflect current realities.

b. Projection period

For this particular assignment, LEAP is to be used to indicate the potential of Solar and Wind Energy in Ethiopia's energy system. Realization of solar and wind energy systems in any significant scale in Ethiopia will take at least a couple of decades. For this reason the period of analysis (the projection period) is taken to be 30 years from the base year.

c. Energy units

The Ethiopian National Energy Balance is reported in Tera Joules. For ease of validation and consistency, the Joule is used in this assessment as well.

d. Currency

The Ethiopian currency Birr is used.

Key variables

The driving variables for energy demand are Households, Sectoral GDP (Value Added), Transportation performance, and land area under cultivation. These driving variables are therefore put in Key Variables for the reasons explained in 7.1. The values for some of the variables are set as constants in Current Accounts (base year) while some are derived from the other variables. For example, *Population* and *Household Size* are set as constants for the base year while *Households* is derived as *Population/Household Size*. The complete list of the Key Variables is listed in Table 7.1.

Table 7.1

Key Variables

Key variable	Expression	Scale	Unit
Population	61.672	Million	Persons
Population Urban	Population*0.147	Million	Persons
Population Rural	Population-Population Urban	Million	Persons
Household size	5		Persons
Household size Urban	4		Persons
Household size Rural	7		Persons
Population Urban Growth_Rate	4.7		%
Population Rural Growth_Rate	2.6		%
End Year Urbanization	25		%
Households	Population/Household size		Households
Households Urban	Population Urban/Household size urban	Million	Households
Households Rural	Population Rural/Households size Rural	Million	Households
GDP	15.460	Billion	ETB
GDP Agriculture	GDP*0.447	Billion	ETB
GDP Industry	GDP*0.117	Billion	ETB
GDP Service	GDP-GDP Agriculture-GDP Industry	Billion	ETB
Income	GDP/Population	Thousand	ETB per year
Income Agriculture	GDP Agriculture/Population Rural	Thousand	ETB per year
Area under agriculture	10	Million	ha

Energy demand

The only available data for national level energy demand and supply is the Ethiopian National Energy Balance from the Ethiopian Rural Energy Development and Promotion Center (EREDPC). The latest available National Energy Balance from the EREDPC is for 1998/99 (1991 EC). For this assessment, the demand sectors and sub-sectors for the LEAP model are made to closely conform to this balance. Energy consumption totals by sector from the model are validated to closely agree with that of the Energy Balance. However, it should be noted that models are not used to replicate historical data; they are used to analyze policy options and to gain insight into benefits and impacts of alternative scenarios.-For this reason, it should not be expected for model outputs to be exactly the same as in the Energy Balance.

The National Energy Balance divides energy consumption into five sectors: households, agriculture, industry, transport, and services. Each of these sectors is then further divided into sub-sectors.

For modeling purposes there is need to disaggregate consumption down to end use level. For each end use, *Final Energy Intensities* are estimated and these with the socio-economic driving variables (*Activity levels*) determine energy consumption at end use, sub-sector and sector levels.

In the LEAP model energy demand is modeled simply as a product of socio-economic Activity Level and energy intensity.

*Energy demand = Activity Level * Energy intensity*
*Energy demand = Socio-economic activity * GJ/Socio-economic activity*

Energy intensity means energy consumed per capita or energy consumed per unit of economic output. The energy intensity attribute is usually used to express the technological aspect of energy demand – energy intensive industries will show high energy intensities and conservation measures result in reduction of energy intensities (for example in the household sector improvements in household energy efficiency translate into lower energy intensities[48]).

The demographic and economic driving variables include number of households, GDP (and its sectoral components of industrial, agricultural and service sector value added), and area of cultivated land in agriculture. The demand analysis is made using the following sector and sub-sector classifications and demand relations.

Table 7.2

Demand classifications

Sector	Sub sector	Demand relations
Households	Rural	Demand (GJ) = No. of rural households * GJ/household
	Urban	Demand (GJ) = No. of urban households * GJ/household
Industry	Large manufacture	Demand (GJ) = Value Added * GJ/Value Added
	Construction	Demand (GJ) = Value Added * GJ/Value Added
	Mining	Demand (GJ) = Value Added * GJ/Value Added

[48] Note that the energy intensity attribute can also be used to quantify changes in economic factors. For example, change in household income result in higher energy intensities. This relationship may be incorporated into the system by relating energy intensity to income through an income elasticity parameter.

	Small scale	Demand (GJ) = Value Added * GJ/Value Added
Transport	Passenger	Demand (GJ) = Passenger-km * GJ/passenger-km
	Freight	Demand (GJ) = Ton-km * GJ/ton-km
Agriculture	Small farms	Demand (GJ) = Ha * GJ/Ha
	Mechanized farms	Demand (GJ) = Ha * GJ/Ha
	Agro-industries	Demand (GJ) = Tonne * GJ/Tonne
Commercial Services	All	Demand (GJ) = Population * GJ/Population
Public Services	Rural	Demand (GJ) = Rural Population * GJ/Population

Households[49]

The desegregation of energy demand in the Household sector to end use and fuel level is shown in the following two tables. The Household sector is first divided into sub-sectors (Urban and Rural), then the Rural sub-sector is further sub-divided into Electrified and Non-Electrified. This further sub division of the Rural sub-sector is made to simplify policy analysis regarding rural electrification.

Eight household end uses are included in the model: cooking, baking, lighting, water heating, space heating, electric appliances, refrigeration, and air conditioning. All traditional, commercial and alternative energy technologies are also incorporated into the system (this is despite the fact that some of these technologies are currently either no in use or have very small market shares).

Table 7.3

Demand data structure for the Household sector

Activity Level	Final Energy Intensity	Demand Cost	Non Energy Fraction	All Variables

A measure of social and economic activity for which energy is consumed

Name	Expression	Scale	Units	Per
Household	Households	Million	Household	
Urban	Households Urban	Million	Household	
Electrified	100	Percent	Saturation	Of households
Cooking	95	Percent	Saturation	Of households
Kerosene stove	55	Percent	Share	Of households
Charcoal stove	25	Percent	Share	Of households
Wood stove	18	Percent	Share	Of households
LPG stove	1	Percent	Share	Of households
Electric stove	Remainder (100)	Percent	Share	Of households

Activity Level	**Final Energy Intensity**	Demand Cost	Non Energy Fraction	All Variables

Annual final consumption of fuel per unit of activity level (for energy and non energy purposes)

Name	Fuel Name	Expression	Scale	Units	Per
Kerosene stove	Kerosene	2.6/.45		Gigajoule	Per household
Charcoal stove	Charcoal	2.6/.35		Gigajoule	Per household
Wood stove	Wood	2.6/.1		Gigajoule	Per household
LPG stove	LPG	2.6/.6		Gigajoule	Per household
Electric stove	electricity	2.6/.8		Gigajoule	Per household

[49] For detailed assumptions on Activity Levels and Final Energy Intensities refer to Annex E.

Industry

The industry sector is composed of Large Scale Manufacturing, Construction, Mining, Small industries, and Electricity and Water. The sub-sectors under the sector are made to conform to the standard sub-classification used in reporting Industrial GDP.

The Large Scale Manufacturing (LSM) sub-sector is the largest both in terms of Value Added and Energy consumption. This sub-sector is further desegregated by industrial group (Non-durable, Basic material, and Equipment and machinery[50]). The sub-classification of the LSM is made using desegregated Value Added and energy consumption data available from the Central Statistical Authority[51]. The CSA provides industrial data for 15 industrial groups from food and beverage manufacture to machinery and equipment production. These 15 classes can, however, be regrouped into the three sectors mentioned above depending on their energy intensity.

Table 7.4
Demand data structure for the Industry sector

Activity Level	Final Energy Intensity	Demand Cost	Non Energy Fraction	All Variables
A measure of social and economic activity for which energy is consumed				

Name	Expression	Scale	Units	Per
Industry	GDP Industry (real)	Billion	ETB	
Large scale manufacture	42	Percent	Share	Of ETB
Non Durable Goods	67	Percent	Share	Of ETB
Biomass	100	Percent	Saturation	Of ETB
Electricity	100	Percent	Saturation	Of ETB
Motor fuels	100	Percent	Saturation	Of ETB
Thermal Energy	100	Percent	Saturation	Of ETB

Activity Level	**Final Energy Intensity**	Demand Cost	Non Energy Fraction	All Variables
Annual final consumption of fuel per unit of activity level (for energy and non energy purposes)				

Name	Fuel Name	Expression	Scale	Units	Per
Biomass	Wood	0.04		Megajoule	Per ETB
Electricity	Electricity	0.5		Megajoule	Per ETB
Motor fuels	Diesel	0.22		Megajoule	Per ETB
Thermal Energy	Residual Fuel Oil	0.79		Megajoule	Per ETB

Transport

The Transport Sector is divided into Passenger and Freight transport. The Passenger transport sub-sector is further desegregated to Intra-city (meaning transport inside cities) and Inter-city (transport between cities). The driving variable (Activity Level) for Passenger transport is Passenger-km while for Freight transport it is Ton-km.

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[50] The Non-durables group includes food and beverage, tobacco and textiles; the Basic materials group includes non-metallic products, iron and steel, paper, and plastic; Equipment and machinery is for equipment and machinery production.
[51] CSA, Report on Large and Medium Scale Manufacturing and Electricity Industries Survey, 2000.

Passenger-km data for public transport vehicles and Freight-km data for long-distance trucks is from the Ministry of Transport and Communication. For cars and short route freight trucks, passenger-km and Freight-km data is derived from the number of vehicles and assumed load factors (for sources and details see Annex E).

Final energy intensities are given in liters per passenger-km or liters per ton-km. Fuel use per km of travel is converted to fuel consumed per passenger-km and ton-km using average load factors for the vehicles (passengers from Passenger transport, Tons for Freight transport).

Table 7.5
Demand data structure for the Transport sector

Activity Level	Final Energy Intensity	Demand Cost	Non Energy Fraction	All Variables

A measure of social and economic activity for which energy is consumed

Name	Expression	Scale	Units	Per
Transport			No data	
Passenger	5.22+5.75	Billion	Passenger-km	
Intra-city	5.22/(5.22+5.75)*100	Percent	Share	Of Passenger-km
Road	100	Percent	Share	Of Passenger-km
Cars	1.53/5.22*100	Percent	Share	Of Passenger-km
Gasoline	1.51/1.53*100	Percent	Share	Of Passenger-km
Diesel	Remainder(100)	Percent	Share	Of Passenger-km
Hybrid	0	Percent	Share	Of Passenger-km

Activity Level	**Final Energy Intensity**	Demand Cost	Non Energy Fraction	All Variables

Annual final consumption of fuel per unit of activity level (for energy and non energy purposes)

Name	Fuel Name	Expression	Scale	Units	Per
Gasoline	Gasoline	15/100/3		Liter	Per Passenger-km
Diesel	Diesel	15/100/3		Liter	Per Passenger-km
Hybrid	Gasoline	Gasoline*0.6		Liter	Per Passenger-km

Agriculture

The Agriculture sector is composed of Small-scale Agriculture (subsistence farmers), Large Commercial Agriculture (producers of annual crops), and Agro-Industries (Sugar, Tea, and Coffee plantations and processing factories).

The Agriculture sector accounts for 45 percent of GDP. Yet according to the Energy Balance (1999), the sector accounted for only 0.2 percent (or 1497 TJ) of final energy consumption. This inconsistency is explained by the fact that in the Energy Balance only the Large Commercial sub-sector is considered.

Table 7.6
Demand data structure for the Agriculture sector

Activity Level	Final Energy Intensity	Demand Cost	Non Energy Fraction	All Variables
A measure of social and economic activity for which energy is consumed				
Name	Expression	Scale	Units	Per
Agriculture			No Data	
Agro Industrial	0.26	Million	Tonne	
Sugar Plantations	98	Percent	Share	Of Tonne
Bagasse	100	Percent	Share	Of Tonne
Motor fuels	100	Percent	Share	Of Tonne
Electricity	100	Percent	Share	Of Tonne

Activity Level	**Final Energy Intensity**	Demand Cost	Non Energy Fraction	All Variables	
Annual final consumption of fuel per unit of activity level (for energy and non energy purposes)					
Name	Fuel Name	Expression	Scale	Units	Per
Bagasse	Bagasse	20.7		Gigajoule	Per Tonne
Motor fuels	Motor fuels	0		Gigajoule	Per Tonne
Electricity	Electricity	0.2		Gigajoule	Per Tonne

Commercial services

The Commercial services sector consists of urban based small scale (often informal) trade and hospitality service establishments (hotels, restaurants, drink houses). Hospitality services are the main energy consumers in the sector. Energy requirements in these establishments is for cooking and baking, lighting, water heating, and electric appliances.

The only available information for the sector is the Energy Balance, which provides estimates for aggregate energy consumption. Desegregation of total final consumption by sub sector and by end use has not been feasible due to the limited amount of data available on energy use for the sector. For this reason, until more data is available, Activity Levels for the sector are all set to 100% and Energy intensities are set to aggregate sector consumption of each fuel.

Public services

The Public service sector is a new addition to the Energy Balance. Public services, which include water supply, health services, education and street lighting, are important services especially in rural areas. These services are also high potential applications for solar and wind energy technologies.

For the purpose of estimating energy demands, the number, distribution, and energy consumption of rural water supply points, health facilities, and schools are required. However, there is little published or unpublished (but accessible) data on these at present. For this reason, the consultants had to make their own assumptions.

