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Photovoltaic Systems for Village Electrification in Mongolia Techno-Economics Analysis of Hybrid Systems in Rural Community Centers

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ABSTRACT

Hybrid systems based on renewable energy are an effective option to solve electrification for isolated areas from the national grids. This paper presents techno-economic analysis of hybrid systems for rural villages in Mongolia. Various type of hybrid systems are compared quantitatively on the basis of net present cost and cost of electricity by each case of load pattern in Gobi region villages. As a result, existing diesel generation system is top-ranked even in high fuel cost in all cases load pattern. But, the great increase of diesel fuel consumption lead to fuel transfer and storage problems. The electricity cost of optimum hybrid systems decreases with increasing of power demand. The PV module cost is indicated approximately 50% of the optimized total hybrid system cost. It is necessary an additional allocation budget for deficit covering the electricity cost in the village, due to current hybrid system cost more than doubled diesel generation electricity cost.

Keywords: Techno-Economic analysis, Hybrid system, Rural village, Renewable energy;

1. Introduction

Mongolia has 314 villages known as soum center (sub-administrative unit, sub-district) and 148 soum centers are not connected to a centralized power grid. Most of the soums have not technical potentiality for connection to centralized power grid and located at remote distance and, they provide the demand for energy by isolated diesel generator. For the reason that fuel price is high in distant soums due to high fuel transportation cost, electricity production cost is around four-fold high in comparison to centralized power production cost [1].

Following that money sum spending for electricity consumption is limited owing to that rural area consumers' average income level is lower the price difference is compensated by state subsidy. Depending on consumer's weak solvency, state subsidy, fuel transportation volume, the power supply service is limited to 3-5 hours in most of soums. Stable fuel supply is also difficult because all kinds of liquid fuels are imported from Russia and China [2].

Stable power supply is important for living condition improvement of soum's residents and alleviation of migration to urban areas. It is required for the generator which has fitted to soum's consumption volume, simply constructed, required for easy service and maintenance and not harmful to environment.

Renewable power resource, especially solar energy resource is high in Mongolia. It is connected to that there is dry climate, and around 257 days are sunny and serene in a year, and direct beam of irradiation is very high. There is opportunity for introduction and appliance of photovoltaic generator and solar heating collector and, it is required for detailed economic and technical analysis.

The purpose of this survey is formulation of suitable type of electrification in a way of conducting an analysis on opportunity for distant soum center electrification with renewable energy technology and photovoltaic generator having compared it with hybrid system and other technology type for energy generation. Our objective is the Mandakh soum center of the Dornogobi province, which total population: 1903 and 452 families, soum center population:

443, average household income: 128.2 US$/month[2] (1US$=1150Tg; 147,264 Tg, Tugrug (Tg) is national currency). Expenditure for electricity consumption: appx. US$6-7/month, it's indicate 5% of household income. The Mandakh soum equipped by 60kWx2 diesel generator and local mini-grid. Main electricity consumers are 120 households, 5 public facilities and others.

2. Techno-Economic Analysis

Doing the detailed economical analysis, we will conduct a comparison by net present cost (lifecycle cost) methodology, which accounts all expenses such as initial capital and routine service.

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \quad (1) \qquad\qquad CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

C_{NPC}: Net Present Cost; CRF: Capital Recovery Factor; $C_{ann,tot}$: total annualized cost [$/yr], sum of annualized capital cost, annualized replacement cost, annual O&M cost, annual fuel cost; i: interest rate [%]; R proj: project lifetime[yr]; N: number of years;

We have used the simulation tools that the HOMER /the optimization model for distributed power/ developed by NREL [3]. The HOMER simulates the operation of a system by making energy balance calculations for each hour in a year. In this analysis, we focused at villages of the Gobi region, which has rich renewable energy resources. The optimum combination of a hybrid system calculated from the meteorological data, estimated demand load and system component cost in the Mandakh soum center of the Gobi desert region. The system component configuration shows in figure 1.

