

Feasibility Study of Renewable Energy Resources for Electrification of Small Island

A Case Study on Tana Lake Island Ethiopia

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Abstract:- Tourism is one of the key incomes of Ethiopia. To increase this income from the current 10% national gross domestic product to high value, electrifying rural tourist attractive areas are very important. Tana Lake Island is one of the best tourist areas in Ethiopia. The present study relates the main renewable energy resources to the electrical production in the small islands in Lake Tana. In this paper different hybrid schemes were performed i.e PV/Wind/Battery and PV/Wind/pumped hydro. To compare the above hybrid scheme HOMER software used as optimization and sensitivity analysis tool. As a result, from economical point of view, PV/Wind/pumped hydro hybrid system is found as low cost of energy about \$0.151/kWh which is much lower than diesel generators and previously studied PV-battery hybrid systems which is estimated to cost about \$0.325/KWh.

Keywords:- Wind, Solar, Hybrid, HOMER, Pumped Hydro, Load Estimation.

I. INTRODUCTION

Ethiopia is located in the eastern part of Africa between 3° to 15° north and 33° to 48° 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 80 million, which is mostly distributed in northern, central and southwestern high lands [1]. 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, oilseeds and recently cut-flower are the major agricultural export commodities. At present the per capita income in Ethiopia is less than USD 200. With only 6% of households connected and 15% of the population having access to electricity in 2007 [2] from Ethiopian Electric Power Corporation (EEPCo), access to electricity in Ethiopia is one of the lowest by any standards [3]. In other way tourism in Ethiopia accounted for 7.5% of the country's gross domestic product (GDP) in 2008, having barely increased over the previous year. The government is proving its

commitment and willingness to develop tourism through a number of initiatives. Tourism is a featured component of Ethiopia's Poverty Reduction Strategy Paper (PRSP) that aims to combat poverty and encourage economic development. From popular tourism places of Ethiopia Islands on Tana Lake are one. Lake Tana is the largest lake in Ethiopia located in Amhara region in the North-Western Ethiopian high lands. The lake is approximately 84kilometer long and 66kilometer wide with a maximum depth of 15meter and an elevation of 1840meter. There are 37 islands on Lake Tana from them 19 islands had churches (monsters). Dek Island is the largest of the 37 islands on Lake Tana covering a land area of 3263 hectare (32.63 Km²) and circumference of 2790.06 m. It is located nearly at the center of the lake, 44 Km (North) away from the regional city Bahir Dar (after a 4 hour travel by boat). According to 2010 Annual Statistical Report from Bahir Dar zuriaworeda administration, there are 7000 peoples in five different Villages. There are 725 households on these Villages who are registered and paid their annual taxes.

II. RENEWABLE ENERGY POTENTIAL ASSESSMENT

A. Solar Energy Assessment of Deck Island

There is only sunshine duration data recorded at the nearby stations (Bahrdar). The solar radiation of the district is estimated as shown in Table 1-1. The last column of Table 1 shows solar radiation data obtained from NASA in (kWh/m²/day).

Mid of month	n _d	δ(°)	ω _s (°)	N (hours)	n	H ₀ (kWh/ m ² /d)	n/N	H(kWh/ m ² /d)	NASA
Ja 15	15	-21.3	86.01	11.47	9.90	8.82	0.86	5.87	6.05
Fe 14	45	-13.7	87.53	11.67	10.10	9.53	0.87	6.35	6.78
Ma 15	74	-2.89	89.52	11.94	8.40	10.22	0.70	6.57	6.95
Ap 15	105	9.34	91.75	12.23	8.00	10.54	0.65	6.63	6.62
Ma 15	135	18.74	93.56	12.47	8.10	10.45	0.65	6.56	6.34
Ju 15	166	23.30	94.51	12.60	7.30	10.29	0.58	6.18	5.5
Jul 15	196	21.56	94.14	12.55	5.80	10.32	0.46	5.59	5.43
Au 15	227	13.87	92.60	12.35	4.90	10.44	0.40	5.22	6.11
Se 15	258	2.33	90.47	12.06	7.90	10.30	0.65	6.48	6.09
Oc 15	288	-9.49	88.31	11.78	9.10	9.74	0.77	6.40	6.09
No 15	319	-19.1	86.46	11.53	9.50	8.99	0.82	5.96	5.82
De 15	349	-23.3	85.58	11.41	9.70	8.58	0.85	5.71	6.49
Average								6.13	6.19

Table 1:- Monthly solar radiation at the project site

For this study the calculated monthly averaged daily radiation summarized in Table 1 (9th column) is used.

