Feasibility Study of Solar-Wind Based Standalone Hybrid System for Application in Ethiopia

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Abstract: Shortage of electric power is a serious problem in Ethiopia. As recently as the year 2009 electric power supply in the country including the capital Addis Ababa, was at best every other day for several months. Until recently, the sole power producer in the country, Ethiopian Electric Power Corporation (EEPCo) produces a total of 800 to 900 MW of power for a country with a population of about 80 million. This clearly shows as to what the shortage would look like.

In this regard, this study investigates the possibility of providing electricity from solar/wind based hybrid standalone system for remotely located people detached off the main grid line. Within the hybrid system setup PV panels, wind turbines, a bank of batteries and for a backup diesel generator is included.
The wind potential of the area has been assessed in a previously published article. The solar potential has also been investigated in another article awaiting publication. It is based on the findings of the solar and the wind energy potential that this study is carried out.

A model community of 200 families, comprising of approximately 1000 to 1200 people in total is considered for the study. A community school together with a health post is also included. The electric load comprises of lighting, water pumps and other small appliances.

For the techno-economic analysis in the feasibility study of the hybrid system the National Renewable Energy Laboratory's (NREL) HOMER software is used. Given all the necessary inputs to the software, the results showed a list of feasible electric supply systems, sorted according to their total net present cost (NPC). Cost of energy (COE in $/kW), penetration level into the renewable resources (renewable fraction), the number of liters of diesel oil used by the generator and also the generator working hours is also given out in the results table. The greenhouse gas emission level of the system is also incorporated within the results.

Furthermore, a sensitivity analysis is carried out for the major sensitive components of the hybrid system. The major sensitive components of the system recognized are the changing price of PV panels and the ever hiking price of diesel oil. From the results it is concluded that the solar energy potential is the most promising resource that can be utilized.

Keywords: *Wind Energy potential; Solar Radiation potential; Primary Load; Deferrable Load; Net Present Cost (NPC)*

1. Introduction

Power generation in Ethiopia started at the end of the 19th century, during the then king Minilik time. The first generator was used in the palace around 1906 and in 1912 the first hydropower plant at a place called Akaki, very close to the capital, Addis Ababa. Ever since, the country could produce only 814 MW (until recently) in its over 100 years long history.
Currently shortage of electric power is a serious problem in Ethiopia. As recently as the year 2009 electric power supply within Addis Ababa, the capital of the country, was at best every other day for several months. Even in the same year we are electricity supply with in the capital is intermittent.

As mentioned in previous articles [1] [2][3], the Ethiopian Electric Power Corporation (EEPCo), the only proprietor of the electric power production corporation with total management control (issue license, set tariff, supervise the generation, transmission, and distribution, sales, import export, etc.), currently produces between just over one MW of power. It is only this amount which is available for a country with a population well over 75 million. Over 95% of the resource for electricity generated is Hydropower. Although the country is endowed with enormous resource of solar energy there is no solar or wind energy contribution in the EEPCo's system.

The total countrywide coverage of the generated electricity is estimated to be some 15%. With only so small coverage, electricity supply in the deeper rural regions is unthinkable. This clearly indicates that something has to be done and the responsibility should all lie on the shoulders of the engineers within the country. The depletion of fossil fuel and the climbing up of the oil price with its involved politics, the pollution associated with the use of fossil fuel is are all left for the reader of this piece of work to consider as additional motivation.

"That the human race must finally utilize direct sun power or revert to barbarism because eventually all coal and oil will be used up. I would recommend all far-sighted engineers and inventors to work in this direction to their own profit, and the eternal welfare of the human race" Frank Shuman -1914

2. Methodology

The location under investigation is Debrezeit, 08″44′N, 39″ 02′E 1850 m. Wind and solar energy potential of the location is studied and have been given in previously published articles and a book [1][2][3]. As it is clearly shown in the references the wind energy potential is not so promising. However, the solar energy potential is absolutely usable. Figure 1 shows the monthly average wind speed at a height of 10 m. At a certain height, Z, the wind speed increases according to equation (1). It has been shown in [1] that average annual wind speeds of 3 to 4 m/s may be adequate for non-grid-connected electrical and mechanical applications such as battery charging and water pumping.

$$v(z)\cdot\ln\left(\frac{z_r}{z_0}\right)=v(z_r)\cdot\ln\left(\frac{z}{z_0}\right) \tag{1}$$

Where: Z_r is the reference height (10 m); z_0, is the roughness length.