Table 7.7
Demand data structure for the Public Services sector

Activity Level	Final Energy Intensity	Demand Cost	Non Energy Fraction	All Variables
A measure of social and economic activity for which energy is consumed				
Name	Expression	Scale	Units	Per
Public Services				No Data
Rural				No Data
Water				No Data
Public	0.27*Population Rural			Unspecified Unit
Hand pump	10		Percent	Share
Diesel	0		Percent	Share
Electricity	Remainder(100)		Percent	Share
Solar	10/15000		Percent	Share
Wind	25/15000		Percent	Share

Activity Level	**Final Energy Intensity**	Demand Cost	Non Energy Fraction	All Variables	
Annual final consumption of fuel per unit of activity level (for energy and non energy purposes)					
Name	Fuel Name	Expression	Scale	Units	Per
Hand pump	Human Energy	2.72/1000*20*3.65*0.3		Kilowatt-Hour	Per Share
Diesel	Diesel	2.72/1000*50*3.65*0.3		Kilowatt-Hour	Per Share
Electricity	Electricity	2.72/1000*50*3.65*0.3		Kilowatt-Hour	Per Share
Solar	Solar	2.72/1000*30*3.65*0.3		Kilowatt-Hour	Per Share
Wind	Wind	2.72/1000*50*3.65*0.3		Kilowatt-Hour	Per Share

Energy transformation

In the LEAP model indigenous energy conversion and transport is referred to as energy transformation. Energy demand must be met with adequate supply either from indigenous production or from imports.

The transformation branch in LEAP is divided into modules. Transformation modules represent energy conversion sectors (industries). Typical transformation modules include electricity generation, petroleum refining, charcoal production, biogas production, and transmission and distribution.

Each module may have one or several processes. Processes are individual energy conversion technologies within modules. For example, the electricity generation module may contain as processes hydropower plants, diesel engine plants, and geothermal plants; while for charcoal production there may be traditional charcoal making and efficient charcoal making processes.

In the Ethiopian case energy transformation branch for the base year include the following modules: charcoal production, biogas production, combined heat and power (CHP), centralized (grid) electricity generation, decentralized electricity generation, ethanol production, bio diesel production, coal mining, natural gas liquids production, and transmission and distribution.

a. Charcoal production

Total charcoal consumption in 1998/99 was 8785 TJ (equivalent to 0.3 million Tons) and accounted for 1.2 percent of total energy consumed in the country. Charcoal production in Ethiopia is an unregulated (and illegal) operation carried out informally by individuals or groups of individuals at very small scales.

The predominant type of charcoal production method in Ethiopia is the earth mound technology. This technique has an energy efficiency of about 25 percent (but depending on the skill of the operator, it can go as high as 35 percent). In the past few years a promotion effort has been underway to introduce better efficiency charcoal kilns, including improved earth mound kilns and metal kilns which improve the charcoal production efficiency by as much as 50 percent.

The Charcoal production module is created as module with four processes (types of charcoal production kilns). The shares of each of these processes (technologies) and their energy efficiencies are as shown in the following tables.

Table 7.8
Charcoal production

Process shares | Efficiency

Process shares: Energy share of total module requirements (%)

Name	Expression
Traditional earth mound	99
Improved earth mound	0.4
Metal kiln	0.4
Brick kiln	Remainder(100)

Process shares | **Efficiency**

Efficiency: the energy content of the output fuels divided by the energy content of the feedstock fuels (%)

Name	Expression
Traditional earth mound	25
Improved earth mound	35
Metal kiln	35
Brick hive kiln	40

b. Biogas production

It is estimated that there are about 500 biogas units installed in the country, of which only a third are in operation (Kidane, 2003). Most of these biogas plants are in the 2.5 to 5 m^3 capacity range. Assuming 2.5m^3 of biogas production per day from 165 units (since only a third are operational), total annual biogas production will be about 3 TJ.

Table 7.9
Biogas production

Process shares | Efficiency

Process shares: Energy share of total module requirements (%)

Name	Expression
Indian floating type	61
Chinese	1.4
Camaratec	9
Deenbandhu	6
Other biogas digesters	Remainder (100)

Process shares	**Efficiency**

Efficiency: the energy content of the output fuels divided by the energy content of the feedstock fuels (%)

Name	Expression
Indian floating type	30
Chinese	30
Camaratec	30
Deenbandhu	30
Other biogas digesters	30

c. Centralized (grid) electricity generation

This transformation module contains EEPCO's ICS generation facilities including its hydropower plants, diesel generators, one geothermal plant, planned additions to the grid (hydro, oil, coal), and potential candidate technologies for grid supply (wind and PV).

The Centralized (grid) electricity generation module is set up to include input data on costs, capacities and system load curves. The System Load Curve (Duration Curve) is required for this module because processes need to be dispatched (assigned to meet electricity demands) depending on their Merit Order. The Merit Order for a process indicates where in the load curve the plant operates (base or peak).

Base year System Peak load and the load duration curve (in percent of the peak) are provided. These two data sets are used to generate the load duration curve in actual demand capacity (in MW) inside the LEAP model[52].

Table 7.10a

Electricity generation grid: System Pea, Planning reserves and System Load Curve

Peak system demand	Module costs	Planning reserve margin	**All variables**	System load curve

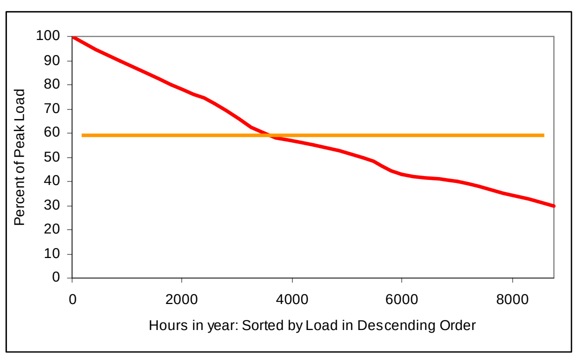
Base year system peak demand for power: used to calibrate calculated system load curve to match

Variable Name	Expression	Scale	Unit
Peak system demand	327.7		Megawatt
Module costs			US Dollar
Planning reserve margin	20	Percent	

Peak system demand	Module costs	Planning reserve margin	All variables	**System load curve**

Load duration curve (% of peak system load)

Hours	1999 expression	
0	100	
876	90	E
1800	80	E
2600	72	E
3500	60	E
4400	55	E
5300	50	E
6000	43	E
7000	40	E
8760	30	E



[52] The Peak Load for the base year is obtained from EEPCO's System Expansion Master Plan study of 2001; the load duration curve is estimated from modeling done on the Model for the Analysis and projection of Energy Demand (MAED) in 2003.

All processes are to be dispatched by Merit Order. Hydropower plants in the module are set to have Merit Order of 1, which means they are used as base load plants, while diesel plants have Merit Order of 3 (peaking plants).

Historical energy production, and current and future committed capacity for each process is provided in the following two tables. The historical energy production data is used to dispatch processes for years before the base year while current and committed capacities determine energy production after the first simulation year (depending on their Merit Order).

Table 7.10b
Electricity generation grid

Dispatch rules	Fist simulation year	Process shares	Efficiency	**Historical prod**	Exogenous cap

Historical energy production: used to dispatch process before the first simulation year.

Units: Gigawatt-Hour

Name	Expression
Hydro turbines	1631.5
Diesel engines	4
Geothermal stations	20
Wind turbines	0
PV	0
Oil combustion turbines	0
Coal steam	0
Natural gas	0

Dispatch rules	Fist simulation year	Process shares	Efficiency	Historical prod	**Exogenous capacity**

Exogenously specified capacity: current and future committed capacity

Units: Megawatt of production capacity

Name	Expression
Hydro turbines	1200
Diesel engines	40
Geothermal stations	7.3
Wind turbines	0
PV	0
Oil combustion turbines	40
Coal steam	0
Natural gas	0

d. Decentralized (off-grid) electricity generation

LEAP assumes that all electricity demand is on grid. Therefore, if electricity demand exceeds available capacity within the grid demand is met by imports. However, in a developing country such as Ethiopia a large section of the population lives away from the grid and the potential demand for off-grid electricity is great. In order to include off-grid technologies into the system, a decentralized electric generation module is created under the transformation branch.

To distinguish between off-grid and grid electricity, a new energy carrier named **"off-grid electricity"** is added into the model (under General/Fuels Menu of LEAP).

There are two options for representation of decentralized electricity generation into the LEAP model. The first is to create one off-grid transformation module and incorporate all off-grid technologies under it, each technology meeting a specified portion of the off-grid demand. The second option is to create individual transformation modules for each off-grid technology (for example, PV, wind, diesel, biomass). The first method is selected because it simplifies analysis since once total off-grid electricity production is computed, the contribution of each off-grid technology towards this total can be shown using process shares.

The process shares for the module were determined using EEPCO data for its SCS system (for diesel and hydro) and estimates for PV. EEPCO SCS generation data for 99/2000 was 14.3 GWh (hydro) and 19 GWh (diesel). For PV, installed capacity for 1999/2000 is estimated to have been 1.8MWp (about 1.5MWp from the Telecom sector) – assuming all installed capacity is utilized, total electricity production would have been about 6.3GWh (1.8MWp * 5 peak hours * 70% system efficiency.

Table 7.11
Electricity generation off-grid

Process shares | Efficiency

Process shares: Energy share of total module requirements (%)

Name	Expression
Diesel	57
MHP	42.93
PV	Remainder(100)
Biomass	0
Wind	0

Process shares | **Efficiency**

Efficiency: the energy content of the output fuels divided by the energy content of the feedstock fuels (%)

Name	Expression
Diesel	25
MHP	100
PV	100
Biomass	40
Wind	100

e. Combined heat and power (CHP)

This transformation module is created specifically to include the CHP plants in the Sugar Agro-industries. The Sugar industry generates heat and power from sugar cane Bagasse. At present heat and electricity generated by the processes are totally consumed inside the industries.

f. Ethanol production

Ethanol is produced by the Fincha sugar agro-industry (which has production capacity of 8 million liters per year). If the market develops for the Ethanol fuel, production capacity at Fincha and the other existing and planned sugar estates may be increased quite substantially.

g. Bio diesel production

Bio diesel fuel production and utilization is in the trial stage in many parts of the world. In Ethiopia, one private company has plans to produce bio-diesel from the Jatropha plant and for this purpose has planted the trees in Benishangul Gumuz region.

h. Natural gas liquid production

This module is added to take into account planned development of the Calub gas fields for production of liquid petroleum from natural gas.

i. Transmission and distribution

The transmission and distribution module is used to set T&D losses in the transformation branch. For grid supplied electricity current T&D losses are about 22 percent (EEPCO) while for off-grid electricity supply 10 percent distribution losses are estimated.

Table 7.12
The Transmission and Distribution module

Losses		
Energy losses (%)		
Name	Output fuel	Expression
Electricity	Electricity	22
Electricity off-grid	Electricity off-grid	10
Natural gas	Natural gas	5

Energy resources

In the LEAP model resources are divided into primary and secondary fuels. The resources and fuels under the resource modules are automatically generated by LEAP from requirements for the resources in the Demand and Transformation branches.

Indigenous energy resource data required for fossil fuels is the total available reserve of the resource (proven or ultimately recoverable) , while for renewable resources annual yields are required.

Fossil fuels

For the Ethiopian case, only two fossil fuels are included in the system: coal and natural gas. The natural gas reserve in the Calub area is estimated to be 2.7 TCF. For coal, the proven amount in place in the Delbi and Moye area is about 13.8 million Tonnes (if probable and possible reserves are included the total goes to 70.5 million Tonnes).

Biomass resources

For biomass resources yield estimates are derived from the Woody Biomass Inventory and Strategic Planning Project (Developing a National Strategic Plan and Policy Framework for the Biomass Energy Sector, WBISPP, MoA, No date). The total woody biomass stock for the year 2000 was estimated to have been 768 million Tons with annual sustainable yield of 37.04 million tons. This estimate excludes resources in Tigray, Afar, Benishangul-Gumuz, Somali, and Addis Ababa regions. If these regions were included total woody biomass yield would exceed 40 million Tons. The Oromiya region accounted for 48 percent of total yields, SNNP for 27 percent, Amhara for 16 percent and Gambela for 9 percent.

Again excluding the regions listed above, total yields for agricultural residue and animal dung for the year 2000 was 19.2 million tons and 18.3 million tons respectively.

Bagasse

Area cultivated for sugar at the four sugar plantations in Ethiopia was 22,430 ha in 1999/2000 (CSA, Annual Abstract, 2001). At 90 ton of cane per ha of area cultivated and 30 percent fiber, total bagasse production would be 0.65 million Ton/year or 5330 TJ/year (at 8.2GJ/Ton).

Solar energy

For solar energy the main determinants for energy yield are total available area for solar energy production, peak power production from a square meter of PV panel, and mean global solar energy availability. The gross solar energy yield available is computed using the following relation:

*Households * Area (m^2/hh) * Insolation (kWh/m^2/day) * 365 days*efficiency*

The key assumptions in the above relation are:

- Every household would have **10 m^2 of area** that it can allocate for solar energy generation.
- Efficiency 14% for mono crystalline PV panels & 90% for the system
- Mean global solar irradiation of **3.74kWh/m^2.day** (taken from SWERA solar energy database)

According to the above assumptions, every household would have about 12.5kWp PV capacity and may generate 60kWh of electricity per day. This amount of energy is four times more energy than is required by the highest income households in Ethiopia[53].

Wind energy

The ENEC-CESEN study of 1986 (Main Report, p. 92) divided the whole of Ethiopia into essentially two wind energy density zones: less than 3.5m/s (65W/m2) for area in the North, West and North-West; and 3.5-5.5m/s (65-200W/m2) for the rest of the country. The gross wind energy yield is estimated with the following relation:

*Transmission (km) * 25km (wind zone) * Suitable area within buffer (%) * 5MW/km^2 (installation density)*

- 6303 km of transmission and sub-transmission lines (EEPCO, Facts in Brief, 2003)
- 25 km buffer from grid transmission for wind production (SWERA recommendation)
- 5MW/km^2 of wind turbine density (SWERA recommendation)

Total power available from wind turbines for grid connection will be about **100GW**. Further assuming 80 percent availability for turbines annual generation will be 890 TWh.