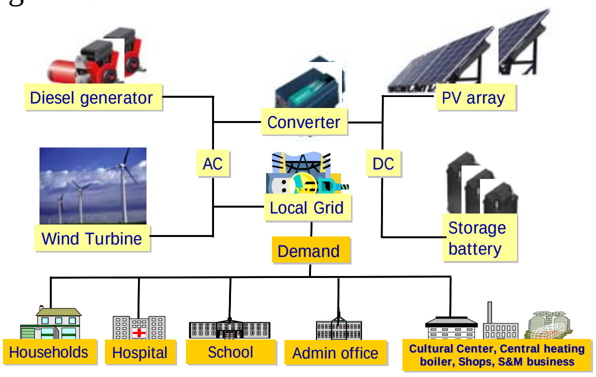


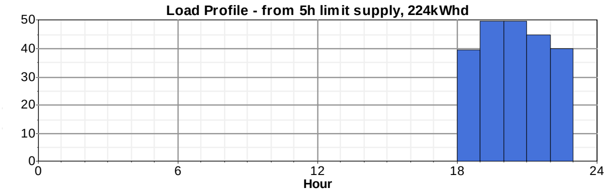
Fig.1: Hybrid System and Local Grid Network configburations for a rural village in Mongolia

The following local data and conditions used: Diesel fuel cost: 0.5 US$/L; Yearly average horizontal irradiation: 4.62 kWh/m^2/day; average wind speed: 4.52 m/s; project life time: 25 years, Real interest rate: 8%. The system component costs shows in Table 1.

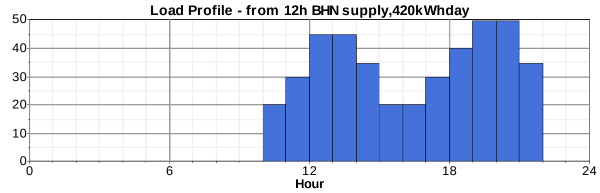
Table 1: System component cost (Fixed capital cost, replacement cost, annual O&M cost)

Power source	Size [kW]	Capital [$]	Replace ment [$]	O&M [$/h], [$/y]	Lifetime [y], [h]
PV	10	66,000	66000	0	25
Wind Turbine	20	47000	46000	300 [$/y]	15
Diesel Gen	60	48000	45000	0.3 [$/h]	15000 h
Converter	10	12500	12500	100 [$/y]	20
Battery	6V, 1156Ah	1200	1100	50 [$/y]	12

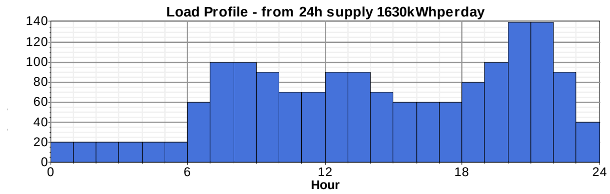
The power load profile estimated from the local survey data in the Mandakh soum. The system optimization simulated by next 4 cases as shown Fig.2, case-1: Current 5h limited supply; case-2: 12h supply BHN Public & Household demand; case-3: 24h supply (demand potential); case-4: Shifted load to daytime by the DSM;



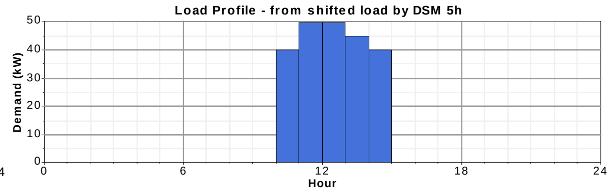
Case-1: Current 5h limited supply



Case-2: 12h supply for the BHN



Case-3: 24h supply for demand potential



Case-4 Shifted load to daytime by the DSM

Fig.2: Power load profile for 4 cases (Current 5h limited, 12h supply BHN, 24h supply, Shifted load to daytime by the DSM)

3. Results and Discussions

The results of simulations sorted by net present cost and cost of electricity are shown in table 2-4. From the ranking simulation results of the case-1, considering the current power supply situation for soum centers, net present cost (NPC) of diesel generation system is a third of the PV/Dsl/Bat and WT/Dsl/Bat hybrid system's NPC (see Table-2). The PV/WT/Dsl/Bat system is the most diesel fuel economy system for that yearly fuel consumption is 7049 litter less than a fourth of the diesel only system fuel consumption.

Table 2: The Net Present Cost (NPC) ranking simulation results for the case-1 load profile.

