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Potential Study of Using Hybrid Renewable Energy Systems for Power Supply of Tourism Camp in Mongolia

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Abstract - Due to the increase in the number of tourists coming from abroad, tourism camps have become interested in offering distinctive experiences, such as being close to nature and eco-friendly. Therefore, utilizing a hybrid renewable energy system for power supply becomes an attractive, nature-friendly, and reliable option for users located in remote areas disconnected from the central network. This article evaluates the electricity demand and associated costs for tourist camps using three different types of hybrid systems consisting of solar photovoltaic systems, wind turbines, diesel generators, battery storage, and converters. PV/wind systems will cost twice as much as PV/wind/battery systems. Additionally, they are not environmentally suitable due to the large number of batteries. PV/wind/battery systems, comprising a 3 kW capacity PV, a 5 kW capacity wind turbine, and batteries, could offer greater flexibility for tourist camps. This system is estimated to generate 19,303 kWh/year of electricity while not emitting greenhouse gases, despite being more expensive than a PV/wind/diesel hybrid system. The HOMER Pro software is used in this paper for optimization and techno-economic analysis.

Key words - Sustainable, Tourism, Hybrid renewable energy system, Optimal size, Techno-economic analysis, HOMER Pro software

Монгол улс дах аялал жуулчлалын баазын цахилгаан хангамжид сэргээгдэх эрчим хүчний хосолмол системийг ашиглах боломжийн судалгаа

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Хураангуй - Гадаад улсаас ирэх жуулчдын тоо өдөр ирэх тусам нэмэгдсэнтэй холбоотойгоор аялал жуулчлалын баазууд нь онгон дагшин байгалийг сонирхон бусдаас өөрсдийгөө ялгах онцгой зүйлүүдийг хийх хүсэлтэй жуулчдын анхаарлыг их татаж байгаа юм. Тиймээс сэргээгдэх эрчим хүчний системийг ашигласан цахилгаан хангамж нь алслагдсан газар нутагт байрлаж байгаа эсвэл Төвийн бүсийн нэгдсэн сүлжээнд холбогдоогүй хэрэглэгчдэд илүү тохиромжтой ба найдвартай. PV панел, салхин турбин, дизель генератор, энерги хуримтлуур, хувиргуур зэрэг бүрэлдэхүүн хэсгүүдээс бүтсэн гурван төрлийн хосолмол системийг ашиглан аялал жуулчлалын баазын цахилгаан ачааллыг хэрхэн, яаж, ямар үнэ өртгөөр хангах боломжтойг энэхүү өгүүлэлд тооцсон болно. HOMER Pro программ хангамж нь энэ өгүүлэлд оновчлол болон техник эдийн засгийн шинжилгээ хийхэд ашиглагдсан.

Түлхүүр үг - Тогтворжилт, Аялал жуулчлал, Сэргээгдэх эрчим хүчний хосолмол систем, Оновчтой систем, Техник-эдийн засгийн шинжилгээ, HOMER Pro программ хангамж

I. INTRODUCTION

Mongolia, a landlocked country in eastern and central Asia, is bordered by Russia to the north and China to the south. With an annual average temperature of -3 degrees Celsius and being one of the world's most sparsely populated territories, Mongolia faces significant challenges in providing sufficient heat and electricity, especially in rural areas, both in terms of quantity and quality.

Many local areas still rely solely on coal-based boilers for district heating, while smaller cities, towns, and villages are supplied with electricity from diesel-fueled units. However, these units often provide power for only a few hours per day due to fuel scarcity or financial constraints, among other limitations. Mongolia grapples with challenges posed by its natural environment, dispersed population, and pollution resulting from outdated infrastructure. Despite these obstacles, the country boasts rich natural and mineral resources, a skilled workforce, and favorable relations with neighbors and the international community, positioning it favorably for renewable energy development. Although its challenges are significant, they are comparatively manageable when contrasted with those faced by many other nations.