[53] Cooking and baking requirements per household are 5GJ/year, which is equivalent to 4kWh/day; demand for electric appliances would be about 5kWh (1kW of equipment operated for 5 hours a day); and water-heating requirements would be 5kWh/day (a 1kW boiler operated for 5 hours).

Hydropower

The gross hydropower generation potential for Ethiopia is estimated to be 630TWh/year with an exploitable potential of about 120TWh/year (ENEC-CESEN, Main report, p. 80.).

Geothermal energy

The geothermal energy potential for Ethiopia is estimated to be 700Mwe (ENEC-CESEN, Main report, p. 77).

Human energy

Total human energy available is estimated as product of total population and 2000kCal per day energy expenditure per person for 365 days.

Animal energy

Total animal energy available is estimated as product of total livestock population and 6000kCal per day energy expenditure per animal for 365 days.

Table 7.13
Energy resources

Base Year Reserves	Yield	Indigenous Cost	Import Cost	Export Benefit

Reserves (stock) of resource remaining in the base year

Name	Expression	Scale	Units
Natural Gas	2.7	Trillion	Cubic Feet
Coal (bituminous)	13.8	Million	Tonne of Coal equivalent

Source: Natural Gas (Ministry of Mines and Energy); Coal (Coal Pre-feasibility Assessment, EEA, 1994).

Base Year Reserves	**Yield**	Indigenous Cost	Import Cost	Export Benefit

Annual yield of renewable resource

Name	Expression	Scale	Units
Wood	37.04	Million	Tonne
Animal Wastes	18.28	Million	Tonne
Agricultural residue	19.26	Million	Tonne
Bagasse	90*22430*0.3		Tonne
Biomass (unspecified)	1	Million	Tonne
Wind	6303*25*0.5*5*0.5*8760		Megawatt-Hour
Solar	Households*10*14%*90%*3.74*365	Million	Kilowatt-Hour
Hydro	120		Terawatt-Hour
Geothermal	700*8760		Megawatt-Hour
Human Energy	Population*2000*365	Million	kCal
Animal Energy	Livestock population*6000*365	Million	kCal

Source: See discussions above.

The Reference energy development scenario (REF)

Basic assumptions for demand projection

National energy demand will grow depending on socio-economic development (population, economic performance) and changes in the energy technology base (or energy intensity). Energy demand growth is assumed to be the same for both the Reference and Alternative scenarios. The scenarios are then compared on how they meet the same demand: the REF scenario keeps the status quo and solar and wind energy will have little or no contribution to energy supply; the ALT scenario illustrates the case where solar and wind energy have significant share in the supply mix.

Socio-economic variables

The basic demand driving variables of population and Real GDP are assumed to grow at 3% and 8.8% respectively. Population growth rate estimates are derived from CSA population forecasts and RGDP growth rates are the growth rates recorded for 2005[54] by the Ministry of Finance and Economic Development (as reported by the National Bank of Ethiopia).

Energy intensity

Energy intensities are generally assumed to grow at 1% per year for cooking and baking end uses and 3% for all other end uses. This assumption is taken with the view that as incomes grow energy requirements will also grow.

Another major assumption for demand is that the penetration rate for improved rural biomass stoves (stoves which have 50% more efficiency than existing ones) will reach 30% by 2030. This assumption is feasible and its impacts will be considerable. This intervention is part of the REF scenario because such a program is already underway by the EREDPC.

Energy demand forecast

Energy demand is expected to grow from 700PJ in 2000 to just over 1900PJ in 2030, a growth rate of 3.5% per year. Sectoral energy shares change where the energy demand from the household sector drops from 91% in 2000 to 78% in 2030 with corresponding increases in the other sectors. Fuel shares in the energy balance also change with share of biomass from total demand declining from 93% in 2000 to 82% in 2030.

Table 7.14
Energy demand projection, 2000-2030, Peta Joules (PJ) [Reference Scenario]

Energy carrier	2000	2005	2010	2015	2020	2025	2030
Biomass	645	769	911	1,069	1,232	1,413	1,623
Oil Products	34	46	64	90	128	183	262
Electricity	3	6	10	16	27	45	71
Renewables	9	9	9	10	11	11	12
Total	**691**	**830**	**995**	**1,186**	**1,398**	**1,653**	**1,970**

[54] Real GDP growth during 200-2005 averaged 4.8 percent (Agriculture: 4.7%, Industry: 5.1%, Service: 4.8%). In 2005 RGDP grew by 8.8 percent (agriculture: 12%, Industry: 6.6%, Services: 5.8%)

Sector	2000	2005	2010	2015	2020	2025	2030
Household	631	751	886	1,036	1,188	1,356	1,546
Industry	24	34	48	67	94	131	183
Transport	19	26	35	48	67	93	131
Agriculture	15	19	25	35	49	72	109
Commercial services	0	0	0	0	0	0	0
Pubic services	0	0	0	0	0	0	0
Total	**691**	**830**	**995**	**1,186**	**1,398**	**1,653**	**1,970**

Figure 7.1
Energy demand by sector, 2000-2030 [Reference Scenario]

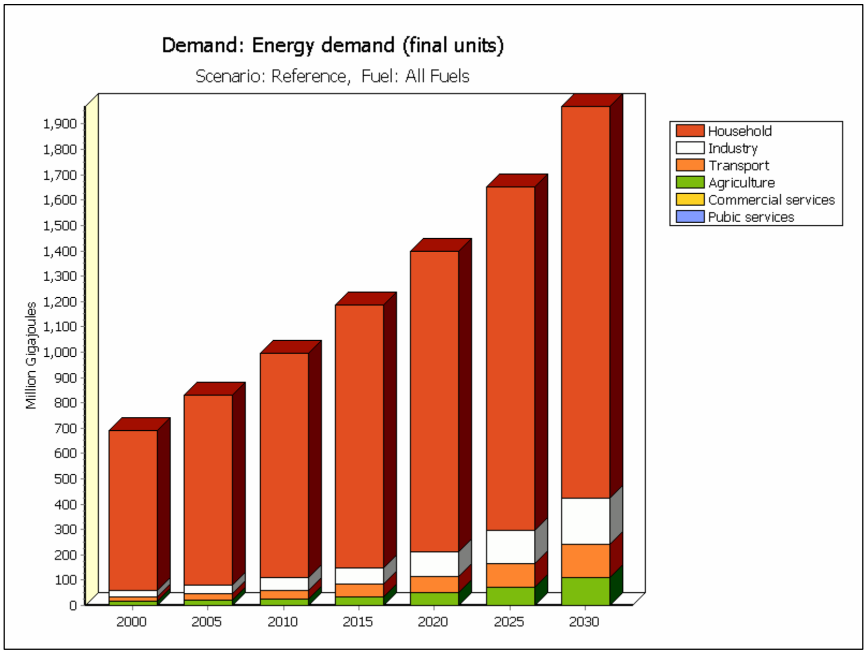
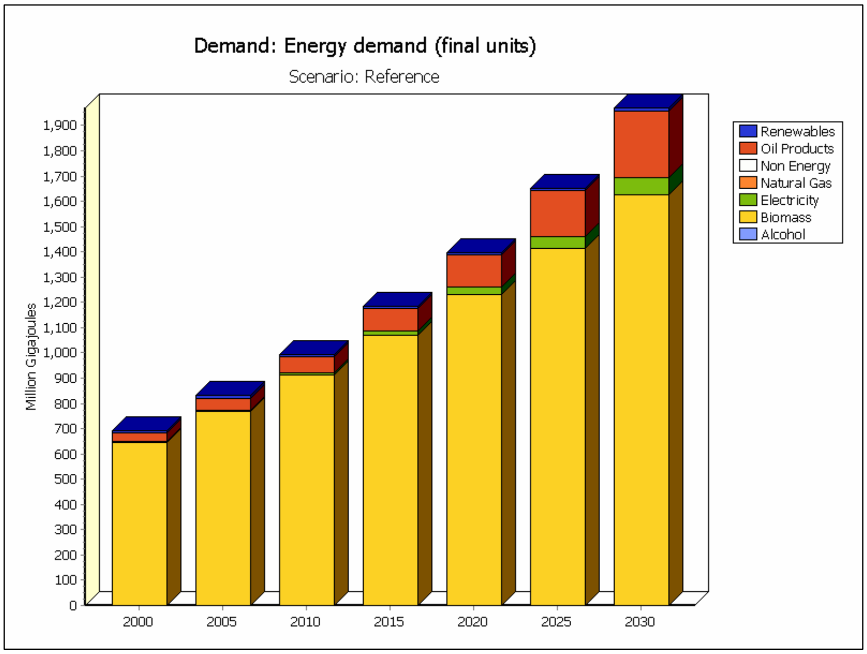


Figure 7.2
Energy demand by fuel, 2000-2030 [Reference Scenario]



Energy supply

For the Reference Scenario Transformation outputs for grid electricity are shown below. The Ethiopian electric grid is hydro based with large hydropower plants accounting for 99% of energy generation on the system. This nearly exclusive dependence on hydro continues into the future and hydropower plants will contribute 96% to total generation on the grid in 2030. In **electrified** rural areas supplies are mostly from off-grid systems but in the future the contribution of grid electricity will increase and by 2030 grid power will account for 66% of total rural electricity demand.

Figure 7.3
Grid electricity generation by source of energy, 2000-2030 [Reference Scenario]

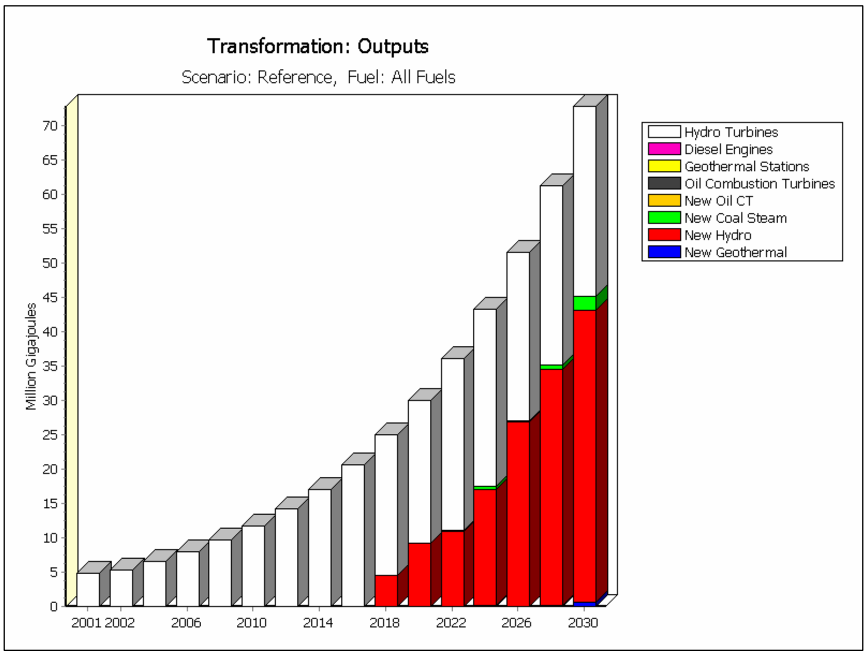
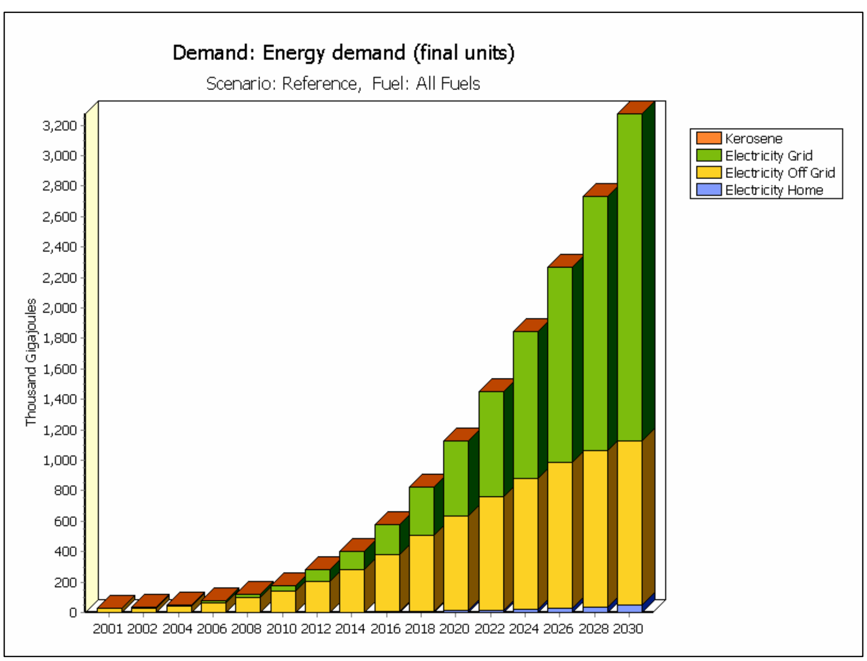


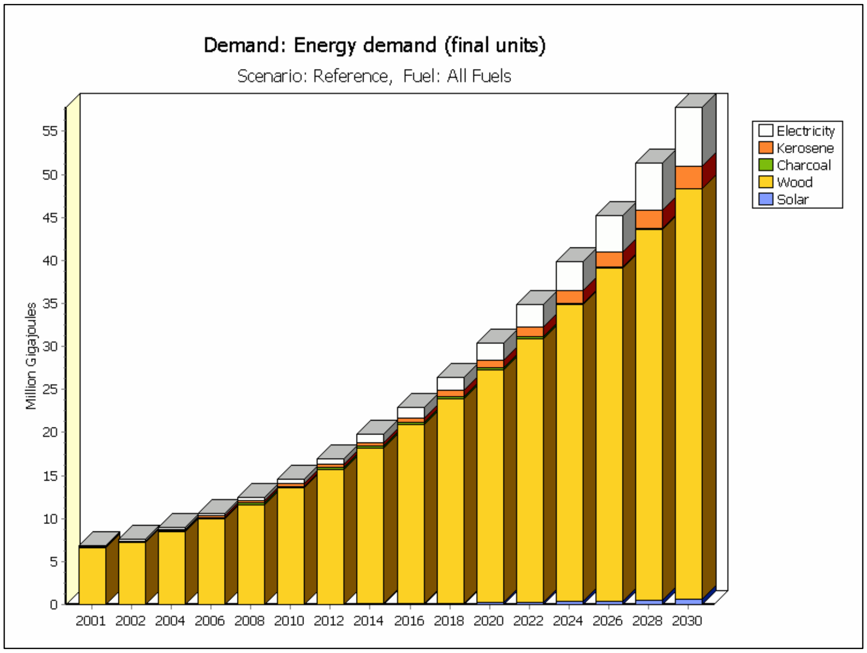
Figure 7.4
Rural lighting, 2000-2030 [Reference Scenario]



Urban water heating

Water heating is an important market for solar thermal applications. In the REF scenario the contribution of solar water heating to total water heating requirements are negligible (0.1% in 2001 to 1.2% in 2030). Biomass fuels will continue to be the main sources of energy for water heating (96% in 2000, 82% in 2030). The share of electricity in the hot water service market increases from 1.2% in 2000 to 12% in 2030.