The solar energy potential of the location is given in figure 2. As can be seen from the figure the solar energy potential is more than 6 kWh /m^2 for almost the whole time of the year. It is only in the rainy season, July and August the potential falls to between 5 and 6 kWh/m^2. This is indeed excellent situation for working on this resource.

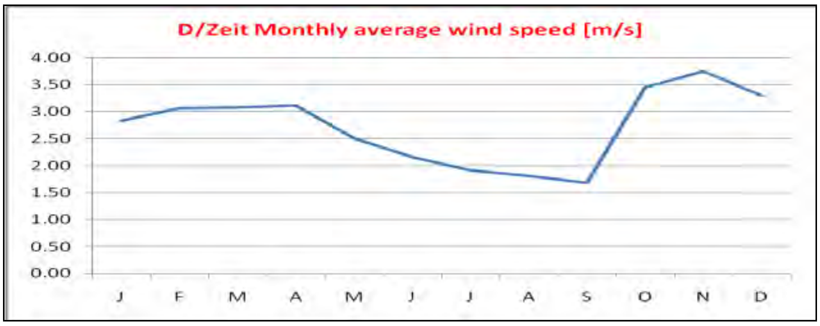


Figure 1: Monthly average wind speed

Having determined the solar and the wind energy potential energy of the location under investigation, a model community of two hundred families is considered for which the necessary basic load of electric lighting and water pumping system is suggested.

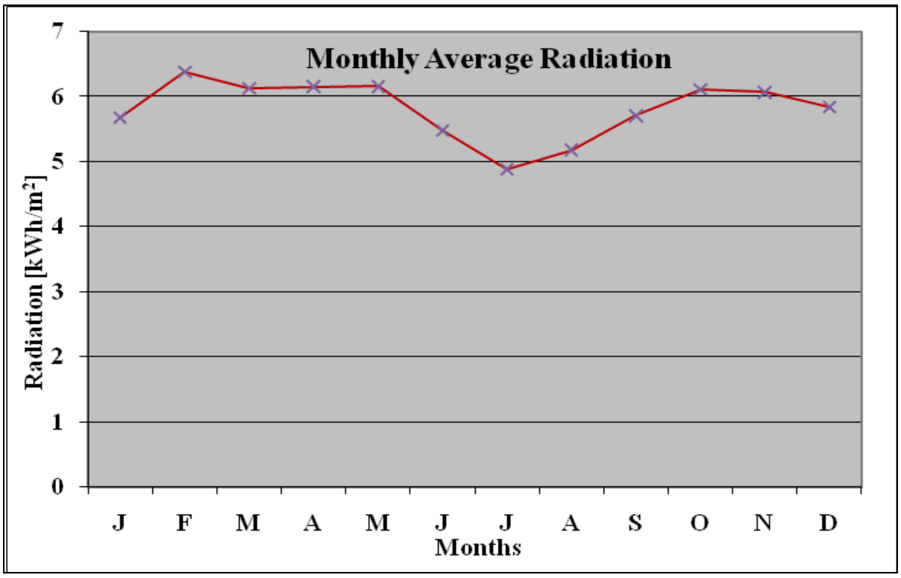


Figure 2 Monthly average daily solar radiations

HOMER software is used for the analysis. HOMER is a micropower design tool developed in 1992 to simulate and optimize stand-alone and grid-connected power systems with any combination of wind turbines, PV arrays, run-of-river hydro power, biomass power, internal combustion engine generators, micro-turbines, fuel cells, batteries, and hydrogen storage, serving both electric and thermal loads (by individual or district-heating systems) [4]. HOMER can perform a 'what-if' analysis to investigate uncertainties or changes in the input variables such as price variation of: fuel, PV panels, turbines or others in the one hand and wind speed, solar radiation, etc. on the other. The simulation results are economically and technically optimal and feasible solutions of hybrid setups listed according to their net present cost (NPC).

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each component of the system, and of the system as a whole.[5]

3. Electric Load

As mentioned earlier, the assumed 200 family community is nothing but a model community. It is to be noted that this number can shrink or expand if need be. Five to six family members are considered in each family. Two load types are suggested: primary load, load that must be met immediately, and deferrable load, load that must be met within a certain time (exact timing is not important).