Mongolia is increasingly involved in energy provision, primarily through coal and, to a lesser extent, crude oil, mostly to China. According to the World Energy 2020 statistics, 84% of global energy is still derived from fossil fuels, with renewable energy accounting for only 11% of global primary energy consumption. The burning of fossil fuels for energy production significantly contributes to greenhouse gas emissions, harming the environment and contributing to global warming. In contrast, renewable energy sources emit fewer greenhouse gases. [2]

While most tourist locations are connected to the National Network for electricity, some special camps opt for eco-friendly energy sources due to their appeal and convenience for tourists. These camps, known as Eco Camps, utilize renewable energy sources, benefitting from Mongolia's substantial renewable energy resources and the government's policies promoting their development.

Mongolia boasts 270-300 sunny days annually, with an estimated 2250-3300 daylight hours per year. The Gobi Desert, covering an area of 5542 km2 and bordering China, ranks third in the world for high solar electricity generation potential, averaging 5.4 kWh/m2/day. Furthermore, the Gobi Desert possesses abundant wind resources, with significant areas experiencing wind speeds exceeding 9.0 m/s at 80 meters. This region enjoys a wind resource duration of 4000-4500 hours annually, attributed to vast, open plains with no barriers hindering wind speed [5].

Factors such as geographical features dictate the choice of renewable energy sources. For instance, the Gobi Desert exhibits immense potential for solar energy, while the western region shows lower potential. Consequently, small hydro plants and wind farms may be suitable for the western region, whereas isolated tourist camps can opt for hybrid systems independent of the National Network. Compared to standalone PV systems, wind turbines, or sole diesel usage, hybrid systems are considered cost-effective and reliable for eco camps [6].

The rapid increase in energy production from renewable sources is driven by the shared interest in reducing greenhouse gas emissions. Nonetheless, optimal sizing and techno-economic analyses for isolated areas remain significant challenges faced by many scholars [7].

This paper aims to show to techno-economic viability and optimal size model of the hybrid energy system for tourism camp in Mongolia. The feasible configurations and system sizing for the optimal system simulated in HOMER Pro software that used widely. The required data for simulation analysis were acquired from multiple sources: the weather data of the camp gained from NASA surface meteorology. [8] The paper is organized as follows: Introduction to power supply for tourism and methodology in Section II. Section III gives a results of hybrid system and Section IV presents discussion. Finally, Section V draws the conclusions.

II. METHODOLOGY

In this research paper, the HOMER software is utilized. Its primary objective is to design and evaluate both technically and financially viable options for off-grid and on-grid power systems. These systems cater to remote, stand-alone, and distributed generation applications. HOMER software conducts techno-economic analyses following the development of the optimal HRES (Hybrid Renewable Energy System). Additionally, sensitivity analysis is performed on the proposed system to assess the financial sustainability across various system parameters [9].

The merits of the HOMER software are noteworthy:

This software sets the global standard for optimizing designs of standalone and grid-connected power systems in remote areas, ensuring a reliable power supply.

Selecting from numerous technological possibilities, economic disparities, and energy source availability can be complex. However, HOMER's optimization and sensitivity analysis simplify the evaluation of various system configurations.

HOMER presents simulation results through diverse tables and graphs, facilitating comparison between setups and enabling evaluation of their economic and technological advantages. Furthermore, it allows the export of tables and charts for incorporation into reports and presentations [10].