Figure 7.5
Urban water heating, 2000-2030 [Reference Scenario]



7.2 Potential Supply Short falls for key supply sectors

Energy demand must always be balanced with energy supply. In the short term available supply capacity may meet growing demand (more energy may be produced from existing facilities) but in the medium to long term capacity must be added to ensure adequate supply capacity.

Grid electricity

In the model, the "Electricity Generation Grid" module represents the electric grid. Existing and committed additions to the grid are input as "exogenous capacity" meaning capacity directly input by the modeller. Another set of variables called "endogenous capacity" is also input in the model to indicate what type of generation facilities will be available for later addition (not committed but available). The model itself decides what type of generation facility needs to be added (based on the priority list the modeller attaches to each type of facility)[55]. The sum of these new requirements is the expected shortfall. In the REF scenario, for grid electricity, the shortfall occurs in 2017 for 4PJ and grows to 46PJ in 2030 (from 18% of total required generation in 2017 to 62% in 2030).

55 These set of "endogenous" facilities are the ones labelled as "New Hydro", "New Oil", and "New Coal" in Figure 5.3 above.

Off-grid electricity

In the model the energy carrier "electricity" is made to represent only grid electricity. Two more energy carriers have been added into the model to analyse supplies and demands separately for "electricity off-grid" and "electricity home." In the Transformation sector of the model "electricity off-grid" is a separate transformation module with diesel stations, micro hydropower plants and other potential power sources as processes (generation facilities). Home systems are not represented in the transformation sector, they are directly input as end use technologies (for example, for rural lighting, they appear as substitutes for kerosene lighting).

Supply shortfall for off-grid electricity is determined from a supply-demand balance for the energy carrier "Electricity off-grid" in the model. For the off-grid module there would not be any committed additions to system capacity as is the case for grid electricity. This means shortfalls appear immediately or in the very short term. For the REF scenario, supply shortfalls appear in 2008 and beyond. The shortfall is then met by adding capacity from diesel and MHP facilities in the same proportion as in the base year.

Auto generation systems (facilities meeting individual demand: solar home systems, solar water heaters, wind and PV pumping)

These supply facilities are not included in the Transformation sector; they are put as end use devices in the demand sector. Supply shortfalls appear immediately after the base year since there is usually no surplus capacity from such systems to meet extra demand. In the REF scenario, these additional requirements are met with additional capacities in the same proportion as in the base year which means the contributions of solar and wind energy systems is limited to shares as in the base year.

7.3 Solar and wind energy in the national energy system

The objective here is to show the potential of solar and wind energy in meeting energy demand at the national level. Two scenarios are developed: the Ambitious S&W energy scenario shows the upper limit of the potential contribution of solar and wind energy in the system[56].

Ambitious S&W energy scenario (AMBSW)

The Ambitious S&W scenario is based on the assumption that S&W energy meets all shortfalls in the key supply sectors identified in 7.2. This means capacity shortfalls in the electric grid, off-grid electricity, and auto-generation systems will be totally met by S&W energy.

Grid electricity

In the Ambitious scenario all shortfall in the system is assumed to be met by wind and solar energy. The shortfall first appears in 2017 at 1.14TWh (208MW) then goes

[56] Although at this stage wind energy resource data is not yet available, wind is included in the scenarios.

up to 12.53TWh in 2030 (2488MW). The shortfall would be 18% of total generation requirements for 2017 and 62%[57] of total requirements for 2030.

Off-grid electricity

The requirement for Off-grid electricity for 2010 is 38.5GWh and that for 2030 would be 299GWh.

Auto generation systems (facilities meeting individual demand: solar home systems, solar water heaters)

The requirement for electric home systems is 0.29GWh for 2010 and 13.3GWh for 2030.

The technical potential for solar water heating is assumed to be the case where solar water heaters replace all water heaters operating on electricity and kerosene. The total water heating demand that these two fuels would meet and that solar water heaters would replace in 2010 and 2030 is 232GWh and 2832GWh respectively.

[57] Note that with present technologies it may not be possible to incorporate as much as 62% of wind or solar power into an electric grid. This is because wind and solar electricity quality is different from that from conventional sources and conversion or filtering of renewable electricity to exactly suit the grid is costly at present.

8 Annexes

Annex 1:- Rural Household Non-cooking Energy Requirements

At present energy consumption in non-electrified rural area in Ethiopia for non-cooking appliances is very minimal. Basic items that energy is required for in rural households are lighting points and entertainment devices. Lighting needs are usually met with kerosene lanterns and kerosene wicks. Entertainment devices include radio/cassette players and, now a days, B&W TVs are becoming available in rural households. Dry cells are mainly used for radio/ cassette players and hand torches. Use of automotive batteries for powering cassette players and B&W TV sets is not uncommon in most rural households in Ethiopia.

Non-cooking energy load for a typical rural household is indicated in Table xx below[58]. Supplying rural households with modern energy with solar PV to cover the most basic electrical energy needs would require a 70Wp system assuming an annual daily average radiation[59] of 3.74kWh/m^2/day.

Table xx: Daily power load in a typical household in a non-electrified area

Description	**Solar-load correlation**	**Load (kW)**	**Hours of use per day (h/d)**	**Days of use per week (d/wk)**	**Energy (kWh/d)**
Radio	Positive	0.008	3.00	7	0.024
Cassette player	Positive	0.015	2.00	7	0.030
B&W TV	Negative	0.015	4.00	7	0.60
Service Lights (1x7W & 1x9W)	Negative	0.016	4.00	7	0.64
Daily load (kWh/day/household)					**0.178**
Energy loses due to system components 15% (kWh/day)					**0.0267**
Total daily load + loses (kWh/day/household)					**0.204**
Daily Charging Current (A)					**4.3**
Panel size that generates the indicated charging current (Wp)					**70**
Yearly total load (kWh/year/household)					**65**

[58] Taken from various studies conducted in non-electrified areas: Ethiopian PV Commercialization Study, EREDPC, 2003.

[59] Annual daily average radiation for the country as a whole calculated based on SWERA solar energy resource assessment.

Annex 2: Cost Comparison of Electricity from Diesel Genset and Solar PV Home System

Daily energy consumption of electricity by a household (Electricity Service for 4 hours/day)

Description	Solar-load correlation	Load (kW)	Hours of use per day (h/d)	Energy (kWh/d)	Days/ week
Radios	Positive	0.008	3.0	0.024	7
Cassette Player	Positive	0.015	2.0	0.030	7
B/W TV	Negative	0.015	4.0	0.060	7
Service Lights (2 x 8W)	Negative	0.016	4.0	0.064	7
	Total (kWh/day) per hhs=			0.178	
	Total (kWh/month) per hhs=			5.34	
	Total (kWh/d) for 200 hhs=			35.6	

No.of households electrified =	200
Energy delivered for 200hh (kWh/day) =	35.6
Annual energy delivered (kWh/year)=	12994
Discounting rate =	10%
Inflation rate =	3%
Life time of system (years) =	20

Diesel Genset - Mini Grid

Diesel Price (ETB/L) =	4.78		Servcie Hours (h) =	4
Fuel consumption- genset (L/kWh) =	0.3		Genset capacity (kW)=	12
Genset load factor =	0.8			
Transmission system loss (%) =	10%			
Fuel cost (ETB/kWh) =	1.43	At base year		
Annual fuel Cost (ETB/kWh) =				
Fuel cost escalting rate =	5%			
Average genset price (ETB/kW) =	2000	(Price ranges between ETB/kW 1500 to 3000)		
Economic Cost of Diesel (ETB/L) =	4.9675	In Addis Ababa		

Year	Fuel cost escalation rate	Annual fuel cost	Inflation	Annual costs O&M	Peiodic Costs	Capital cost	Salvaged value of genset	Total Cost	Total survice (kWh)
0	1.0	0	1.0	0		201556		201556	0
1	1.1	19565	1.0	14020				33585	12994
2	1.1	20543	1.1	14453				34997	12994
3	1.2	21570	1.1	14900				36471	12994
4	1.2	22649	1.1	15361				38010	12994
5	1.3	23781	1.2	15836	19643			59261	12994
6	1.3	24971	1.2	16327				41297	12994
7	1.4	26219	1.2	16833				43052	12994
8	1.5	27530	1.3	17354				44884	12994
9	1.6	28907	1.3	17893				46799	12994
10	1.6	30352	1.3	18448	49352		-1236	96916	12994
11	1.7	31869	1.4	19021				50891	12994
12	1.8	33463	1.4	19612				53075	12994
13	1.9	35136	1.5	20222				55358	12994
14	2.0	36893	1.5	20852				57744	12994
15	2.1	38737	1.6	21501	26399			86637	12994
16	2.2	40674	1.6	22171				62845	12994
17	2.3	42708	1.7	22862				65570	12994
18	2.4	44843	1.7	23576				68419	12994
19	2.5	47086	1.8	24312				71397	12994
20	2.7	49440	1.8	25071	30604			105115	12994
NPV								627709	110625

Capital Costs

Cost of diesel genset (ETB) =	24722	Cost of 12 kW genset
Cost of distribution system (ETB)=	120000	LV mini grid (about 3km of 2 cables+ poles +fittings+labour+etc)
Other electrical equipments (ETB)=	40000	(internal wiring and bulbs - 2x7W CFL)
Transportation of Equipment (ETB)=	7236	(5% of the cost of distribution system and genset)
Contingency (5%)=	9598	This includes training as well
Total system cost (ETB) =	201556	

Annual Costs

O&M + guard	12000	O&M, bill collection, guard (2xEB500/month)
Oil change	600	(lubricants 4 times a year)
Genset service & maintenance =	1000	(filters, minor maintenance,etc 4 times a year)
Total	13600	

Periodic Costs

Genset (Overhaul)	4944	20% of cost of genset every five years
Maintenace of distribution line	12000	10% of cost of distribution lines every five years
Replacement of genset	24722	Replacement of genset every 10 years

Financial cost of electrcty (ETB/kWh) 5.67

(not so much difference between financial and economic cost for diesel genset electricity)

Financial Indicators

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity Load =	12994.00	kWh/year
Total Life Cycle Cost (LCC) =	627709	ETB
Annualized LCC (ALCC) =	73730.42	ETB
Levelised Energy Cost =	5.67	ETB/kWh

Effect of fuel price on cost of electricity

Fuel Price ETB/L	Electricity Cost ETB/kWh
4.78	5.67
5.00	5.77
5.25	5.88
5.50	6.00
6.00	6.22
6.50	6.44
7.00	6.67
8.00	7.12
9.00	7.51

Solar Home System

Daily electricity requirement	kWh/day	0.178	kWh/day/household
Annual Electricity Load =	KWh/year	64.97	
Daily average radiation (kWh/m2/day) =		3.74	National annual average solar radiation (SWERA estimation)
PV system efficiency =		15%	15% system loses
Energy loses due to system components (kWh)		0.027	
Daily energy Solar Elect. Demand (kWh/hh)=		0.205	daily electricity needed (including loses)-used for system sizing
Charging Current (A) =		4.6	
Module size required (Wp) =		70	
Cost of module per Wp (ETB/Wp) =		63	(Price of modules above 60Wp ranges between ETB 60 and 65)
Economic Cost of Modules (ETB/Wp) =		47	