B. Wind energy estimation of Deck Island

Mean wind speed (V_m) is the most commonly used indicator of wind production potential where defined as

$$V_i = \frac{1}{N} \sum_{i=1}^N V_i \tag{1}$$

Where N is the sample size, and V_i is the wind speed recorded for the Ith observations Where the sample size is large, it is useful to group the wind speed data into intervals to create a histogram of the wind speed distribution.

➤ *Distribution of Wind Speed*

The distribution of wind is expressed by Weibull distribution which is called a Raleigh distribution for K=2. It is given by equations (2 to 4).

$$f(v) = \frac{\pi \cdot v}{2\bar{v}^2} \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \tag{2}$$

$$prob(v \leq V) = 1 - \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \tag{3}$$

$$prob(v \geq V) = \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \tag{4}$$

Where, f(v)= Weibull probability density function of wind distribution

\bar{v} = mean wind speed (m/s)

v=instantaneous wind speed (m/s)

prob(v ≤ V)=probability of instantaneous wind speed is less than V

prob(v ≥ V) = probability of instantaneous wind speed is greater than V

Wind speeds are always measured at 10 m height anemometer. But, wind turbines are installed at higher elevations at which the wind speed is completely different from the 10 m measurement.

➤ *Annual Energy and Capacity Factor*

The calculation of the annual energy yield of a wind turbine is of fundamental importance in the evaluation of any project. The long-term wind speed distribution is combined with the power curve of the turbine to give the energy generated at each wind speed and hence the total energy generated throughout the year. It is usual to perform the calculation using 1m/s wind speed bins as this gives acceptable accuracy. The annual energy expressed mathematically as

$$Energy = \sum_{i=1}^{i=n} H(i)P(i) \tag{5}$$

Where H(i) is the number of hours in wind speed bin i and P(i) is the power output at that wind speed. Another measure is the load or capacity factor, defined as the ratio of the actual energy generated in a time period to the energy produced if the wind turbine had run at its rated power over that period.

The power in wind is given by $P (w/m^2) = 1/2 \rho AV^3$

Using the above equations (1 to 5) wind energy of the selected site shown as follows

Selected wind turbine is 30KWAC Rotor Diameter 13m
Annual energy at average (mean) speed is = 0.456*8760*5 = 19.97MWh

C. Pumped Hydro Sizing

The national power system is dominated by large hydropower systems. From the total capacity of 30GW to 40GW hydropower potential, only about 2GW is developed and planned to develop about 14GW by end of 2030. All of this generation concentrates on large hydropower plants. Although not developed as such, there is plenty of small hydropower resources in Ethiopia. The average annual potential (exploitable with small slope plants without reservoir) is estimated to be about 20 TWh/year. The electric energy generated from small slope plants, being smaller in capacity and geographically dispersed, is of great importance for rural electrification [31]. Table3.1 summarizes regional distribution of small hydropower potentials.

Region	Approximate small hydropower potential
Oromia	35 MW
Amhara	33 MW
Benishangul-Gumuz	12MW
Gambella	2MW
SNNP	18MW

Table 2:- Regional estimation of small hydropower potentials in Ethiopia [13]

➤ **Designed Micro Hydro for Pumped Storage System**

The amount micro hydro to be designed is 30KW and the available amount of head is 100m

$$P (KW) = 9.81 \frac{QH}{6}$$

Where Q is flow rate

H is Available amount of head = 100m E is turbine efficiency = 0.85

$$30KW = 9.81 * Q * 100 * 0.85 \text{ then } Q \text{ is } 0.03599 \text{m}^3/\text{s}$$