A community school and a health post are also included within the community. Electric load suggested are lighting, water pumping, radio receiver, and some clinical equipment. It is to be noted that the load suggested here is estimated by considering the poorest people in the remotest corners of the country with no access to any of the modern energy supply types, not even a kerosene lamp or a candle light. A typical daily load pattern is presented in table 1.

The primary load consists of 2 to 3 light bulbs and a radio receiver per household and also some more light bulbs for the for the community school and the health post. Limited clinical equipment such as vaccine refrigerators, communication VHF radio, microscope, and AM/FM stereo are also considered.

Table 1 Monthly average daily electrical load [kWh]

Months	Jan	Feb-May	June	July	Aug	Sep	Oct-Dec
Deferrable Load	6	6	5	4	4	5	6
primary load	139	141	141	139	139	141	141
Total Load	145	147	146	143	143	146	147

The deferrable load is mainly water pumping. Four to five family members per house hold and about 100 liters of water per day is suggested. Water Pumps of a 150 W power rating and pumping capacity of 10 liters per minute is chosen. Six pumps at six convenient locations are to be installed. Additional pump for the School and the clinic is also to be installed. A four day storage system is considered. The resulting total load is as given in Table 1.

4. The Hybrid Setup and the Findings

The hybrid system studied is one combining solar and wind energy conversion system, with diesel generator(s) and a bank of batteries included for backup purposes. Power conditioning units, such as converters, are also a part of the system. The operational concept of the hybrid system is that renewable resources are the first choice for supplying load and any excess energy produced is stored in the battery. The diesel generator is a secondary source of energy. Electronic controller circuitry is used to manage energy supply and load demand. A schematic diagram of the standalone hybrid power supply system sought is shown in figure 3.

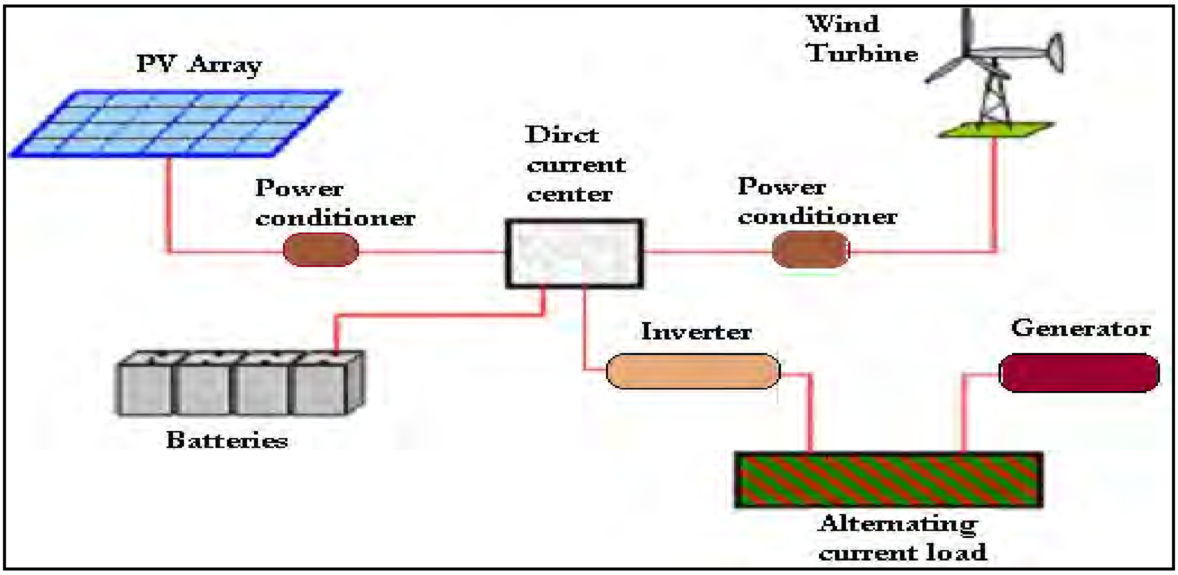


Figure 3: Schematic diagram for the standalone hybrid power supply system

HOMER requires input information in order to analyze the system and to give the feasible solutions. The main input to the software is the load. After carefully determining the hourly community electric load for both the primary and the deferrable load types the monthly average of the daily load is supplied to the software. The load profiles are shown in figure 4 and figure 5.

