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Improved Sustainable Power Supply Option for Ethiopian Remote Area

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ABSTRACT: many nations are embarking on introduction of clean/ renewable energy for displacement of oil-produced energy. Moreover, hybrid power generation system technology is an emerging energy option since it promises great deal of challenges and opportunities for developed and developing countries. Ethiopia is one of developing countries, which has an area of 1,127,127 sq km, and more than 80% of its population resides in rural areas without access to electricity. This research paper focuses on feasibility study, design and modeling of a hybrid electric power generation system using solar/biogas energy resource for area around Tefribirhan village in Oromia regional state. The work was begun by investigating solar, biomass energy potentials of the specified site, compiling data from different sources and analyzing it using HOMER software. The solar energy potential has been given in the form of solar radiation plots and calculated using regression coefficients specific to the sites based on the sunshine duration data. According to the results obtained through the analysis, the site has abundant solar energy potential (5.21 -6.42 kWh/m²/day) and, 10 kW biomass generators are considered to find out the most cost effective system. The main reason of using to fulfill the energy demand in peak hour both for winter and summer season and also meet the terms of backup requirements. As biomass resource is available in prosperity, fuel cost is considered zero. The main cost is considered for biogas generation procedure and biogas power generator and only cow dung is considered for the biogas production.

Based on the promising findings of these two energy resource potentials, solar/biogas design of a standalone hybrid energy supply system has proceeded. The hybrid standalone supply system is intended to supply electricity to model community of 100 households which have lighting, water pumping, a radio receiver, medical equipment for a health clinic and school with total consumption of 88.02 kWh/day.

KEYWORDS: Hybrid system, Biogas, Biomass Resource, Sunshine Duration, Solar Radiation, , photovoltaic, HOMER optimization, standalone system, PV-wind hybrid, breakeven grid extension distance etc.

I. INTRODUCTION

As we know that, world economies are heavily reliant on energy. However, in many developing countries and less developed countries, a significant proportion of the population lives without access to electrical power. Ethiopia is one of developing countries, which has an area of 1,127,127 sq km, a population of 89 million in 18 million households and more than 80% of its population resides in rural areas without access to electricity [1]. Extension of the central electricity grid to rural areas is either financially not viable or practically not feasible as these locations are, sparsely populated and have a very low power demand. As a result, many of these communities remain without electricity and may never receive grid power.

The remote village around Tefribirhan at (8°29'N, 40°01'E) [2], are one of those rural areas which have no access to electricity. Due to its remote locations and its small size, electrification with traditional diesel power is impractical. A major limitation to the development of many rural communities has been the lack of this usable electricity. The main

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benefits of using electric power includes: improved education, improved health care, better transportation, improved communication systems and higher promotion of economic growth.

Growing concerns of global warming, and depleting oil/gas reserves and due to the contradiction between gradual growths of the global energy demand, renewable energy such as solar energy, wind energy, bio-energy, and hydropower might become a new manner in which we produce energy for sustainable development.

Energy consumption is proportionally to the level of economic development. However, as stated in the above section, a significant proportion of Ethiopian population resides in rural areas. Most of these areas are not yet electrified. Only 3.8 percent of rural households are electrified [3]. For this area, the electric supply option (off-grid or grid tied) is not properly analyzed and still it is a big problem.

The federal government of Ethiopia is committed to integrate rural development strategies, which aims to eliminate poverty and create full employment by the year 2020. Rural people must be at the heart of this strategy. In order to fulfill this, Development of alternative energy from renewable sources such as wind, solar, geothermal, as well as biomass will be the first alternative for this rural area. Based on Ethiopia's Climate Resilient Green Economy (CRGE) Strategy, Currently this supply option gates great attention. From these resource, solar energy systems and biogas with an auxiliary design forms are thought to be the best solution for rural electrification due to significant availability of these resource near by the rural community in Ethiopia (since the country lies in the sunny belt between northern latitudes of 3° and 15°). So far, these renewable energy resources are not exploited sufficiently in the country, mainly due to lack of proper site selection, technology transfer, and on-job training experiences.