If micro hydro operates for 12 hours the total amount of water in reservoir is total amount of water in reservoir = $0.03599 \text{m}^3 / \text{s} * 60 * 60 * 12 = 1554.78 \text{m}^3$ So the pump operating time used to pump water to reservoir is 10 hr/day the amount of flow rate discharge water in to the reservoir is $1554.78 * 1000 / (10 * 3600) = 43.188 \text{lit}/\text{sec}$

- Then the hydraulic power is $P = 9.81 * Q * H$ $P = 9.81 * 43.188 * 100 = 42.3 \text{KW}$

- Design of pump motor. Motor power $= P = \frac{P}{\eta}$

Where P = is hydraulic power η = efficiency of pump

.Typical pump efficiency is 75%

$$P = 42.3 \text{KW} / 0.75 = 56.4 \text{KW}$$

Mechanical energy required is $56.4 \text{KW} * 10 = 564 \text{KWh}$.

III. HYBRID SYSTEM OPTIMIZATION USING HOMER

A. Load profile of the island

➤ **Primary load**

The table shown below shows that all primary loads of this specific island

Type	Number	Amount of energy required (kwh/day)	Total Amount of energy required (kwh/d)
Home appliances	725	3.215	2330.875
Historical monasteries	7	5.485	38.3775
Health center	1	2.262	2.262
Primary school	1	3.07	3.07
High school	1	14.66	14.66
Flour making milling	2	10	20
Total primary load in island			2410.2045

Table 3:- Summary of total primary load

➤ **Deferrable Load**

Deferrable load is electrical demand that can be met anytime within a certain time span, which exact timing is not important. Water pumping and battery-charging are examples of deferrable loads because the storage inherent to each of those loads allows some flexibility as to when the system can serve them. There are three main deferrable loads in the villages of Deck Island

- Pumped water for micro hydro
- water pump for daily use
- Pumped irrigated land

Month	Ja	Fe	Ma	Ap	Ma	Ju	Jul	Au	Se	Oc	No	De
Average load (KWh)	56.83	56.83	56.83	56.83	56.83	55.2	55.2	55.2	56.02	56.83	56.83	56.83

Table 4:- Monthly deferrable load

B. Summary of Input Data to HOMER

➤ **Basic Inputs**

The basic inputs of the Homer includes:-Primary load of the research site, Deferrable load of the research site, Solar radiation of the research site, Wind speed of the research site and Designed flow rate for pumped storage system and other related data Pumped Hydropower efficiency of 75% with 35% minimum flow ratio and 100% maximum flow ratio is taken. Derating factor of 90% and 20% ground reflectance PV system without tracking system is considered. PV panels are to be mounted at slope of 10.25° (latitude of the site). Inverter and converter efficiencies are assumed to be 90%. The Homer graphical representation of power curve for wind turbine, wind resources for selected site, Monthly global horizontal radiation of selected site are shown on the figures below.