Financial Cost Analysis					Economic Cost Analysis			Comparison between Diesel genset and SHS	
Year	Capital Cost	Periodic Cost	Total Cost	Total Service (kWh)	Capital Cost	Periodic Cost	Total Cost	Savings	Cumulative Saving
0	7299		7299		5640		5640	-1258154	-1258154
1			0	65			0	33585	-1224569
2			0	65			0	34997	-1189572
3			0	65			0	36471	-1153102
4			0	65			0	38010	-1115092
5		927	927	65		640	640	-126223	-1241315
6			0	65			0	41297	-1200017
7			0	65			0	43052	-1156966
8			0	65			0	44884	-1112081
9			0	65			0	46799	-1065282
10		1075	1075	65		741	741	-118111	-1183393
11			0	65			0	50891	-1132502
12			0	65			0	53075	-1079427
13			0	65			0	55358	-1024068
14			0	65			0	57744	-966324
15		1246	1246	65		860	860	-162637	-1128961
16			0	65			0	62845	-1066116
17			0	65			0	65570	-1000546
18			0	65			0	68419	-932127
19			0	65			0	71397	-860729
20			0	65			0	105115	-755614
NPV			8587	553			6528	-1089749	

Capital Costs

Module (ETB)=	4410	
Solar Battery (ETB)=	800	(solar battery (80Ah - considering 2 days autonomy) - 5 years life time)
Controler (ETB) =	560	10A controler
CFL (ETB) =	300	two CFL lights
Cables (ETB) =	300	(30 m insulated 2x2.5 @ETB10/m)
Other accessaries =	250	(switches, socket/plugs, DC-DC converter, module support, battery box, etc)
Installation &Trans =	331	5% of equipment cost
Contingency =	348	5% of total cost
Total System cost =	7299	

Annual Costs

O&M	0.00	For SHS

Periodic Costs

Solar battery =	1500	Every 5 years

Financial Indicators - for comparison of diesel genset and SHS

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity Load =	64.97	kWh/year
Total Life Cycle Cost (LCC) =	8587	ETB
Annualized LCC (ALCC) =	1008.66	ETB
Levelised Energy Cost =	15.53	ETB/kWh

Financial Cost of electricity (ETB/kWh) =	15.53
Economic Cost of electricity (ETB/kWh) =	11.80

Economic Costs

Capital Costs

Module (ETB) =	3267	(VAT + duty is about35% of total cost)
Solar= battery (ETB)	552	(VAT + duty is about 45% of total cost)
Controler (ETB) =	415	(VAT + duty is about 35% of total cost)
CFL (ETB) =	300	
Cables (ETB) =	300	
Other accessaries =	250	
Installation &Trans =	288	(less VAT of 15%)
Contingency =	269	
Total System cost =	5640	

Periodic Cost

Solar battery =	552	Every 5 years

Annex 3: Grid Based PV Electricity

Module size (Wp) =			100			
Cost of module before tax (ETB/Wp)=			34.8	($4/Wp - International Price)		
Tax on modules (Duty + VAT) =			38%			
Cost of module after tax (ETB/Wp) =			48.02			
Suppliers profit+installation+transport =			30%	45.24		
Installed Price of Module (ETB/Wp) =			62.43			
Cost of inverter (for grid)-before tax (ETB/Wp)			13.92	($1.6/Wp-International price)		
Tax on inverters =			45%			
Price of inverters (ETB/Wp) =			20.18			
Supports + accessries /100Wp system (ETB) =			200			
G = 3.74	kWh/m2/d	SWERA	==>	129.68	kWh/yr	Annual electricity generated
G = 5.2	kWh/m2/d	CESEN	==>	180.31	kWh/yr	Annual electricity generated

Price of module & inverter (ETB/100Wp)				Annual Elec. Delivered (kWh/year)	
Year	with no tax	with tax		SWERA	CESEN
0	6394.40	8865.20		0.0	0
1	63.94	88.65		129.7	180.31
2	63.94	88.65		129.7	180.31
3	63.94	88.65		129.7	180.31
4	63.94	88.65		129.7	180.31
5	63.94	88.65		129.7	180.31
6	63.94	88.65		129.7	180.31
7	63.94	88.65		129.7	180.31
8	63.94	88.65		129.7	180.31
9	63.94	88.65		129.7	180.31
10	63.94	88.65		129.7	180.31
11	63.94	88.65		129.7	180.31
12	63.94	88.65		129.7	180.31
13	63.94	88.65		129.7	180.31
14	63.94	88.65		129.7	180.31
15	63.94	88.65		129.7	180.31
16	63.94	88.65		129.7	180.31

17	63.94	88.65		129.7	180.31
18	63.94	88.65		129.7	180.31
19	63.94	88.65		129.7	180.31
20	63.94	88.65		129.7	180.31
NPV	6939	9620		1104.1	1535.1
total kWh	1104	1104			
ETB/kWh	6.28	8.71			
ETB/Wp	69.39	96.20			

1. Using SWERA generated solar resource estimation of 3.74kWh/m2/day for a national annual average daily radiation

Financial Indicators

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	129.68	kWh/year
Total Life Cycle Cost (LCC) =	9620	ETB
Annualized LCC (ALCC) =	1129.96	ETB
Levelised Energy Cost =	8.71	ETB/kWh

Economic Cost

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	129.68	kWh/year
Total Life Cycle Cost (LCC) =	6939	ETB
Annualized LCC (ALCC) =	815.03	ETB
Levelised Energy Cost =	6.28	ETB/kWh

2. Using CESEN generated solar resource estimation of 5.2kWh/m2/day for a national annual average daily radiation

Financial Indicators

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	180.31	kWh/year
Total Life Cycle Cost (LCC) =	9620	ETB
Annualized LCC (ALCC) =	1129.96	ETB
Levelised Energy Cost =	6.27	ETB/kWh

Economic Cost

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	180.31	kWh/year
Total Life Cycle Cost (LCC) =	6939	ETB
Annualized LCC (ALCC) =	815.03	ETB
Levelised Energy Cost =	4.52	ETB/kWh

When module price = $0.5/Wp

1. Using SWERA generated solar resource estimation of 3.74kWh/m2/day for a national annual average daily radiation

Financial Indicators

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	129.68	kWh/year
Total Life Cycle Cost (LCC) =	3692.14	ETB
Annualized LCC (ALCC) =	433.68	ETB
Levelised Energy Cost =	3.34	ETB/kWh

Economic Cost

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	129.68	kWh/year
Total Life Cycle Cost (LCC) =	2643.28	ETB
Annualized LCC (ALCC) =	310.48	ETB
Levelised Energy Cost =	2.39	ETB/kWh

Almost same as economic cost of SCS

2. Using CESEN generated solar resource estimation of 5.2kWh/m2/day for a national annual average daily radiation

Financial Indicators

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	180.31	kWh/year
Total Life Cycle Cost (LCC) =	3692.14	ETB
Annualized LCC (ALCC) =	433.68	ETB
Levelised Energy Cost =	2.41	ETB/kWh

Almost same as economic cost of electricity from SCS

Economic Cost

Annualization Factor Pa(20yrs) =	8.51	
Annual Electricity generated =	180.31	kWh/year
Total Life Cycle Cost (LCC) =	2643.28	ETB
Annualized LCC (ALCC) =	310.48	ETB
Levelised Energy Cost =	1.72	ETB/kWh

Just a little bit higher than the economic cost electricity from ICS

Annex 4: Cost Comparison between a Solar Water Heater and an Electric Boiler for Household and Commercial Applications

Application type	-	Service hot water
System configuration	-	With storage
Building or load type	-	House
Number of units	Occupant	5
Rate of occupancy	%	100%
Hot water use	L/d	125
Desired water temperature	℃	40
Days per week system is used	d	7
Cold water temperature	-	
Minimum	℃	16
Maximum	℃	18
Months SWH system in use	month	12
Annual Thermal Energy demand	MWh (thermal)	1.27
	GJ (thermal)	4.56

Annual average daily radiation (kWh/m2/day) = 3.74
(Global radiation on horizontal surface)

Inflation	%	3%
Discount rate	%	10%
Project life	years	20

Economic Price of Electricity= 1.3161

Electricity Price = 0.4093 ETB/kWh = as hhs with elec. boiler consume not less than 200kWh/month

Annual Energy demand = 1267 kWh/year (thermal)

Electricity cost escalation rage = 9.4% (Average elec. cost escalation rate = 9.4%- for bolck consumption less than 200kWh/month - for domestic consumers)

Electricity tariffs considered in the calculations: (Average electricity cost escalation rate = 8.2%%- for all bolcks - for commercial consumers)

	Financial Cost (Price)	Economic Cost	
Domestic (ETB/kWh) =	0.4093	1.3161	(tariff category for consumption over 100kWh)
General (ETB/kWh) =	0.5341	1.1867	Average tarrif for commercial/ general category (0.4990/0.5691) and (1.2303/1.1430)
Industry (ETB/kWh) =	0.3349	1.4922	15kV category

Efficiency of electric boiler is assumed to be 100%

Electric Boiler Current price for 150 liter Capacity (ETB) = 1500

Solar Water Heater (SWH- 150L) installed price in Addis Ababa(ETB)= 5600

								Financial Cost Comparison	
Year	Electricity Cost Escalation	Inflation	Energy required (kWh/year)	Financial Elec boiler (ETB)	Economic Elec Boiler (ETB)	Financial SWH (ETB)	Economical SWH (ETB)	Saving	Cumulative Saving
0	1.00	1.00	0	1500	1125	5,600	4200.0	-4100	-4100
1	1.09	1.03	1267	567	1824	0	0.0	567	-3533
2	1.20	1.06	1267	621	1996	0	0.0	621	-2912
3	1.31	1.09	1267	679	2183	142.6	142.6	536	-2376
4	1.43	1.13	1267	743	2388	0.0	0.0	743	-1633
5	1.57	1.16	1267	813	2613	0.0	0.0	813	-820
6	1.71	1.19	1267	889	2858	155.8	155.8	733	-87
7	1.88	1.23	1267	973	3127	0.0	0.0	973	885
8	2.05	1.27	1267	1064	3421	0.0	0.0	1064	1949
9	2.24	1.30	1267	1164	3743	170.3	170.3	994	2943
10	2.46	1.34	1267	1273	4095	0.0	0.0	1273	4216
11	2.69	1.38	1267	1393	4479	0.0	0.0	1393	5609
12	2.94	1.43	1267	1524	4900	186.1	186.1	1338	6947
13	3.22	1.47	1267	1667	5361	0.0	0.0	1667	8615
14	3.52	1.51	1267	1824	5865	0.0	0.0	1824	10439
15	3.85	1.56	1267	1995	6416	203.3	203.3	1792	12231
16	4.21	1.60	1267	2183	7020	0.0	0.0	2183	14414
17	4.61	1.65	1267	2388	7679	0.0	0.0	2388	16802
18	5.04	1.70	1267	2613	8401	222.2	222.2	2391	19193
19	5.51	1.75	1267	2858	9191	0.0	0.0	2858	22051
20	6.03	1.81	1267	3127	10055	0.0	0.0	3127	25178
Household	**NPV =**		**10786**	**11297**	**32627**	**6015**	**4615**	5282	
	Cost per kWh =		**ETB/kWh**	**1.05**	**3.02**	**0.56**	**0.43**		
Commercial	**NPV =**		**10786**	**12931**	**29295**	**6015**	**4615**		
	Cost per kWh =		**ETB/kWh**	**1.20**	**2.46**	**0.56**	**0.43**		

(Electricity cost escalation rate of 8.2% is used for commercial applications - an average figure for block consumptions)

Financial Feasibility (Financial Cost Comparison):

Internal Rate of Return - IRR	%	21%
Simple Payback	yr	7.6
Year-to-positive cash flow	yr	7.1
Net Present Value - NPV	ETB	5282
Benefit-Cost (B-C) ratio	-	1.88

Annex 5: Cost Comparison between Diesel and Solar PV Water Pumping

A water pumping system which delivers water for a community of 200 households.
Assumptions:

- 5 persons per household
- 3 livestock per household (Tropical livestock Unit is considered)

Estimated amount of water delivered for a community for domestic and livestock water supply

Description			Water pumping application		Unit	#of units	Water use per unit		Daily Water requirement
Domestic (200hhs*5person)			Domestic		Person	1,000.0	L/d/person	30.0	30
Livestock(200hhs*3cattle)			Livestock		Head	600.0	L/d/head	40.0	24
								Total	54

Daily water requirement		m³/d	54	
Suction head		m	50	
Drawdown		m	2	
Discharge head		m	2	
Pressure head		m	0	
Friction losses		%	7%	
Total head		m	57.78	
Equivalent energy demand/day		kWh	8.5	(before cosidering loses at generator and pump systems)
	Annual	kWh	3103.3	

Calorific Value of diesel (MJ/L)=	38.7
Pump efficiency	70%
Break thermal Genset efficiency	25%
Genset operating load factor (LF)=	0.8

<u>Diesel Genset Water Pump</u>

Financial cost analysis

Fuel Consumpion (L/L) =	8.4E-05	Liter of diesel per liter of water pumped at a given 57.78m head
Fuel cost (ETB/L) =	4.78	Cost of diesel in Addis Ababa
Daily Water supply (m3) =	54	
Cost of fuel per day (ETB) =	21.60	cost of fuel per day at base year
Fuel cost escalation rate =	5%	
Discounting rate =	10%	
Infaltion =	3%	
Economic cost of diesel (ETB/L)=	4.9675	in Addis Ababa
Diesel Genset Cost (ETB/kW) =	3000	

Energy requred from fuel/day =	48.6	kWh
Generator Capacity =	3.8	kW

(See note below for explanation)