Mathematical modeling of hybrid system

A. PV array power output model

The solar energy output modules can be calculated according to the following equation. [11]

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right)\left[1 + \alpha_P\left(T_c - T_{c,TSC}\right)\right] \quad (1)$$

Where, Y_{PV}- the rated capacity of the PV array, [kW], f_{PV}- the PV derating factor, [%], $\bar{G}_T$- the solar radiation incident on the

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PV array, in the current time step [kW/m^2], $\bar{G}_{T,STC}$- the incident radiation at standart test condition, [1 kW/], α_P- the temperature coefficient of power, [%/°C], T_c-the PV cell temperature in the current time step, [°C], $T_{c,TSC}$- the PV cell temperature under standart test conditions, [°C]

B. Wind turbine model

HOMER calculates the power output of the wind turbine in each time step using a three-step process. First, HOMER calculates the wind speed at the hub height of the wind turbine. Then it calculates how much power the wind turbine produces at that wind speed at standard air density. Finally, HOMER adjusts that power output value for the actual air density.

$$U_{hub} = U_{anem} \cdot \frac{\ln(z_{hub}/z_0)}{\ln(z_{anem}/z_0)} \quad (2)$$

Whereby, U_{hub}- the wind speed at the hub height of the wind turbine, [m/s], U_{anem}- the wind speed at anemometer, [m/s], z_{hub}- the hub height of the wind turbine, [m], z_{anem}- the anemometer height, [m], z_0- the surface roughness length, [m]

Power curves typically specify wind turbine performance under conditions od standard temperature and pressure. To adjust actual conditions, power output value for the actual air density is calculated as the following equation:

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) \cdot P_{WTG,STP} \quad (3)$$

Where, P_{WTG} -the wind turbine power output, [kW], $P_{WTG,STP}$ -the wind turbine power output at standard temperature and pressure [kW], ρ -the actual air density [kg/m^3], ρ_0 -the air density at standard temperature and pressure [1.225 kg/m^3]

C. Diesel generator model

HOMER assumes that the fuel curve is a straight line. Fuel consumption rate for electricity production can be calculated using following equation:

$$F = F_0 \cdot Y_{gen} + F_1 \cdot P_{gen} \quad (4)$$

Where, F_0 -the fuel curve intercept coefficient [units/hr/kW], Y_{gen} –rated capacity of the generator [kW], F_1 -the fuel curve slope [units/hr/kW], P_{gen} -the electrical output of the generator [kW]

D. Battery model

The maximum amount of power that can be absorbed by the two-tank system is given by the following equation:

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1-e^{-k\Delta t}\right)}{1-e^{-k\Delta t}+c\left(k\Delta t-1+e^{-k\Delta t}\right)} \quad (5)$$

Where, Q_1-the available energy[kWh] in the storage at the beginning of the step time, Q-the total amount of energy [kWh] in the storage at the beginning of the step time, c- the storage capacity ratio [unit less], k-the storage rate constant [h-1], Δt-the length of the step time [h]

The storage charge power corresponding to this maximum charge rate is given by the following equation:

$$P_{batt,cmax,mcr} = \frac{(1-e^{-\alpha_c \Delta t})(Q_{max}-Q)}{\Delta t} \quad (6)$$

Where, α_c-is the storage's maximum charge rate [A/Ah], Q_{max}-is the total capacity of the storage bank [kWh]

$$P_{batt,cmax,mcr} = \frac{N_{batt} I_{max} V_{nom}}{1000} \quad (7)$$

Where, N_{batt}-the number of batteries in the storage bank, I_{max}-the storage's maximum charge current [A], V_{nom}-the storage's nominal voltage [V]

E. Economic model

NPC-Net present cost

The Net present cost (or life cycle cost) of hybrid system is the present value of all the costs of installing and operating the system over the project lifetime, minus the present value of all the revenues that it earns over project lifetime.

$$NPC = \frac{C_A}{CRF(i,n)} \quad (8)$$

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n-1} \quad (9)$$

Where, i-nominal interest rate, n-number of years.

F. Emissions

There were six pollutants estimated in research such as carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (UHC), particulate matter (PM), sulfur dioxide ($S0_2$), and nitrogen oxides (NOx). Before simulating the system, HOMER determines the emissions factor (kg of pollutant emitted per unit of fuel consumed) for each pollutant. After the simulation, it calculates the annual emissions of that pollutant by multiplying the emissions factor by the total annual fuel consumption.