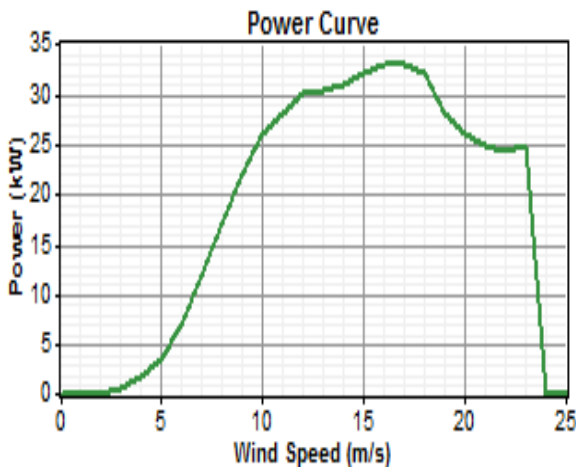


Fig 2:- Power Curve of FL30 wind Turbine

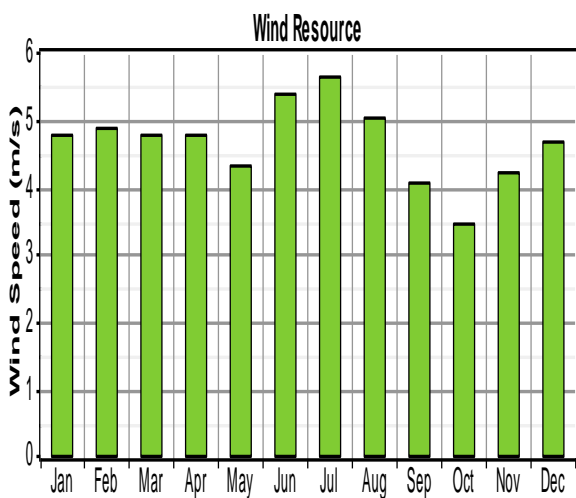


Fig 3:- Wind Speed in Deck Island at 25 m Height

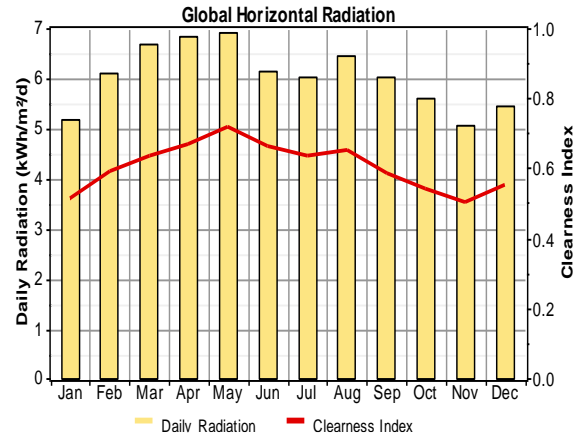


Fig 4:- Monthly Solar Radiation of d (kW/m^2)

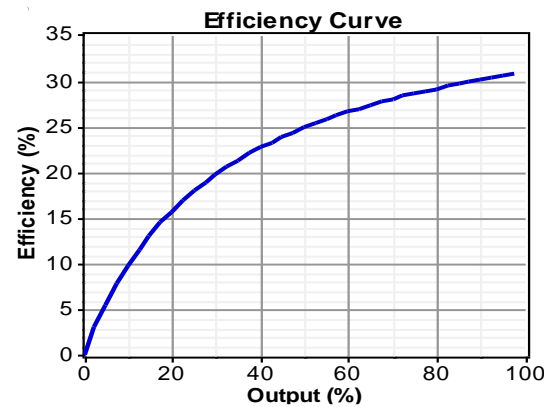


Fig 5:- Cummins Diesel Generator Efficiency Curve

Diesel generator is allowed to operate under a minimum load ratio of 70%. Its fuel curve characteristics are calculated using HOMER and an intercept coefficient of 0.02 l/hr/kW and slope of 0.23 l/hr/kW are found using data from manufacturer's website [28]. The generator efficiency against its percentage loading is shown in Figure 5. Based on the available head the designed flow rate of the pumped storage system is 38.8l/s