Therefore, in this study identifying a renewable power generation option (solar home system, grid extension and solar/biogas minigrid) is designed and simulated, to electrify the community living in Tefribirhan village in mertiwereada oromia regional state.

II. RELATED WORK METHODOLOGY

The methodology used in this study was begun by investigating solar and biomass energy potentials of the specified site, compiling data from different sources and analyzing it using HOMER software. The data regarding solar irradiation for the site understudy are collected from the National Metrological Agency (NMA) and from different websites and analyzed using the software.

A. Solar Radiation Estimation of the Site:

Ethiopia is one of the developing countries without properly recorded solar radiation data and, like many other countries, what is available is sunshine duration data. However, given a knowledge of the number of sunshine hours and local atmospheric conditions, sunshine duration data can be used to estimate monthly average solar radiation, with the help of empirical equation below [5]. These equation used Angstrom equation and found the corresponding coefficients which can be applied to different sites in Ethiopia.

$$H = H_o \left(a + b \left(\frac{S}{S_o} \right) \right) \quad (1)$$

Where:

H = is the monthly average daily radiation on a horizontal surface (MJ/m²)

H_O = is the monthly average daily extraterrestrial radiation on a horizontal surface (MJ/m²)

S = is the monthly average daily number of hours of bright sunshine

S_O = the monthly average of the maximum possible daily hours of bright sunshine,

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a and b are regression coefficients for M number of data points.

$$a = \frac{\sum \frac{H}{H_0} \sum \left(\frac{S}{S_0}\right)^2 - \sum \frac{S}{S_0} \sum \frac{SH}{S_0 H_0}}{M \sum \left(\frac{S}{S_0}\right)^2 - \left(\sum \frac{S}{S_0}\right)^2} \quad (2)$$

$$b = \frac{M \sum \frac{S}{S_0} \sum \frac{H}{H_0} - \sum \frac{S}{S_0} \sum \frac{H}{H_0}}{M \sum \left(\frac{S}{S_0}\right)^2 - \left(\sum \frac{S}{S_0}\right)^2} \quad (3)$$

The extraterrestrial radiation, H_0 on a horizontal plane outside the atmosphere, is given by:

$$H_0 = \frac{24 \cdot 3600 \cdot G_{SC}}{\pi} \left(1 + 0.033 \cdot \cos \left(\frac{360 n_d}{365} \right) \right) * \left(\cos \phi \cos \delta \sin \omega_s + \frac{\pi \omega_s}{180} \sin \phi \sin \delta \right) \quad (4)$$

Where;

n_d = is the day number,

G_{SC} = is the solar constant (1367 W/m^2),

ϕ = is the latitude of the location ($^\circ$),

δ = is the declination angle ($^\circ$), given by;

$$\delta = 23.45 \sin \left(360 \frac{248 + n_d}{365} \right) \quad (5)$$

ω_s = the sunset hour angle ($^\circ$), which is given by equation 6 below

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta) \quad (6)$$

$$S_0 = \frac{2}{15} \omega_s \quad (7)$$

After calculating the coefficient a and b, The regression coefficients a and b anywhere in the world [4];

$$\frac{H}{H_0} = 0.23 + 0.48 \frac{S}{S_0} \quad (8)$$

The maximum possible sunshine duration (monthly average day length S_0) is given by calculated solar radiation data of the site and the data taken from NASA satellite measurement data base were compared with other and finally Monthly average solar resources is shown in Figure.1 below.