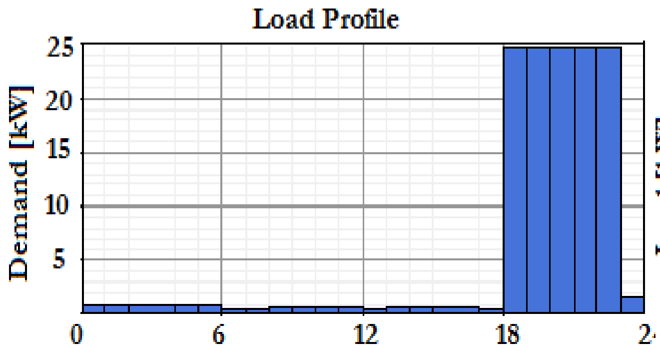


Figure 4 Primary load profile

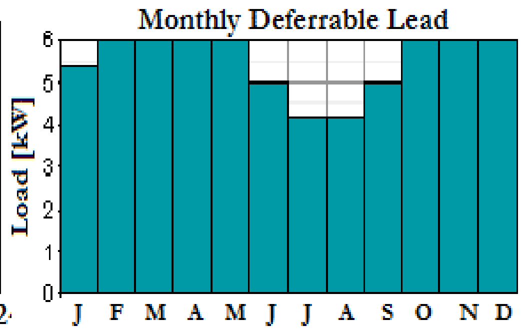


Figure 5 Deferrable load profile

Additional data supplied to the software is summarized in table 2.

Table 2 Input data to HOMER

	PV	Wind Turbine G20	Diesel Generator	Battery (Surrette 6CS25P)	Convertor
Size (kW)	1	20	44	1156 Ah	1
Capital ($)	1200-6000	45,000	11,000	833	700
Replacement cost ($)	1200-6000	30,000	7,000	555	700
O & M cost ($/yr)	0	900	0.4 ($/hr)	15	0
Sizes considered (kW)	0, 5, 10, 15, 20, 30, 50, 70, 100		0, 44, 88		0, 20, 40, 60, 80, 100
Quantities considered		0, 1, 2, 3		0, 40, 60, 80, 100, 200	
Life time	25 yrs	25 yrs	40,000 hrs	9,645 kWh	15 yrs

5. Results

Having fed the necessary input data given in the earlier section to the software the software is run. The resulting list of optimal combinations of realizable setups obtained is given in both overall and categorized forms. Table3 shows extracted part of the long list from the complete overall table. The extraction is based on the contribution made by renewable resources in the realizable set-ups.

As can be seen in the table the first row contains a system with no contribution (0 %) from the renewable resources. The next row contains a PV-Gen-battery-Converter set-up. For just a 16.7 % increase in total NPC over the first set-up ($201,609 to $235,177), the percentage contribution made by renewables increased from 0 to 58 %. This can be an attractive solution for implementation. Of course, there is no wind turbine involved in the system; the wind energy potential at this location is quite low, as can be seen from figure 4-19 and also from previous investigation [1].

Table 3 Extracts from the overall optimization results list

PV(kW)	Wind Turbine G20	Diesel Generator (kW)	Battery	Converter (kW)	Dispatch strategy	Initial capital	Total NPC	COE ($/kWh)	Renewable fraction	Diesel (L)	Generator (hrs)
		44	40	20	CC	$ 58,320	$ 201,609	0.322	0	18623	1785
20		44	40	20	LF	$ 130,320	$ 235,177	0.376	0.58	12078	1909
15	1	44	40	20	LF	$ 157,320	$ 276,081	0.441	0.53	12550	1947
20		44	80	20	LF	$ 163,640	$ 276,560	0.442	0.62	10617	1729
30		44	40	20	CC	$ 166,320	$ 278,443	0.445	0.66	13037	2127
30		44	60	40	LF	$ 196,980	$ 279,851	0.448	0.77	7048	1062
20	1	44	40	20	LF	$ 175,320	$ 285,862	0.457	0.62	11339	1811
30		44	80	40	LF	$ 213,640	$ 290,597	0.465	0.83	4883	716
20	1	44	60	20	LF	$ 191,980	$ 305,266	0.488	0.64	10417	1701
30		44	100	40	LF	$ 230,300	$310,604	0.497	0.85	4053	590

Figure 6 shows the monthly average electrical production and table 4 the overall system report.