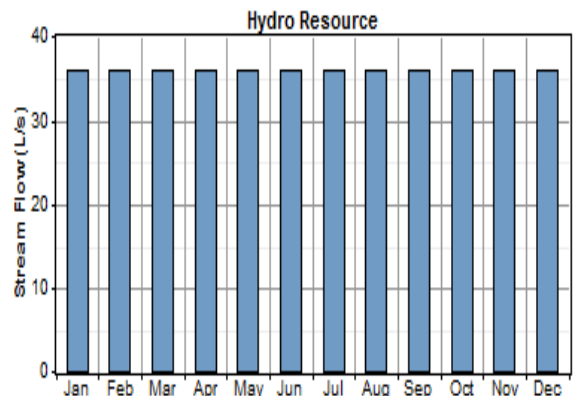


Fig 6:- Designed Flow Rate of Pumped Storage System

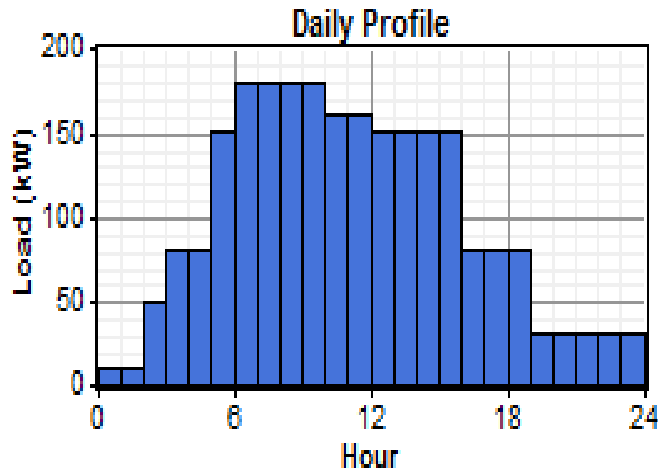


Fig 7:- Primary Load for Deck Island

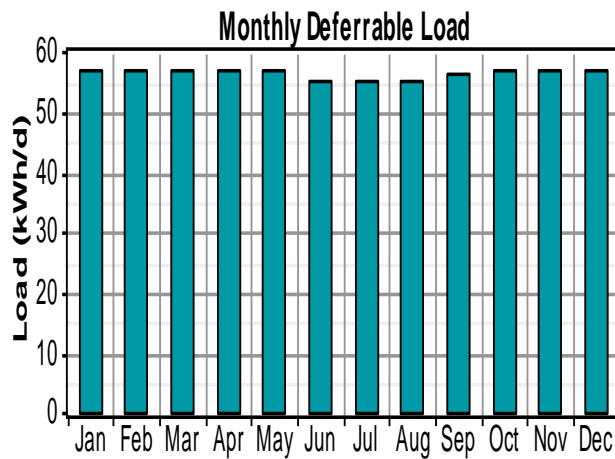


Fig 8:- Deferrable Load for Deck Island

To select appropriate storage and hybrid system here consider two cases

➤ Case 1 When the Storage System is Battery

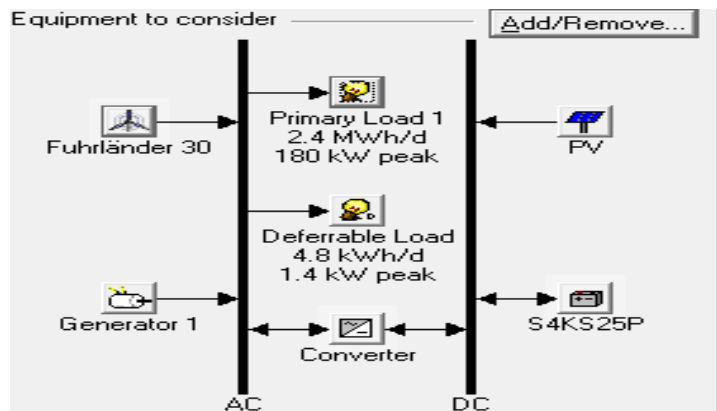


Fig 9:- Wind/PV/Diesel/Battery hybrid System

	PV	Wind turbine	Diesel	Battery BT	Converter
Size (kW)	1	30	0 - 250	1000 Ah	1
Capital (\$)	2200-2400	32000	0 - 37500	833	700
Replacement Cost(\$)	2200-2500	21333	0 - 6000	555	700
O & M cost(\$/yr)	25	50	0.4/hr	15	10
Sizes (kW) considered	0, 5, 10, 15,	-----	0, 22, 26, 33,	-----	0, 10, 20, 30,
Quantities	-----	0, 1, 2, 4, 6, 8,	-----	0, 20, 40, 60, 80,	-----
Life Time	20 yrs	20 yrs	40000 hrs	15000 kWh	15 yr