Year	Fuel escalation rate	Annual fuel cost	Inflation	Annual costs O&M	Peiodic Costs	Capital cost	Salvaged value of genset	Total Cost	Total survice (Water)
0	1.0	0	1.0	0	0.0	56581.397		56581	0
1	1.1	8279	1.0	5368				13647	19710
2	1.1	8693	1.1	5542				14235	19710
3	1.2	9128	1.1	5721				14849	19710
4	1.2	9584	1.1	5907				15491	19710
5	1.3	10064	1.2	6098	2640.14123			18802	19710
6	1.3	10567	1.2	6297				16864	19710
7	1.4	11095	1.2	6502				17597	19710
8	1.5	11650	1.3	6714				18364	19710
9	1.6	12233	1.3	6933				19165	19710
10	1.6	12844	1.3	7159	20158.7457		-2829.07	37333	19710
11	1.7	13486	1.4	7394				20880	19710
12	1.8	14161	1.4	7636				21797	19710
13	1.9	14869	1.5	7887				22755	19710
14	2.0	15612	1.5	8146				23758	19710
15	2.1	16393	1.6	8414	3548.12904			28355	19710
16	2.2	17212	1.6	8691				25904	19710
17	2.3	18073	1.7	8978				27051	19710
18	2.4	18977	1.7	9275				28252	19710
19	2.5	19925	1.8	9582				29508	19710
20	2.7	20922	1.8	9900	27091.6685		-1007.94	56906	19710
21	2.8	21968	1.9	10229				32197	19710
22	2.9	23066	1.9	10569				33635	19710
23	3.1	24220	2.0	10921				35141	19710
24	3.2	25431	2.0	11286				36716	19710
25	3.4	26702	2.1	11663	4768.38874		-2709.17	40424	19710
							NPV	246921	178908

Capital Costs

Cost of diesel genset (ETB) =	11387	Read Note below
Cost of water pump (ETB) =	16000	AC submersible pump (Q60m3/d, H60m)
Cost of Pipes/reservior (ETB)=	17000	10m3Rotot tank+60m 2inch flexible PVC pipe
Installation & transport (ETB)=	9000	This includes training as well
Other electrical equipment(ETB)=	500	Extra cables connectors, etc
Contingency (5%)=	2694.35	
Total system cost (ETB) =	56581.4	

Annual Costs

O&M		3600	1 person at ETB300/month
Oil change		600	
Genset service & maintenance =		1000	(filters, minor maintenance,etc 4 times a year)
	Total	5200	

Periodic Costs

Genset (Overhaul)	2277.41	20% of cost of genset every five years
Purchase of new genset	15000	Replacement of genset every 10 years

Financial Cost per m3 of water (ETB/m3)=	1.38	discounting water delivered over 25 years
Economic Cost per m3 of water (ETB/m3)=	1.39	(no diff. b/n financial and economic cost for diesel genset water pump)

Note:
Assuming delivering of 54m3 of water daily from 57.8m head,
daily energy required without considering generator and
pump efficiency is 8.5kWh. Assuming pump efficiency of 70%,
load factor of 0.8 and 4 hours of operation per day, The genset capacity
will therefore be 3.8kW.
Cost of genset is = 3.8kW x ETB3000/kW=ETB 11,387
When choosing size of genset, aquifer recharging rate must also be taken into consideration.

Solar Water Pump

Daily water Requirement	M3/d	54	
Daily water Requirement	L/s	4.01	pump operating for 3.74 peak sunshine hours
Daily average radioation (kWh/m2/day) =		3.74	National annual average solar radiation (SWERA estimation)
Daily energy Solar Elect. Demand (kWh)=		12.8	Assuming 67% efficiency (i.e. 70% pump efficiency and 5% wire loses,etc)
Module size required (kWp) =		3.4	
Cost of module per Wp (ETB/Wp) =		63	
Economic Cost of Modules (ETB/Wp) =		47	

Financial Cost Analysis / **Economic Cost of PV**

Year	Capital Cost	Annual Cost	Total Cost	Capital Cost	Annual Cost	Total Cost	Savings	Cumulative Saving
0	283258.447	0	283258	224629.96	0	224630	-226677.05	-226677.05
1		1854	1854		1854	1854	11793	-214884
2		1910	1910		1910	1910	12325	-202558
3		1967	1967		1967	1967	12882	-189676
4		2026	2026		2026	2026	13465	-176211
5		2087	2087		2087	2087	16716	-159495
6		2149	2149		2149	2149	14714	-144781
7		2214	2214		2214	2214	15383	-129398
8		2280	2280		2280	2280	16083	-113314
9		2349	2349		2349	2349	16817	-96497
10		2419	2419		2419	2419	34914	-61583
11		2492	2492		2492	2492	18388	-43195
12		2566	2566		2566	2566	19230	-23965
13		2643	2643		2643	2643	20112	-3853
14		2723	2723		2723	2723	21035	17183
15		2804	2804		2804	2804	25551	42733
16		2888	2888		2888	2888	23015	65749
17		2975	2975		2975	2975	24076	89825
18		3064	3064		3064	3064	25187	115012
19		3156	3156		3156	3156	26351	141364
20		3251	3251		3251	3251	53655	195018
21		3349	3349		3349	3349	28848	223866
22		3449	3449		3449	3449	30186	254053
23		3552	3552		3552	3552	31588	285641
24		3659	3659		3659	3659	33057	318699
25		3769	3769		3769	3769	36656	355354
		NPV	304626			245997	($57,705)	

Financial Cost Analysis

Capital Cost

Cost of PV Module (ETB) =	215369.9	
Cost of DC solar pump (ETB) =	24000	(DC pump with switch and regulator - no need for inverter)
Cost of Pipe and reservoir(ETB)=	17000	
Installation and transport (ETB) =	10000	this includes training as well
Cost of module support frame	3400	assuming ETB100 per m2 area of module
Contingency 5%	13488	
Total system cost (ETB) =	283258.4	

Annual Costs

O&M	1800	As there is no much work on operation

Economic Cost

System cost (ETB) =	213933.3
Contingency 5% (ETB) =	10696.66
Total System Cost (ETB)=	224630

Financial Cost per m3 of Water (ETB/m3)=	1.70
Economic Cost per m3 of Water (ETB/m3)=	1.37

Cost per m3 of water usnig 5.2 kwh/m2/day (estimation by CESEN for national average)

Financial Cost per m3 of Water (ETB/m3)=	1.35
Economic Cost per m3 of Water (ETB/m3)=	1.02

(NOTE: Diesel Fuel price must be above ETB 7.20/L for PV water pump to compete with diesel pump)

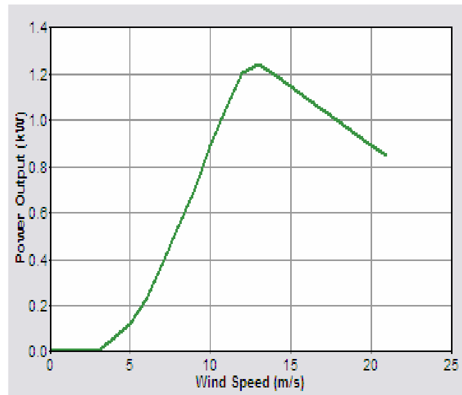
Financial Feasibility Indicators (Based on Financial Cost Comparison):

Internal Rate of Return - IRR	%	7%
Simple Payback	yr	15.6
Year-to-positive cash flow	yr	14.2
Net Present Value - NPV	ETB	-57705
Benefit-Cost (B-C) ratio	-	0.81

Annex 6
Manufacturer's Information – Specification and Performance of a Wind Generator

Wind Generator Power Curve for BWC XL.1

(Bergey Windpower)



Model	BWC XL.1
Manufacturer	Bergey Windpower
Swept area, square feet	52.8
Rotor diameter, feet	8.2
Cut-in wind speed, mph	5.6
Rated wind speed, mph	24.6
Rated output, watts	1,000
Peak output, watts	1,800
Maximum design wind speed, mph	120
Rpm at rated output	490
Blade material	Pultruded fiberglass
Tip speed ratio (TSR)	5.8
Generator type	PM 3 AC to DC
Governing system	Side facing
Governing wind speed, mph	29.0
Shut-down mechanism	Dynamic brake
Tower top weight, pounds	75
Lateral thrust, pounds	200
Battery system voltages	24
Controls included in cost	Battery controller
Utility intertie	With batteries
KWH / month @ 8 mph	55
KWH / month @ 9 mph	85
KWH / month @ 10 mph	115
KWH / month @ 11 mph	150
KWH / month @ 12 mph	188
KWH / month @ 13 mph	220
KWH / month @ 14 mph	250
Cost, US$	$1,695.00
Cost per sq. ft. swept area, US$	$32.10
Cost per pound, US$	$22.60
Weight per swept area, pounds	1.42
Weight per TSR, pounds	13
Years in production	1
Warranty, years	5
Routine maintenance	Annual inspection
Notes	

Wind speed (m/s)	Power Output (kW)
0	0
1	0
2	0
3	0
4	0.062
5	0.123
6	0.233
7	0.376
8	0.54
9	0.7
10	0.891
11	1.064
12	1.208
13	1.24
14	1.202
15	1.149
16	1.099
17	1.047
18	0.993
19	0.941
20	0.895
21	0.848

Annex 7

Analytical Calculation for Wind Turbines Performance

An Excell spread sheet model which uses mean wind speed to perform analystical calculation of wind machine performance.

Overview

This is a simple spread sheet model which uses the mean wind speed to perform analytical calculation of wind machine performance. It can be helpful to maximize the benefite of the SWERA generated wind data which provides an estimation of annual mean wind speed for any particular location. The user inputs project site specific data (eg. Avg. wind speed, site altitude, anemometer height, etc.) and the wind turbine power curve data as provided by the manufacturer (Column 2). The probility of wind speed (Column 4) for the range of wind speeds graduated into bins of 1m/s (Column 1) starting from 0m/s up to 20m/s is calculated using the Weibull and Rayleigh probability distribution of wind speed and a shape factor, k. Instantaneous wind turbine power (Column 5) is calculated by multiplying the corrected wind power on the turbine power curve (Column 3) for each bin of wind speed by the Weibull wind speed probability (Column 4).

The results or the output of the model are the annual mean wind speed at the hub height, air density factor (which is an input to correct the performance of the turbine curve for a specific site), average output power (which is the sum of instantaneous wind turbine power), daily energy output (the sum of the average power output of the turbine on a continuous, 24 hour, basis), monthly and annual energy output, and percent operating time (the time the turbine is producing some power).

The definitions given for each calculated cell (and column) help the user to develop this model on Excel spread sheet.

Input data

Site Altitiude - is the meters above sea level for the project site.

Anemometer Height - is the height at which the average wind speed is measured. If the SWERA generated annual mean wind speed is used, the value to input is 50 meters.

Mean Wind speed - annual average wind speed in meters per second at the height of measurement (at the anemometer height).

Weibull k - The probability distribution of wind speed where k is the shape factor. An excellent fits to the distribution curve is obtained for values of k ranging between 1.8 to 2.3. Rayleigh distribution is a special case of Weibull distribution where the value of k =2. If Weibull k is not know, use k = 2 fo inland sites, use 3 for coastal sites as a first approximation.

Wind Shear Exponent - The user enters the wind shear exponent, which is a dimensionless number expressing the rate at which the wind speed varies with the height above the ground. A low exponent corresponds to a smooth terrain whereas a high exponent is typical of a terrain with sizeable obstacles. This value is used to calculate the average wind speed at the wind turbine hub height and at 10 m. The wind shear exponent typically ranges from 0.10 to 0.40. The low end of the range corresponds to a smooth terrain (e.g. sea, sand and snow from 0.10 to 0.13). A wind shear of 0.25 corresponds to a rough terrain (i.e. with sizeable obstacles). The high end of the range (0.40) corresponds to a project in an urban area. A value of 0.14 (=1/7) is a good first approximation when the site characteristics are yet to be determined.

Tower Height - is the hub height of the turbine (eg. 30 meters).

Turbulence Factor - is a derating for turbulence, product variability, and other performance influencing factors. Use 0.1 (10%) - 0.15 (15%) in most cases. Setting this factor to 0% will over-predict performance for most situations.

Hub Height is the height of the turbine's hub height.

Turbulence Factor is a derating for turbulence, product variability, and other performance influencing factors. Use 0.1 (10%) - 0.15 (15%) is most cases. Setting this factor to 0% will over-predict performance for most situations.

Outputs / Results

Hub Mean Wind Speed - extrapolated wind speed at the height of the turbine hub.

Air Density Factor - the reduction of air density at a given altitude from sea level.

Average Power Output - is the average continuous equivalent output of the turbine.

Daily Energy Output - average energy produced per day.

Annual and Monthly Energy Output - Calculated using the daily value.

Percent Operating Time - sum of the time the turbine generates some power.

Instruction - How to Develop the Spread Sheet:

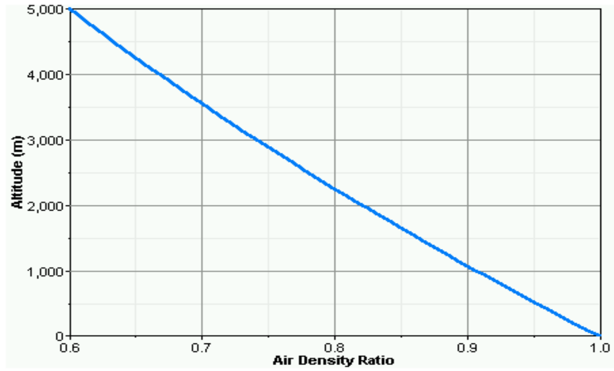
First enter all site data required under the ***Input*** column.