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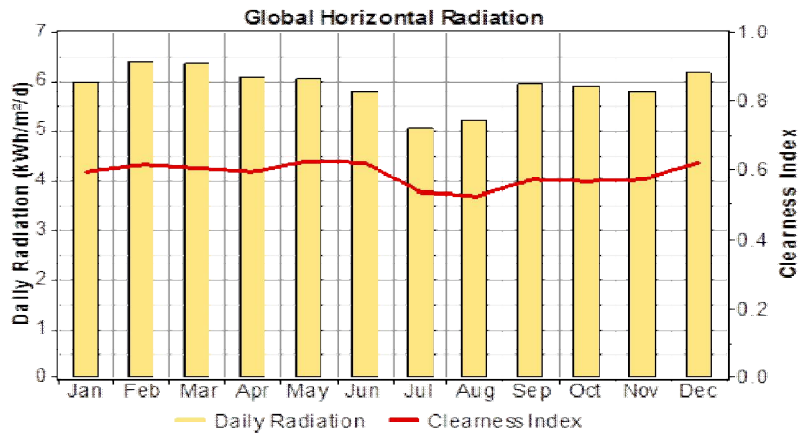


Fig.1 Monthly average solar radiation data

B. Biomass Resource of the site:

The biomass resource takes various forms (e.g., wood waste, agricultural residue, animal waste, energy crops) and may be used to produce heat or electricity. HOMER models biomass power systems that convert biomass into electricity. In this study cow dung was used. Power generation by using cow dung consists of several process steps, which are shown in figure 2. First, cow dung is stored in biogas digester and produced gas in gasification process is cleaned and supplied to a syngas engine to produce electricity [6].

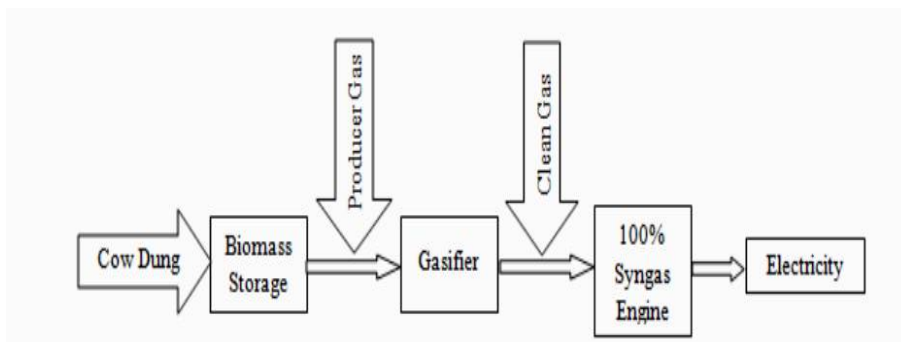


Fig 2. Electricity Generation by cow dung gasification

The following table .1 gives an estimate of quantity of dung required for various plant sizes.

Size of plant (gas production/ day) (m ³)	Amount of wt dung required (kg)	No of cattle
2	35-40	2-3
3	45-50	3-4
4	55-60	4-6
6	80-100	6-10
8	120-150	12-15
10	160-200	16-20

Table,1 estimate of quantity of dung required for various plant sizes.

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Based on this table, as already explained in the above the total house hold considered in the village is 100 and for each household 1-2 cattle per home was considered and finally the following biomass resource was be simulated from the software.