Table 5:- Size and Cost description of Wind/PV/Diesel/Battery hybrid system

➤ Case 2 When the Storage System Pumped Micro Hydro

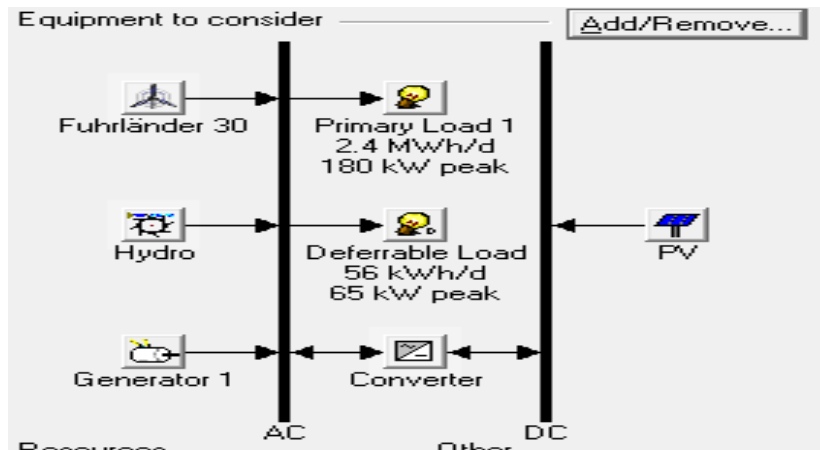


Fig 10:- Wind/PV/diesel /Pumped hydro hybrid system

	PV Module	Wind turbine	Diesel Generator	Pumped Hydro storage System	Converter
Size (kW)	1	100	0 - 250	30	1
Capital (\$)	2200-2400	32000	0 - 37500	46000	700
Replacement Cost(\$)	2200-2400	21333	0 - 6000	46000	700
O & M cost(\$/yr)	25	50	0.4/hr	300	10
Sizes (kW) considered	0, 5, 10, ..	-----	0, 22, 26, 33,		0, 10, 20,
Quantities	-----	0, 1, 2, 4, 6,	-----	-----	-----
Life Time	20 yrs	20 yrs	40000 hrs	>25 yrs	15 yr

Table 6:- Size and Cost Description of Wind/PV/Diesel/Pumped Hydro Hybrid System

IV. RESULT AND DISCUSSION

➤ *Results In Case of Battery Storage*

In this case renewable energy resources are Wind and PV Sola energy combined with diesel and Battery storage system. The results obtained are based on the current price of diesel (\$1.1/litere) and PV capital of \$2200/kW. From Table 7, the levelized COE is observed to be in the range of \$0.186/kWh to \$0.519/kWh. Presence of plenty of renewable resource is indicated by the level of the renewable fraction ranging from 77% to 95% in the renewable fractions column of Tables (7 &8). Although capacity shortage is allowed to a maximum of 17%, the unmet load is limited to a maximum of 8%. There are feasible combinations without any diesel generator (a renewable fraction of 100%). It can be seen from the two Tables (7 &8) that the PV/wind /battery system is better which is followed by PV/wind /diesel /battery system types with increasing total NPC and COE. As shown there detail.