Then, enter the formulae below in each cell under the ***Output*** column:

H : Hub Mean Wind Speed (m/s) =	$C*(F/B)^E$	
I : Air Density Factor =	-0.18	Read from the graph for the corresponding altitude
J : Average Output Power (kW) =	The value of the sum under Column 5 in the table below	
K : Daily Energy Output (kWh) =	J * 24	
L : Annual Energy Output (kWh) =	K * 365	
M : Monthly Energy Output (kWh) =	L / 12	
Percent Operating Time =	Sum of Column 4 where the turbine is producing some power	

Inputs:		
Site Altitude (m) =	2,000	A
Anem. Height (m) =	10	B
Mean Wind Speed(m/s) =	5.6	C
Weibull K =	2	D
Wind Shear Exp. =	0.14	E
Tower Height (m) =	30	F
Turbulence Factor =	0.10	G

Outputs:		
Hub Mean Wind Speed (m/s) =	6.53	H
Air Density Factor =	-0.18	I
Average Output Power (kW) =	0.17	J
Daily Energy Output (kWh) =	4.1	K
Annual Energy Output (kWh) =	1,508.5	L
Monthly Energy Output (kWh) =	125.7	M
Percent Operating Time =	89.1%	N



The graph shows that at an altitude of 2000m, the air density ratio is about 0.82, meaning that air at that altitude is 82% as dense as air at standard temperature and pressure. (In other words, air density factor is -18%).

Use the instruction in the text box on the right side of the page to generate the values in the table:-

This table is used to estimate the average power that **SW Whisper H40** wind turbine can generate:-

Column 1	Column 2	Column 3	Column 4	Column 5
Wind speed (m/s)	Power (kW)	Corrected Power (KW)	Wind Probability (Φ_u)	net kw@v
0	0	0.000	0.00	0.00000
1	0	0.000	0.04	0.00000
2	0	0.000	0.07	0.00000
3	0	0.000	0.09	0.00000
4	0.033	0.024	0.11	0.00268
5	0.071	0.052	0.12	0.00609
6	0.132	0.097	0.11	0.01108
7	0.201	0.148	0.10	0.01546
8	0.285	0.209	0.09	0.01895
9	0.4	0.294	0.07	0.02182
10	0.514	0.378	0.06	0.02188
11	0.65	0.478	0.04	0.02060
12	0.801	0.589	0.03	0.01806
13	0.904	0.664	0.02	0.01387
14	0.92	0.676	0.01	0.00920
15	0.906	0.666	0.01	0.00566
16	0.881	0.647	0.01	0.00330
17	0.852	0.626	0.00	0.00184
18	0.819	0.602	0.00	0.00098
19	0.771	0.566	0.00	0.00049
20	0.734	0.539	0.00	0.00024
		Totals =	**1.00**	**0.172**

Instruction - to generate the values in the table

Column 1:

Enter numbers 0 to 20 as bins of wind speed. These are wind speeds in meters per second.

Column 2:

Eneter these values from the manufacturers description of the turbines power curve for various wind speeds.In this example SW Whisper H40 wind turbine is used. See the manufacturer's information for the power curve.

Column 3:

In each cell in Column 3 put the value obtained by multiplying the corresponding row of each cell in Column 2 by (1 - G) * (1 + I).

Column 4:

In each cell in column 4 put the value obtained using the following formula:

$[D/(1.123*H)] * [Column1/(1.123*H)]^{(D-1)} * Exp[-(Column1/1.123*H)^{D}]$

i.e., Column1 means the corresponding row cell in Column 1.

Column 5:

Multiply the corresponding row cells of Column 3 and Column 4 and put the product in each cell of Column 5.

Summary

This spread sheet takes **SW Whisper H40** wind turnibe of 0.9kW rated power as an example to develop the model. The user can develop the model on Excel spread sheet following the instructions given above and use it to perform analytical calculation of any wind turbine whose power curve is available.
Mean annual wind speed for any particular location in Etihopia is made available in the SWERA wind atlas.
In the absence of detail information, this model can provide a very good first approximation of energy generation using a particular type of wind turbine in a certain location.
If sufficient data is availble, other softwares like RETScreen, WASP, etc provide better estimations of energy production.

References

1. J.W.Twidell and A.D. Weir, Renewable Energy Resources, Cambridge University Press, 1986.
2. National Renewable Energy Laboratory, HOMER - The Micropower Optimization Model,Vs. 2.42.
3. Mick Sargillo, Home Power - Choosing a Home-Sized Wind Generator, 2002.

Annex 8

Analytical Calculation for BWC XL.1 Wind Turbines Performance

Developed using Excell spread sheet model which uses annual mean wind speed and wind generators power curve.
Used to calculate the Annual Energy Output in kWh

Inputs:	
Site Altitude (m) =	2,000
Anem. Height (m) =	50
Mean Wind Speed(m/s) =	6.5
Weibull K =	2
Wind Shear Exp. =	0.14
Tower Height (m) =	15
Turbulence Factor =	0.10

Outputs:	
Hub Mean Wind Speed (m/s) =	5.49
Air Density Factor =	-0.18
Average Output Power (kW) =	0.20
Daily Energy Output (kWh) =	4.8
Annual Energy Output (kWh) =	1,735.6
Monthly Energy Output (kWh) =	144.6
Percent Operating Time =	85.0%

This table is used to estimate the average power that **BWC XL.1** wind turbine can generate:-

Column 1	Column 2	Column 3	Column 4	Column 5
Wind speed (m/s)	Power (kW)	Corrected Power (KW)	Wind Probability (Φ_u)	net kw@v
0	0	0.000	0.0000	0.00000
1	0	0.000	0.0512	0.00000
2	0	0.000	0.0947	0.00000
3	0	0.000	0.1245	0.00000
4	0.062	0.046	0.1381	0.00629
5	0.123	0.090	0.1363	0.01231
6	0.233	0.171	0.1224	0.02096
7	0.376	0.276	0.1015	0.02804
8	0.54	0.397	0.0782	0.03102
9	0.7	0.514	0.0563	0.02894
10	0.891	0.655	0.0379	0.02483
11	1.064	0.782	0.0240	0.01878
12	1.208	0.888	0.0143	0.01271
13	1.24	0.911	0.0080	0.00732
14	1.202	0.883	0.0043	0.00376
15	1.149	0.844	0.0021	0.00180
16	1.099	0.808	0.0010	0.00081
17	1.047	0.769	0.0004	0.00034
18	0.993	0.730	0.0002	0.00014
19	0.941	0.691	0.0001	0.00005
20	0.895	0.658	0.0000	0.00002
		Totals =	**1.00**	**0.198**

Summary
This spread sheet takes **BWC XL.1** wind turnibe of 1kW rated power as an example to develop the model. The user can develop the model on Excel spread sheet following the instructions given in the Annex for **"How to Develop the Model"** and use it to perform analytical calculation of any wind turbine whose power curve is available.
Mean annual wind speed for any particular location in Etihopia is made available in the SWERA wind atlas. In the absence of detail information, this model can provide a very good first approximation of energy generation using a particular type of wind turbine in a certain location.
If sufficient data is availble, other softwares like RETScreen, WASP, etc provide better estimations of energy production.

Annex 9:- Feasibility of Wind Farm generated using RETScreen modeling software.

RETScreen® Financial Summary - Wind Energy Project

Annual Energy Balance

Project name		Wind Farm			
Project location		,Ethiopia			
Renewable energy delivered	MWh	36,872	Net GHG reduction	t_{CO2}/yr	331
Excess RE available	MWh	-			
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t_{CO2}	6,947
Grid type		Central-grid	Net GHG emission reduction - 25 yrs	t_{CO2}	8,270

Financial Parameters

Avoided cost of energy	$/kWh	0.0795	Debt ratio	%	70.0%
RE production credit	$/kWh	-	Debt interest rate	%	8.0%
			Debt term	yr	15
GHG emission reduction credit	$/$t_{CO2}$	8.0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	3.0%			
Energy cost escalation rate	%	5.0%			
Inflation	%	8.0%			
Discount rate	%	10.0%			
Project life	yr	25			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.8%	$	216,400	O&M	$	526,823
Development	1.4%	$	380,000			
Engineering	2.3%	$	630,000	Debt payments - 15 yrs	$	2,235,167
Energy equipment	76.1%	$	20,787,200	**Annual Costs and Debt - Total**	**$**	**2,761,990**
Balance of plant	11.7%	$	3,186,000			
Miscellaneous	7.8%	$	2,131,635	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**27,331,235**	Energy savings/income	$	2,931,288
				Capacity savings/income	$	-
Incentives/Grants		$	-			
				GHG reduction income - 21 yrs	$	2,646
				Annual Savings - Total	**$**	**2,933,935**
Periodic Costs (Credits)						
Drive train		$	1,000,000	Schedule yr # 10,20		
Blades		$	1,000,000	Schedule yr # 15		
		$	-			
End of project life - Credit		$	-			

Financial Feasibility

			Calculate energy production cost?	yes/no	Yes
Pre-tax IRR and ROI	%	13.5%	Energy production cost	$/kWh	0.0708
After-tax IRR and ROI	%	13.5%	Calculate GHG reduction cost?	yes/no	Yes
Simple Payback	yr	11.4	GHG emission reduction cost	$/$t_{CO2}$	(1,464)
Year-to-positive cash flow	yr	11.4	Project equity	$	8,199,371
Net Present Value - NPV	$	4,395,366	Project debt	$	19,131,865
Annual Life Cycle Savings	$	484,229	Debt payments	$/yr	2,235,167
Benefit-Cost (B-C) ratio	-	1.54	Debt service coverage	-	1.12

Yearly Cash Flows

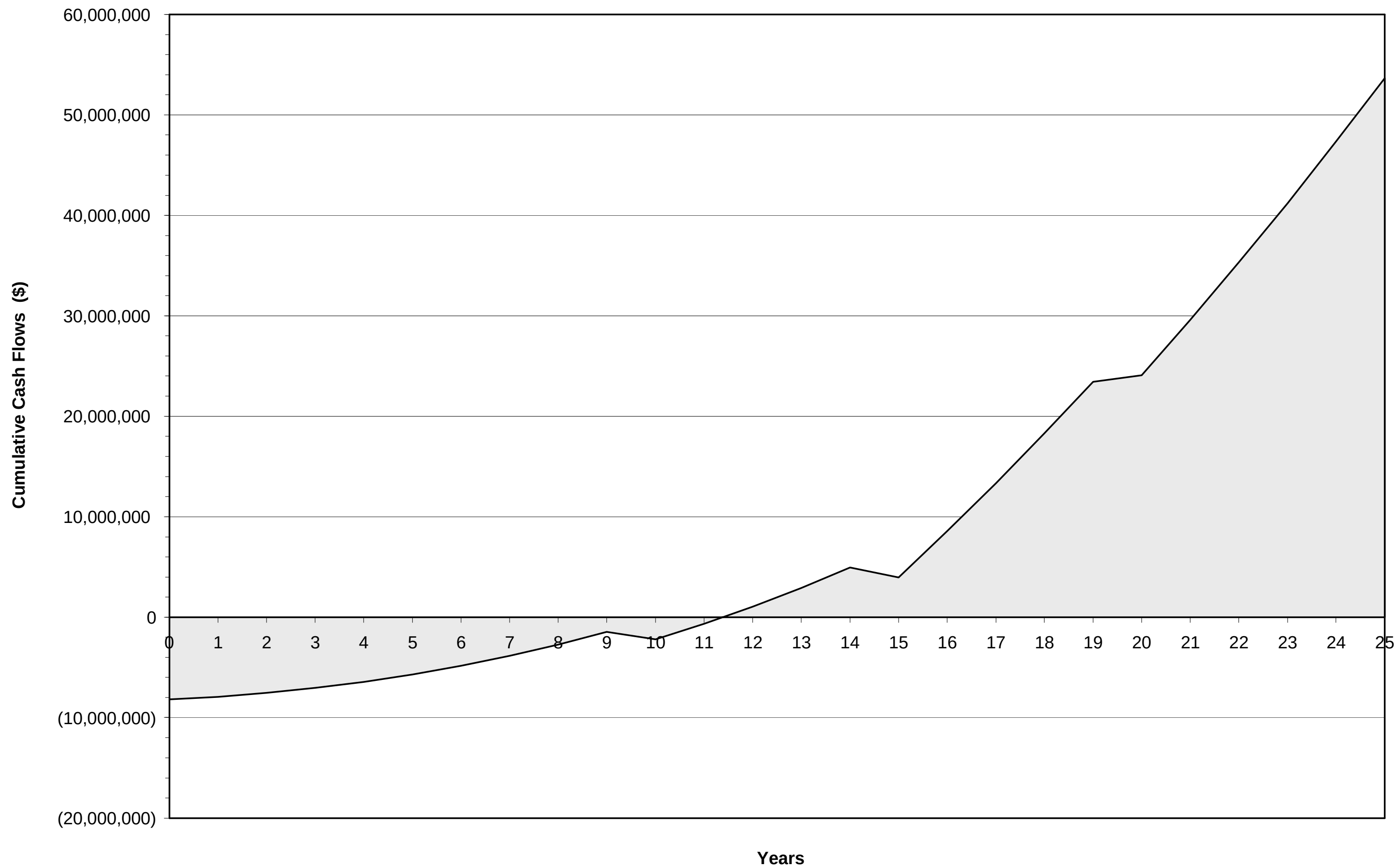
Year #	Pre-tax $	After-tax $	Cumulative $
0	(8,199,371)	(8,199,371)	(8,199,371)
1	276,442	276,442	(7,922,929)
2	384,899	384,899	(7,538,030)
3	497,412	497,412	(7,040,618)
4	614,073	614,073	(6,426,545)
5	734,974	734,974	(5,691,571)
6	860,197	860,197	(4,831,374)
7	989,822	989,822	(3,841,552)
8	1,123,920	1,123,920	(2,717,633)
9	1,262,554	1,262,554	(1,455,079)
10	(753,148)	(753,148)	(2,208,227)
11	1,553,632	1,553,632	(654,595)
12	1,706,148	1,706,148	1,051,553
13	1,863,339	1,863,339	2,914,892
14	2,025,204	2,025,204	4,940,096
15	(980,448)	(980,448)	3,959,647
16	4,598,015	4,598,015	8,557,662
17	4,773,684	4,773,684	13,331,347
18	4,953,804	4,953,804	18,285,150
19	5,138,248	5,138,248	23,423,398
20	665,902	665,902	24,089,300
21	5,519,441	5,519,441	29,608,741
22	5,710,686	5,710,686	35,319,427
23	5,910,297	5,910,297	41,229,724
24	6,113,016	6,113,016	47,342,740
25	6,318,446	6,318,446	53,661,186