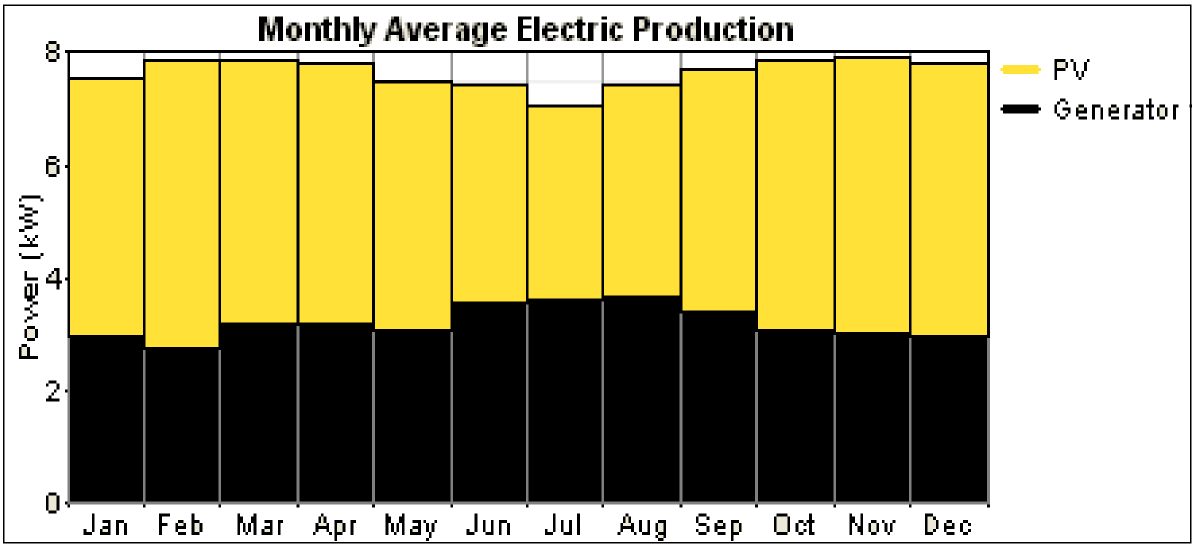


Figure 6: Electricity production for a 58 % penetration of the renewable

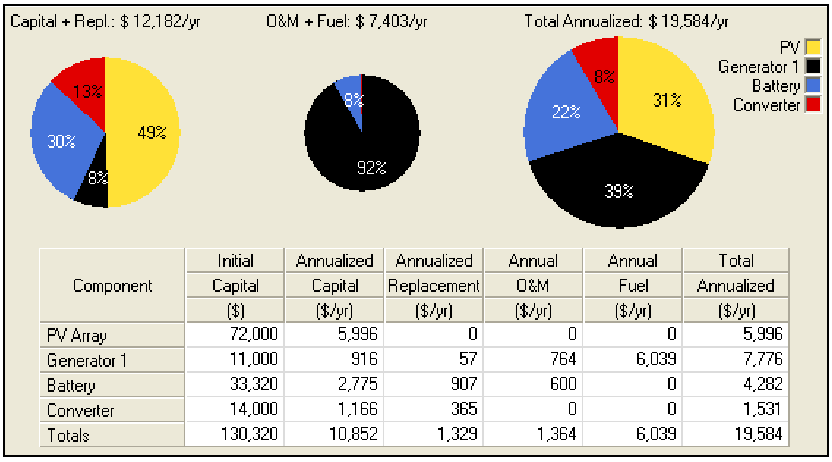
The maximum contribution by renewables, 85 %, is achieved by the set-up given in the last row of the table. For this set-up the NPC is $310,604, which is a 32 % increase in the total NPC over the setup with a renewable contribution of 58 %. This setup can also be seen as an alternative for implementation despite the higher cost. It is understood that a system is considered as renewable system if the renewable contribution is about 27% or above. Hence, if the renewable future is to be given its merits then this system will be the option. It should be noted that this set-up once again does not include a wind turbine as the wind potential of the location is minimal.