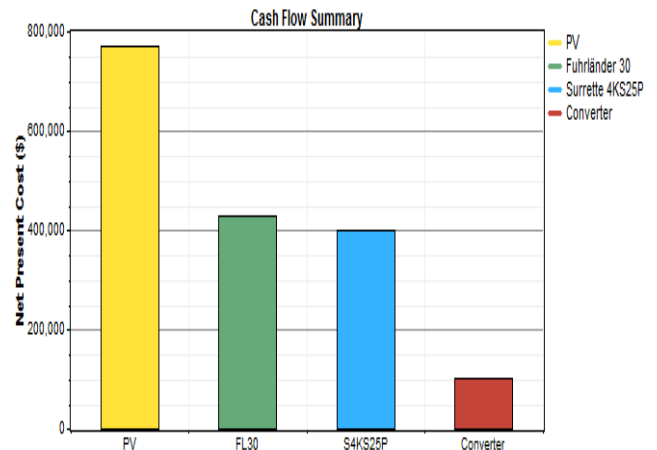


Fig 11:- Cash Flow Summary of this Case

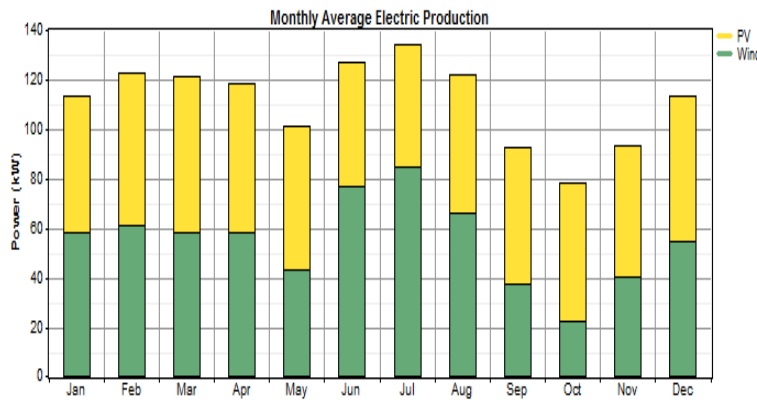


Fig 12:- Monthly Average Electric Production of this Case

Rank	PV (kW)	FL30- turbine	Gen (kW)	BT-Battery	Converter (kW)	Total NPC (\$)	COE (\$/kWh)	Renewable fraction	Unmet load fraction	Diesel (L/yr)
1	300	10	-	300	100	1,701,359	0.186	1.00	0.08	-
2	300	10	1	300	100	1,776,818	0.193	0.99	0.08	1,815
3	-	30	-	600	100	2,193,241	0.243	1.00	0.01	-

Table 7:- A Optimization Results in a Categorized Format at 2200KW PV Cost and \$1.1/litre

Rank	PV (kW)	FL100- turbine	Gen (kW)	BT-Battery	Converter (kW)	Total NPC (\$)	COE (\$/kWh)	Renewable fraction	Unmet load fraction	Diesel (L/yr)
1	300	10	-	300	100	1,437,359	0.157	1.00	0.08	-
2	300	10	1	300	100	1,512,818	0.164	0.99	0.08	1,815
3	--	30	-	600	100	2,193,241	0.243	1.00	0.04	-

Table 8:- A Optimization Results in a Categorized Format at 0.6 PV Cost Multiplier

Sensitivity analysis is also carried out using the variation of PV capital cost multiplier against diesel price. At higher price of PV modules wind/PV/diesel/battery systems are chosen with lower and slightly higher price of diesel respectively. As PV module price decrease just PV/wind/battery system is more economical and the system becomes less sensitive to variation of diesel price.

➤ *Results In Case of Pumped Hydro Storage*

In this case the renewables energy resources are Wind, PV hybrid with pumped storage system. The results obtained are based on the current price of diesel (\$1.1/l) and PV capital of \$2200/kW. From Table 6-4, the level zed COE is observed to be in the range of \$0.151kWh to \$0.418/kWh. Presence of plenty of renewable resource is indicated by the level of the renewable fraction ranging from 85% to 100% in the renewable fractions column of Tables 6-4. Although capacity shortage is allowed to a maximum of 10%, the unmet load is limited to a maximum of 9%.. There are feasible combinations without any diesel generator (a renewable fraction of 100%). It can be seen from the two Tables6-4 that the PV/wind /diesel/ pumped storage hydro is better which is followed by wind //pumped hydro system types with increasing total NPC and COE. As shown there detail.