Rank No	PV (kW)	Wind Turb 20kW	Diesel (kW)	Battery 6V 1156Ah	Converter (kW)	Total capital	Total NetPresent Cost (US$)	Cost of Electricity ($/kWh)	Renew fraction	Capacity shortage	Dsl fuel consump (L)
1			60			$54,000	**$254,698**	**0.292**	0	0	29,200
2		2	60			$139,000	**$353,153**	**0.405**	0.45	0	26,925
3		4	60	80	80	$411,000	**$701,206**	**0.803**	0.68	0	20,960
4	40	2	40	80	60	$558,000	**$716,334**	**0.821**	0.87	0	7,049
5	40		60	100	60	$513,000	**$769,633**	**0.882**	0.58	0	21,080
6	80	4		120	80	$939,000	**$1,123,514**	**1.305**	1	0.02	

Table 3: The NPCost ranking simulation results for the shifted load profile to daytime case by the ideal Demand Side Management

Rank No	PV (kW)	Wind Turb 20kW	Diesel (kW)	Battery 6V 1156Ah	Conv (kW)	Total capital	Total NetPresent Cost (US$)	Cost of Electricity ($/kWh)	Renew fraction	Capacity shortage	Dsl fuel consump (L)	NPCost reduction [%]	Fuel consump reduction
1		2	60			$139,000	**$342,529**	**0.392**	0.48	0	24,935	3.0	7.4
2		2	40	40	40	$221,000	**$407,548**	**0.467**	0.54	0	17,232	41.9	17.8
3	40	2	40	20	60	$486,000	**$592,187**	**0.679**	0.87	0	7,513	17.3	-6.6
4	40		40	80	60	$473,000	**$627,232**	**0.719**	0.76	0	9,404	18.5	55.4
5	60	4		30	60	$674,000	**$764,042**	**0.898**	1	0.05	-	32.0	-

The Table-3 shows the ranking simulation result for shifted load to daytime for matching to PV output characteristics by the ideal DSM (demand side management). The NP Cost of WT/Dsl/Bat, PV/WT/Dsl/Bat and PV/Dsl/Bat hybrid systems reduced by 41.9%, 17.3%, 18.5% respectively. Also, during the increase of energy flow without pass by a battery storage, the battery capacity reduced than the case-1.

Table 4: The NPCost ranking simulation results for the load profile case-2 (at 12hour supply, for Basic Human Needs)

Rank No	PV (kW)	Wind Turb 20kW	Diesel (kW)	Battery 6V 1156Ah	Converter (kW)	Total capital	Total NetPresent Cost (US$)	Cost of Electricity ($/kWh)	Renew fraction	Capacity shortage	Dsl fuel consump (L)
1			60			$54,000	**$510,043**	**0.312**	0	0	59,261
2		4	60			$215,000	**$651,643**	**0.399**	0.5	0	48,895
3		4	60	100	100	$460,000	**$919,293**	**0.563**	0.53	0	39,586
4	100	4	60	80	100	$1,096,000	**$1,266,176**	**0.776**	0.96	0	5,206
5	100		60	100	160	$1,034,000	**$1,304,251**	**0.799**	0.78	0	19,875
6	100	4		120	100	$1,096,000	**$1,285,275**	**0.811**	1	0.04	

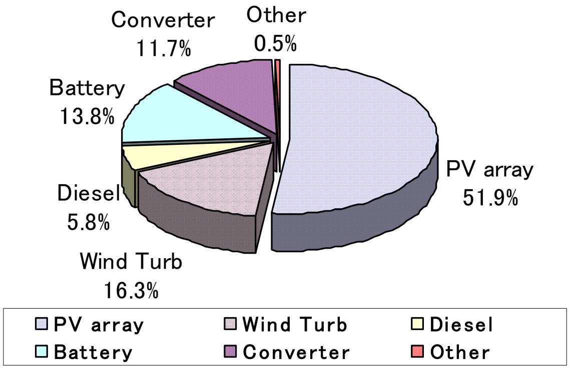


Fig. 3: Cost Breakdown of Hybrid System Component for the fourth system of Table 3.