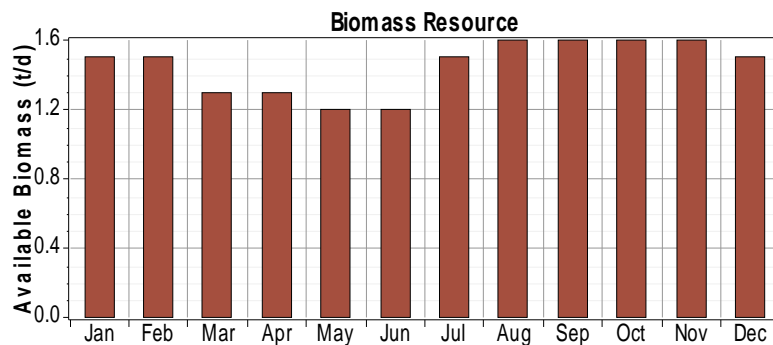


Fig 1 Monthly average biomass data of the site

C. Electrical load estimation:

Electric load in the rural villages of Ethiopia can be assumed to be composed of lighting, radio receiver and television set, water pumps, health post and primary schools load. In this study, the entire load types with clinical load addition for the specified number of community raised in the above is properly modeled with the help of software. The software models three types of loads. **Primary load** is electric demand that must be served according to a particular schedule. **Deferrable load** is electric demand that can be served at any time within a certain time span. **Thermal load** is demand for heat. In this research only Primary and deferrable load were considered.

The following Figures 2 and 3 shows, the 24 hour primary and monthly average deferrable load profiles of the site.

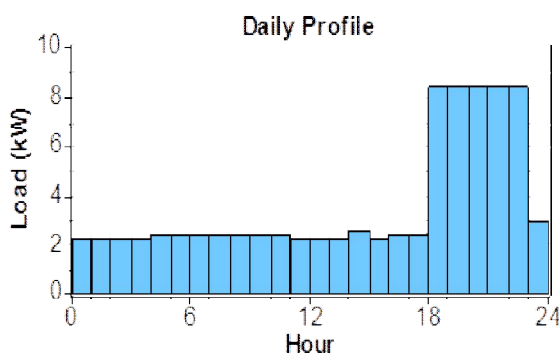


Fig.2 Primary load profile of the community

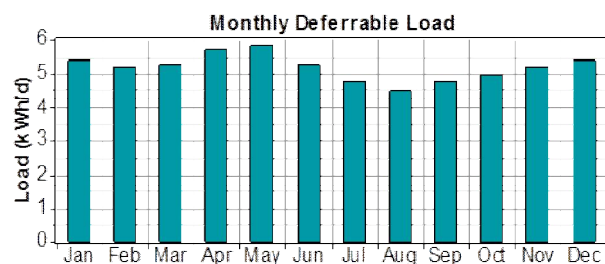


Fig.3 Monthly average deferrable load profile of the community

III. SYSTEM ARCHITECTURE

This research proposes a solar photovoltaic and biogas hybrid system for generation of electricity to overcome from global warming effect, economic and statistical impact on prosperity and dependency with biogas generator(s) and bank of batteries. As the demand from the load does not always equal the primary source, battery banks are generally used rather than using biogas generator alone as ancillary. Power conditioning units, such as inverters, are also part of the supply system. A schematic diagram of the standalone hybrid power supply system sought is shown in figure 4 and its representation by HOMER is indicated in figure 5.

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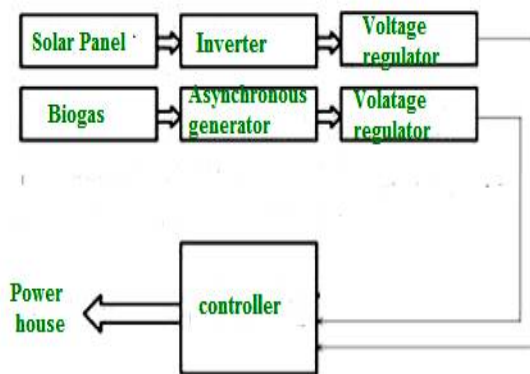


Fig.4 General Scheme of standalone hybrid power supply system

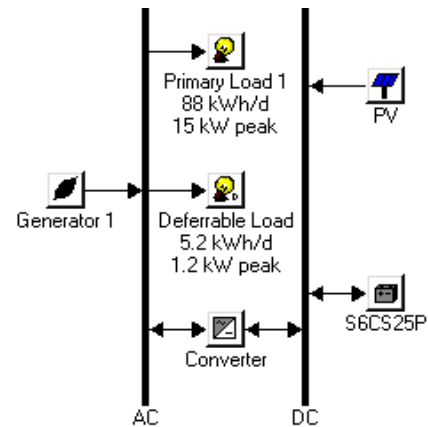


Fig 5. HOMER diagram for the Hybrid system

There are three principal tasks performed by HOMER software. These are;