Version 3.2

NRCan/CETC - Varennes

Wind Energy Project Cumulative Cash Flows
Wind Farm, ,Ethiopia

Renewable energy delivered (MWh/yr): 36,872 **Total Initial Costs: $ 27,331,235** **Net average GHG reduction (t_{CO2}/yr): 331**



IRR and ROI: 13.5% **Year-to-positive cash flow: 11.4 yr** **Net Present Value: $ 4,395,366**

RETScreen® Sensitivity and Risk Analysis - Wind Energy Project

Use sensitivity analysis sheet?	Yes	Perform analysis on	After-tax IRR and ROI	
Perform risk analysis too?	Yes	Sensitivity range	20%	
Project name	Wind Farm	Threshold	15.0	%
Project location	,Ethiopia			

Sensitivity Analysis for After-tax IRR and ROI

RE delivered (MWh)		Avoided cost of energy ($/kWh): 0.0636 (-20%)	0.0716 (-10%)	**0.0795** (0%)	0.0875 (10%)	0.0954 (20%)
29,497	-20%	1.1%	4.2%	7.0%	9.6%	12.2%
33,184	-10%	4.2%	7.3%	10.3%	13.2%	16.0%
36,872	0%	7.0%	10.3%	**13.5%**	16.6%	19.8%
40,559	10%	9.6%	13.2%	16.6%	20.1%	23.6%
44,246	20%	12.2%	16.0%	19.8%	23.6%	27.5%

Initial costs ($)		Avoided cost of energy ($/kWh): 0.0636 (-20%)	0.0716 (-10%)	**0.0795** (0%)	0.0875 (10%)	0.0954 (20%)
21,864,988	-20%	11.4%	15.5%	19.6%	23.7%	27.9%
24,598,112	-10%	9.0%	12.6%	16.1%	19.7%	23.3%
27,331,235	0%	7.0%	10.3%	**13.5%**	16.6%	19.8%
30,064,359	10%	5.4%	8.4%	11.3%	14.2%	17.0%
32,797,482	20%	4.1%	6.9%	9.6%	12.2%	14.7%

Annual costs ($)		Avoided cost of energy ($/kWh): 0.0636 (-20%)	0.0716 (-10%)	**0.0795** (0%)	0.0875 (10%)	0.0954 (20%)
421,459	-20%	8.7%	11.9%	15.0%	18.1%	21.3%
474,141	-10%	7.9%	11.1%	14.2%	17.4%	20.5%
526,823	0%	7.0%	10.3%	**13.5%**	16.6%	19.8%
579,506	10%	6.1%	9.5%	12.7%	15.8%	19.0%
632,188	20%	5.2%	8.6%	11.9%	15.1%	18.2%

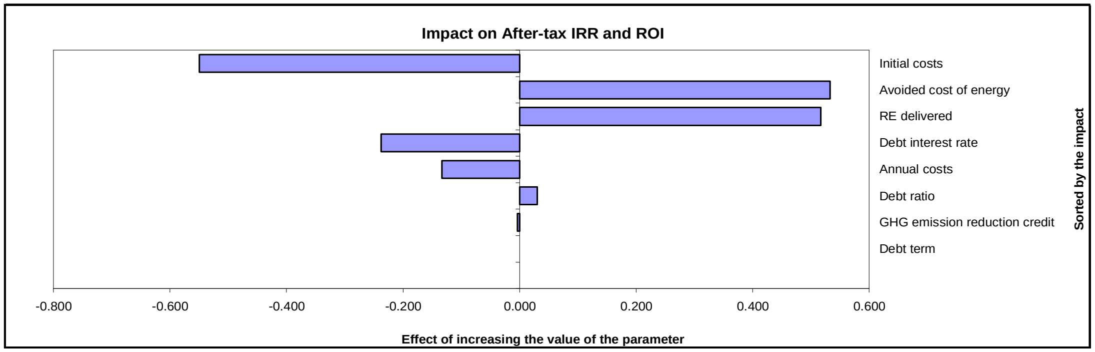
Debt interest rate (%)		Debt ratio (%): 56.0% (-20%)	63.0% (-10%)	**70.0%** (0%)	77.0% (10%)	84.0% (20%)
6.4%	-20%	13.5%	14.2%	15.0%	16.0%	17.5%
7.2%	-10%	13.1%	13.6%	14.2%	15.0%	16.2%
8.0%	0%	12.6%	13.0%	**13.5%**	14.1%	14.9%
8.8%	10%	12.1%	12.4%	12.7%	13.2%	13.7%
9.6%	20%	11.7%	11.8%	12.0%	12.3%	12.6%

Debt interest rate (%)		Debt term (yr): 12.0 (-20%)	13.5 (-10%)	**15.0** (0%)	16.5 (10%)	18.0 (20%)
6.4%	-20%	14.0%	14.7%	15.0%	15.5%	15.9%
7.2%	-10%	13.5%	14.0%	14.2%	14.7%	15.0%
8.0%	0%	12.9%	13.4%	**13.5%**	13.9%	14.1%
8.8%	10%	12.3%	12.8%	12.7%	13.1%	13.2%
9.6%	20%	11.8%	12.1%	12.0%	12.3%	12.3%

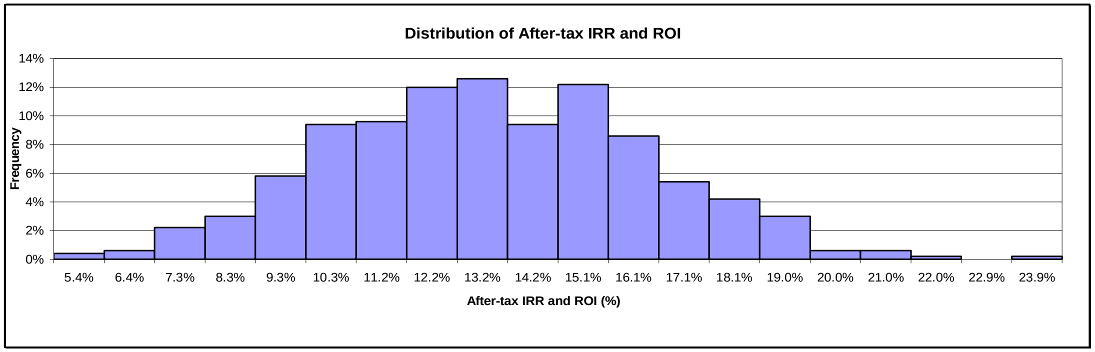
Net GHG emission reduction - 21 yrs (t_{CO2})		GHG emission reduction credit ($/$t_{CO2}$): 6.4 (-20%)	7.2 (-10%)	**8.0** (0%)	8.8 (10%)	9.6 (20%)
5,557	-20%	13.5%	13.5%	13.5%	13.5%	13.5%
6,252	-10%	13.5%	13.5%	13.5%	13.5%	13.5%
6,947	0%	13.5%	13.5%	**13.5%**	13.5%	13.5%
7,641	10%	13.5%	13.5%	13.5%	13.5%	13.5%
8,336	20%	13.5%	13.5%	13.5%	13.5%	13.5%

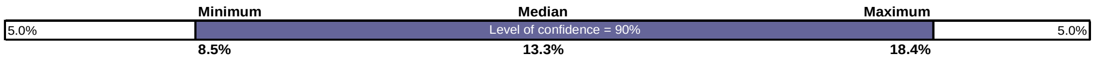
Risk Analysis for After-tax IRR and ROI

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Avoided cost of energy	$/kWh	0.0795	15%	0.0676	0.0914
RE delivered	MWh	36,872	15%	31,341	42,402
Initial costs	$	27,331,235	20%	21,864,988	32,797,482
Annual costs	$	526,823	15%	447,800	605,847
Debt ratio	%	70.0%	5%	66.5%	73.5%
Debt interest rate	%	8.0%	30%	5.6%	10.4%
Debt term	yr	15	0%	15	15
GHG emission reduction credit	$/$t_{CO2}$	8.0	50%	4.0	12.0



Median	%	13.3%
Level of risk	%	10%
Minimum within level of confidence	%	8.5%
Maximum within level of confidence	%	18.4%

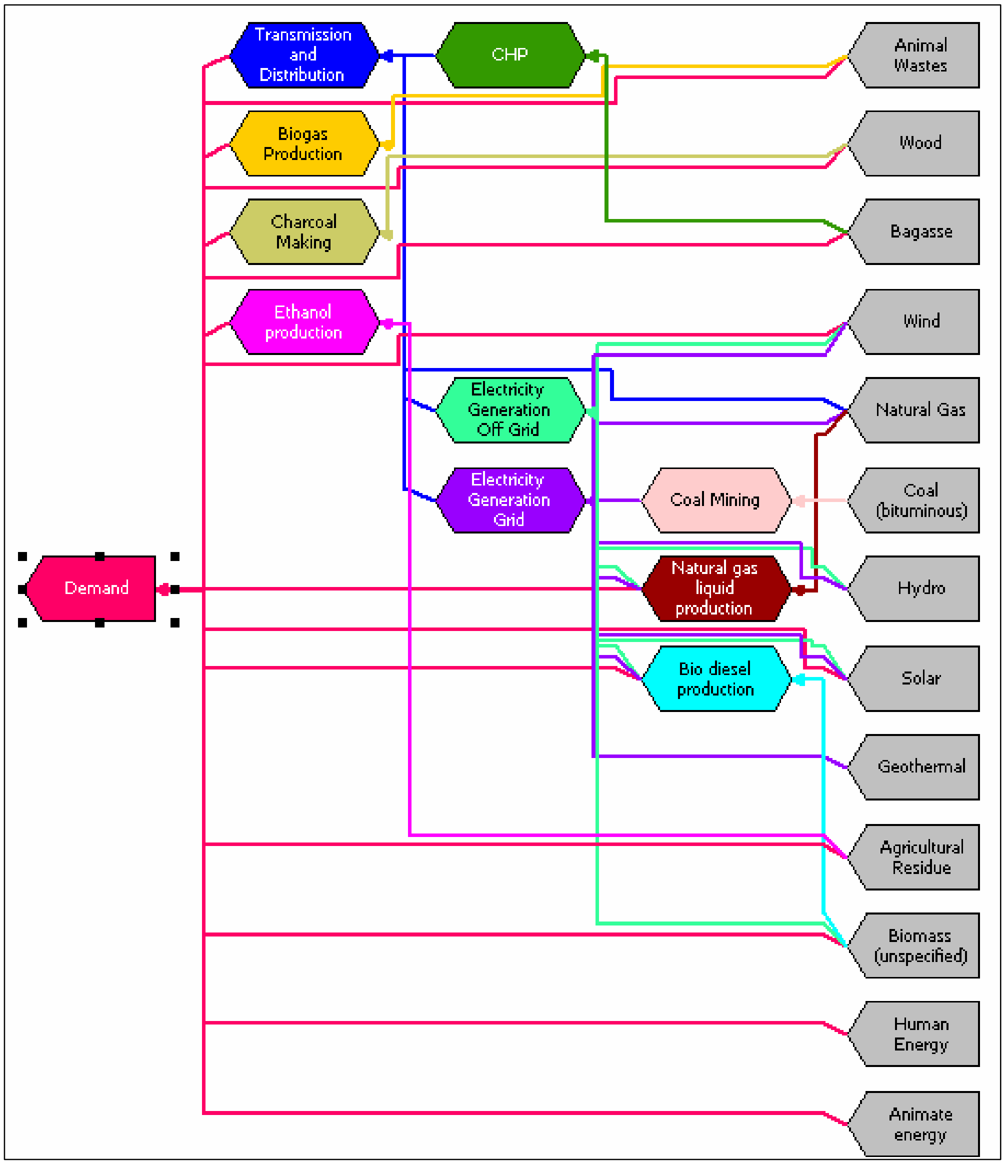




Annex 10.

Figure A10.1

Energy flows in the Ethiopian Energy System (from the LEAP model)



Annex 10

Table A10.1

Ethiopian GDP development, 2000-2005

Items		**Year**					
		1999/00	**2000/01**	**2001/02**	**2002/03**	**2003/04**	**2004/05**
GDP at Constant Basic Prices		59,575	63,973	63,756	61,654	68,472	74,506
Sector	Agriculture & Allied Activities	28,595	31,626	30,950	27,361	32,100	35,948
	Industry	7,457	7,817	8,213	8,665	9,254	9,865
	Services	24,197	25,122	24,997	26,096	27,614	29,221
Growth in Real GDP		5.4	7.4	-0.3	-3.3	11.1	8.8
Real GDP per capita		951.9	993.1	961.9	904.4	976.8	1034.0
Share in GDP (in %)	Agriculture & Allied Activities	44	45	49	44	47	48
	Industry	13	12	13	14	14	13
	Services	41	39	39	42	40	39
Growth in Real GDP per capita		2.3	4.3	-3.1	-6.0	8.0	5.9
Agriculture & A. Activities	Growth	2.2	10.6	-2.1	-11.6	17.3	12.0
Industry	Growth	1.8	4.8	5.1	5.5	6.8	6.6
Services	Growth	9.5	3.8	-0.5	4.4	5.8	5.8

Source: National Bank of Ethiopia (online at www.nbe.gov.et) based on data from the Ministry of Finance and Economic Development and NBE Staff computations.