Table 4 System report for the 58 % renewable penetration

System architecture		**Sensitivity case**	
PV Array	20 kW	Solar Data	5. 81 kWh/m^2/d
Wind turbine		Wind Data	2.51 m/s
Gen.	44 kW	Diesel Price	0.5 $/L
Battery	40 Surrette 6CS25P	PV Capital Cost Multiplier	0.6
Inverter	20 kW	PV Replacement Cost Multiplier	0.6
Rectifier	20 kW		

Annual electric production (kWh/yr)			**Annual electric energy consumption (kWh/yr)**			**Emissions (kg/yr)**	
PV array	38,823	58%	AC primary load	50,772	97%	CO2	31,806
Wind turbine			Defferable load	1,306	3%	CO	78.5
Generator	28,152	42%	Total	52,077	100%	Unburned HC	8.7
Excess electricity	5,591					Particulate matter	5.92
			Cost summary			SO2	63.9
Unmet load	0		Total NPC	$ 235,177			
Capacity shortage	0		Cost of energy	0. 376 $/kWh		NOx	701

The cost breakdown for the set-up of 58% penetration of the renewable supported by a pie-chart, is also given in figure 7.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	72,000	5,996	0	0	0	5,996
Generator 1	11,000	916	57	764	6,039	7,776
Battery	33,320	2,775	907	600	0	4,282
Converter	14,000	1,166	365	0	0	1,531
Totals	130,320	10,852	1,329	1,364	6,039	19,584

Figure 7 Cost summary for the 58 % renewable resource contribution

The sensitivity analysis given in figure 8 shows the PV capital cost multiplier against diesel price. The net present cost of the most cost effective set-ups for a particular set of diesel and PV price is shown.

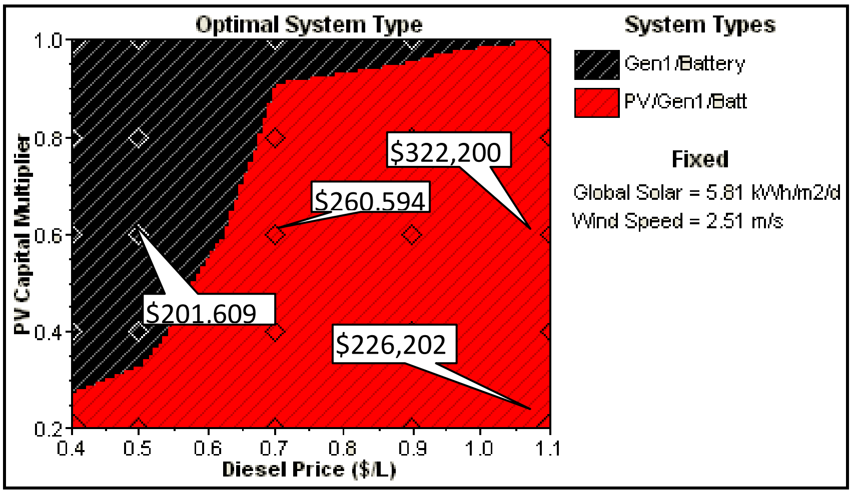


Figure 8 Sensitivity of PV cost to diesel price

6. Discussion and/or Conclusion

The feasibility study for the hybrid system is based on the findings of the wind and solar energy potentials at the particular locations. From the results, the wind energy potential of this site, Debrezeit, is not attractive enough for independent wind farm applications. However, it can be concluded that the potential in some cases could be a viable option if integrated into other energy conversion systems such as PV, diesel generator and battery. The results of this study can be considered as applicable to a significant size of the regions in the country having similar climatic conditions.

Regarding the solar energy it is definitively conclusive that there is abundant resource. The feasibility study, which is based on the findings of the two potential showed a list of possible feasible set-ups according to their Net Present Cost (NPC). The level of the renewable resource penetration can be said is closely tied with the net present cost. The choice as to which feasible system to pick from the list is linked to the choice of whether to consider the renewable resource or the net present cost. This decision is left to the policy makers of the country. However, as in the quotation given in the Introduction part Engineers shoed persistently press the policy makers to consider the utilization of the renewable resource.

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