- i) Simulation
- ii) Optimization
- iii) Sensitivity analysis

A Key Model Input Assumption to the software for the Stand-alone Design: The values given in the below table are primarily chosen based on the size of the load for the specified community. The yearly load pattern of the site is given in the above fig 2&3. The given costs are estimated according to the current local and global price of the components. The range of sizes for the PV, Biogas Generator and the converter and the number of batteries are the other inputs into the software which are given so as to give flexibility to the software and optimize the output results.

	PV	Biogas generator	Battery(Surrette 6CS25P)	Converter
Size (kW)	1	1	1156Ah	1
Capital (\$)	1200-4000	600	880	700
Replacement (\$)	1200-4000	500	650	700
O & M cost(\$/yr)	0	0.015\$/hr	15	0
Sizes Considered(kW)	0,5,10,15,20,25,30,35, 40 50 60 70	0,10,20,30,40	-	0,20,30,40,50,60 70,80
Quantities considered	-	-	0,10,25,30,40,50,60 80.90,100,120	-
Life time	25	25,0000hrs	9,645kwh	15

Table 2: input into software

B Breakeven Grid Extension Distance:

The distance from the grid which makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. Farther away from the grid, the stand-alone system is optimal. Nearer to the grid, grid extension is optimal.

Table 3 below shows, cost associated with gird extension. The cost is estimated depending on EEPCO information.

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Name of site	Voltage level	Capital cost(\$/ km)	O&M cost (\$/yr/km)
TeferiBirhan	33Kv	9500 \$/km	2.5- 3.5 % of capital cost

Table .3 Grid extension cost

IV. RESULTS

Once the biomass and solar resource data are entered into the software, by changing the most important controlling variables HOMER is run repeatedly to obtain optimum results. In addition to those control input parameters, multiple prices of PV modules have been used for sensitivity analysis. Consequently, a list of realizable optimal combinations of the hybrid system set-up is obtained in the simulation output.

Optimization list is generated in either of two forms; an overall form in which the top-ranked system configurations are listed according to their net present cost (NPC) and in a categorized form; where only the least-cost system configuration is considered for each system type.

Table 4 shows a list of the possible combinations of system components in an overall form. The tables are generated based on a particular set of inputs selected from the input summary and the solar and biomass resource data for site. The most cost effective system, i.e. the system with the lowest net present cost, is the PV- biogas generator-battery-converter set-up with the generator operating under a load following (LF) strategy. For this set-up, the total net present cost (NPC) is \$73,974, the cost of energy (COE) is 0.170 \$/kWh, contribution from renewable resources is 100%, and which is significant percent for practical implementation.

PV(Kw)	Label (Kw)	Battery	Converter (Kw)	Total NPC(\$)	COE(\$/kwh)	RF	Capacity Shortage
10	10	15	10	73,974	0.170	1.00	0
5	10	20	10	74,005	0.170	1.00	0
0	10	25	10	74,656	0.171	1.00	0
5	15	10	10	75,557	0.173	1.00	0
0	15	15	10	78,274	0.179	1.00	0
5	15	15	10	78,460	0.180	1.00	0
15	10	10	10	79,219	0.182	1.00	0
10	10	20	10	79,448	0.182	1.00	0
5	10	25	10	79,788	0.183	1.00	0

Table 4 extracts from the overall optimization results

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Figure 6 shows the monthly average electrical production of this system.