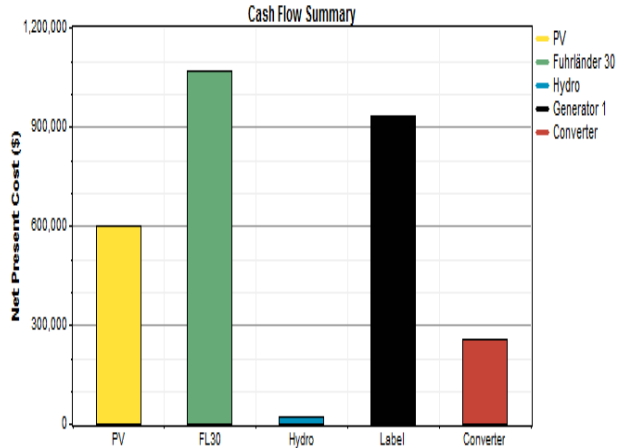


Fig 13:- Cash Flow Summary of this Case

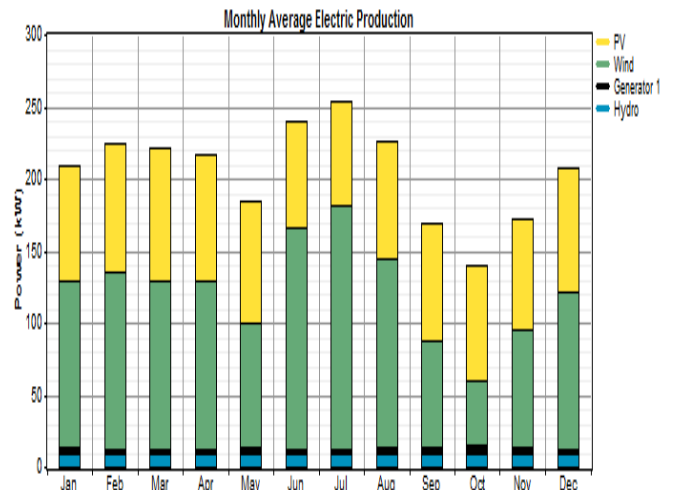


Fig 14:- Monthly Average Electric Productions of this Case

Rank	PV (kW)	FL-30 turbine	Hydro (kW)	Gen (kW)	Converter (kW)	Total NPC (\$)	COE (\$/kWh)	Renewable fraction	Unmet load fraction	Diesel (L/yr)
1	400	20	30	10	200	2,888,459	0.151	0.95	0.09	4688
2	400	40	30	-	150	2,960,333	0.154	1.0	0.06	-
3	-	60	30	60	-	8,374,711	0.418	0.78	0.04	4471

Table 9:- A Optimization Results in a Categorized Format at 2200KW PV Cost and \$1.1/litre diesel cost in Case of Pumped Storage System

Rank	PV (kW)	FL-30 turbine	Hydro (kW)	Gen (kW)	Converter (kW)	Total NPC (\$)	COE (\$/kWh)	Renewable fraction	Unmet load fraction	Diesel (L/yr)
1	400	20	30	10	200	2,712,459	0.141	0.95	0.09	4688
2	400	40	30	-	150	2,784,333	0.154	1.0	0.06	-
3	-	60	30	60	-	8,374,711	0.418	0.78	0.04	4471

Table 10:- A Optimization Results in a Categorized Format at 0.6 PV Cost Multiplier in Case of Pumped Storage

V. CONCLUSIONS

In this thesis, feasibility study of renewable energy recourses of Small Island for electrification of 725 families (7000 peoples) on Tana Lake in Deck Island is carried out. Wind resource, solar potentials, Pumped storage and community load in the island are analysed. HOMER is used for optimization and sensitivity analysis of different possible hybrid system. Based on current electric power using trend of rural community of the country considered Different power devices as Primary and deferrable electric loads. Water pumps for daily used, water pump for pumped storage system and water pump for irrigated land is also considered as deferrable load. The total community (about 725 families) is estimated to have a primary peak demand of 180 kW, a deferrable peak demand of 65 kW and a storage capacity of 1935 kWh. Different system configurations/types are found as feasible options. In Case of battery storage system one feasible system from Wind/Diesel/PV/battery is better at lower diesel price and is not sensitive to PV module prices. When diesel price increases slightly, Wind/PV/diesel/battery systems become more favoured at lower PV module price. In Case of Pumped storage system one feasible system from Wind/PV/Diesel/ Pumped hydro system become favoured at high wind speed and high PV module price .When PV price is small and Wind speed slow PV/Wind/Diesel/Pumped hydro become more favourite .One sample overall system shows a cost of energy of \$0.151/kWh and a renewable fraction of 95%. In this system excess electricity of 18% and unmet load of 0.9% have been found. The selected hybrid scheme Wind/PV/Diesel/ Pumped hydro has a high cost of energy than the current electric tariff of the country, the electric access of Ethiopia is very small (less than 35%) in view of this off grid electrical expansion is one the best solution to increase access of electricity through the country as well as to increase attractiveness of the tourist. Finally I would like to conclude that if there is enough head around the Small Island the pumped storage system is the better solution for storing electrical energy in form of pumped hydro.

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