The average load size of this case-2 is (420kWh/day) double fold larger than case-1, so the size of hybrid systems and NPC increase two times as case-1. The electricity cost is downward trend from case-1, except diesel only system. The fuel consumption quantity of diesel main system indicate doubled value from case-1. The PV module cost is indicated approximately 50%(Fig.3) of the total system cost for the fourth system of Table-4. Therefore, it can be expected that the system NPC cut down by reduction of PV module price in the future.

Table 4: The ranking simulation results for the load profile case-3 (at 24h supply)

Rank No	PV (kW)	Wind Turb 20kW	Diesel (kW)	Battery 6V 1156Ah	Converter (kW)	Total capital	Total NetPresent Cost (US$)	Cost of Electricity ($/kWh)	Renew fraction	Capacity shortage	Dsl fuel consump (L)
1		10	60	200	200	$933,000	**$2,089,574**	**0.371**	0.47	0.04	113,230
2			160			$134,000	**$2,423,403**	**0.383**	0	0	276,590
3		10	160			$523,000	**$2,643,893**	**0.417**	0.36	0	236,507
4	200		100	100	200	$1,776,000	**$2,888,784**	**0.463**	0.55	0.03	123,304
5	200	10	100	100	200	$2,165,000	**$3,003,376**	**0.476**	0.77	0.01	77,087
6	400	20		400	200	$4,145,000	**$4,799,266**	**0.788**	1	0.05	
7	600			800	200	$5,176,000	**$6,021,047**	**0.962**	1	0.01	

The electricity cost of diesel only system tends to remain constant at the range 0.25-0.38 US$/kWh. But, it's required nine-fold larger quantity of diesel fuel than the case-1. But, the great increase of diesel fuel consumption, lead to fuel transfer and storage problems. The simulation result shows that is the electricity cost of optimum hybrid systems decreases with increasing of power demand.

The electricity cost of optimum hybrid systems shows tendency to decline on increasing of power demand (see Fig.5). It should be understood that the system size and total cost increase in a large power demand.

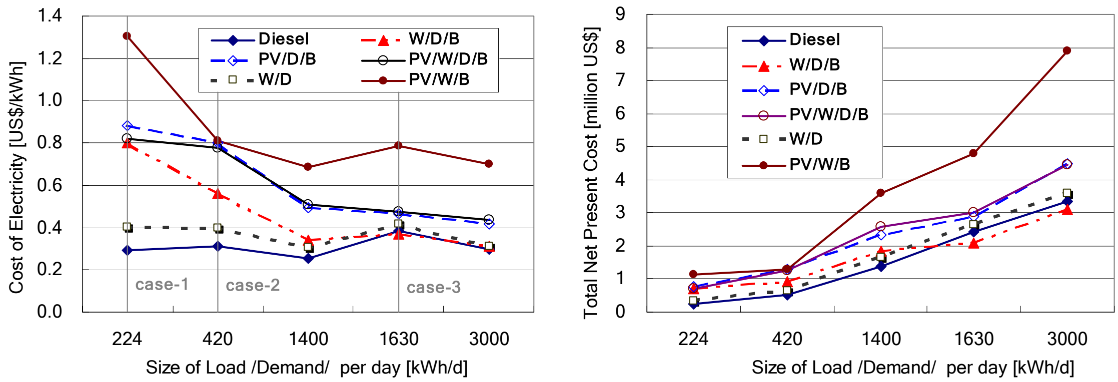


Fig.5: The relationship of the demand size and the total NPC and COE of optimized systems

5. Conclusions

In conclusions, various type hybrid systems are compared quantitatively on the basis of net present cost and energy cost by each case of load pattern in Gobi regions' village.

Existing diesel generation system is top-ranked even in high fuel cost in all cases load pattern. The electricity cost of diesel only system tends to remain constant at the range 0.25-0.35 US$/kWh. But, the great increase of diesel fuel consumption lead to a fuel transfer, storage and energy security problems. The simulation result shows that is the electricity cost of optimum hybrid systems decreases with increasing of power demand. Total hybrid system cost can be reduced at maximum 20% by the demand side management. The PV module cost is indicated approximately 50% of the optimized total hybrid system cost. It is necessary an additional allocation budget for deficit covering the electricity cost in the soum center, due to current hybrid system cost more than doubled diesel generation electricity cost.

6. References

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