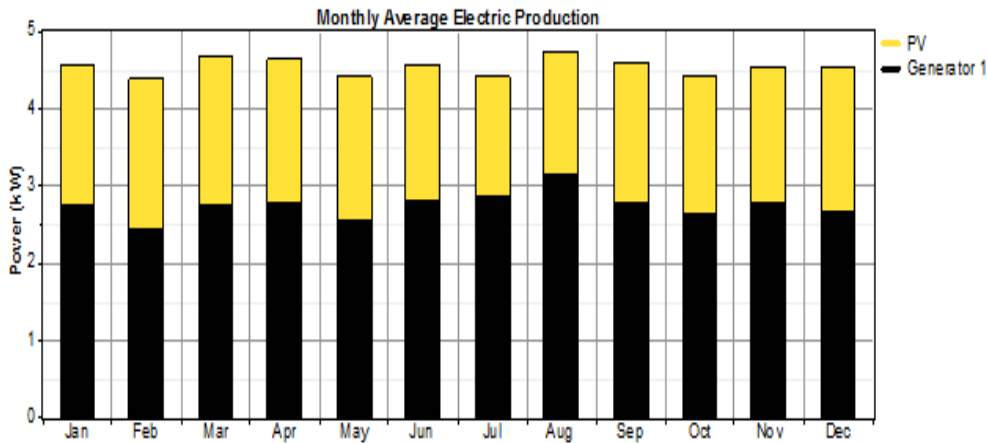
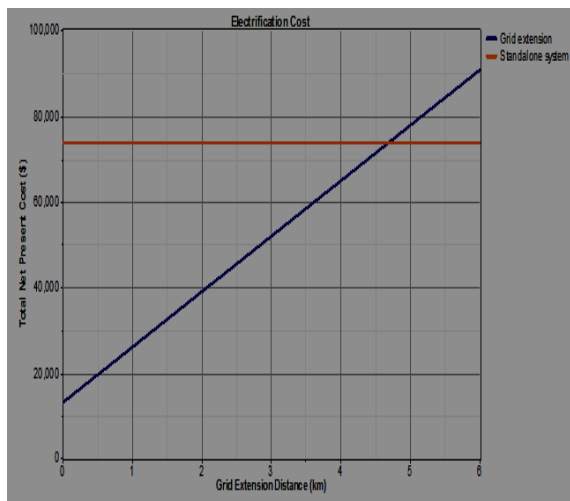


Figure 6: Contribution of the power units with 100 % RF, 1st row in Table 4

VI. COMPARISONS

Comparison of the Grid extension with standalone (Off-Grid) system:

This comparison can be performed with the help of the software model based on breakeven grid extension distance, which is the distance from the grid which makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. The capital cost of 33 KV per kilometer for the location is 9500\$/km and the annual operation maintenance coast of the line is 3% of the capital cost per kilometer per year. TefriBirhan is located 15 km from nearby station; the breakeven distance is 4.8 km, meaning which is the net present cost of grid extension equals the net present cost of the stand-alone system. The village is located far from breakeven grid extension. If you go farther from this point (breakeven grid extension distance) the stand alone is the optimal solution. Therefore, the standalone system is the optimal solution of power supply for the site.



VII. CONCLUSION

Two power supply options have been identified. The first option was a hybrid standalone power generation system which comprises of PV arrays, Biogas generator with battery banks and power convertor and the second option was to construct new transmission line from nearest substation to selected site. From the results, various alternative feasible hybrid set-ups, with different levels of contribution by the renewable resources, were obtained. The choice is restricted by varying net present cost of each set-up. The COE of the feasible set-ups obtained in this study are in the range of (17 to 19cents/kwh) which is high compared to the current global electricity tariff and the tariff in the country (< 6 cents/kwh) where the main source of electric energy is hydro-power. However, the absence of electricity usage in rural areas (<3.6% coverage), this cost should not be seen as a significant impairment.

The second option looked at power supplied from the nearest substation. These options also performed better for grid extension for distances less than 4.8 km. The breakeven distances from the grid extension is 4.8Kilometer. Villagesare

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located above the breakeven grid extension distance from the nearest substation. Therefore the above standalone hybrid system is the best solution to supply the specified community.

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BIOGRAPHY



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