G. Case study

This research paper focuses on Gurvanbulag ger camp (GGCamp) within the tourism sector. The eco camp is situated 290 kilometers west of Ulaanbaatar city in Gurvanbulag soum, Bulgan province. Gurvanbulag lies in the central region of Mongolia, encompassing forests, mountains, rolling steppe, and Gobi sand dunes within its unique terrain. This distinctive area falls within the buffer zone of the Khogno Khan Mountain Nature Reserve. It's renowned for its ancient burial sites and rock paintings, spanning 2686 square kilometers, with a population of 3123 residing at an altitude of 1097 meters.

The climate in Gurvanbulag soum ranges from hot summers to cold winters, with temperatures dipping to -20 degrees Celsius in January and rising to +20 degrees Celsius in April. The summer month witness higher solar radiation, particularly in May and June, making them the peak solar radiation months. As July arrives, solar radiation gradually decreases but remains effective for utilization. Hence, optimizing renewable energy usage aligns with the summer season.

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Figure 1. Gurvan bulag ger camp (GGCamp) demonstration

Figure.1. Gurvan bulag ger camp (GGCamp) demonstration Wind speeds in Gurvanbulag exhibit a pattern, increasing in May, reaching their lowest point in July. Despite Gurvanbulag ger camp (GGCamp) being operational solely during summer, renewable wind energy remains viable for utilization during other seasons like winter and spring. However, for a combined renewable energy system, the optimal usage occurs during summer. Solely relying on wind energy is feasible outside the summer season.

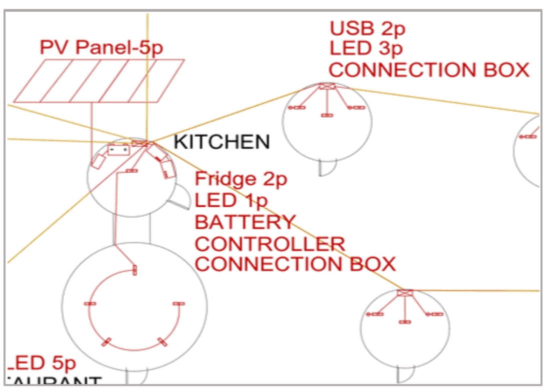

Figure 2. Detailed system structure of each ger

H. Load calculations

The Gurvanbulag ger camp comprises 15 gers, a restaurant, two restrooms, and two showers, although the exact numbers may vary depending on circumstances. Each ger is equipped with three lamps, two USB chargers, and the capability to connect various electrical components such as televisions and refrigerators. The camp doesn't have a unified power system but operates on separate power supplies. Electricity for the gers is supplied by PV panels, providing power for lighting and USB charging.

For hot water supply to the showers, the Gurvanbulag ger camp uses a diesel generator to heat the water. Subsequently, a water pump is employed to distribute the warm water to the showers and restrooms. The restaurant contains two large refrigerators, each with a capacity of 200 liters, and they consume high amounts of power. In the summer, the outdoor and indoor lights are turned off during the day and only used at night. Additionally, the camp has 10 outdoor lamps and can sustain approximately 3 days autonomously. Table 1 displays the calculation of electric component loads, and the total power demand of the camp is estimated to be 12 kWh.

Table 1. Electrical components energy

№	Electrical components	Numbers	Power ,W	OP/time,hour	Energy	Day energy, Wh	Night, Wh
1	Lamps in ger	45	5	3	675		657
2	USB	30	6	2	360	64	296
3	250 liter refrigerator	2	200	24	9600	4800	4800
4	Restaurant Lights	5	15	6	450	-	450
5	USB type A	4	6	2	48	8	40
6	DC pump(Outside)	2	12	2	48	-	48
7	Lamps(Outside)	10	3	8	240	-	240
8	TV	2	30	2	120	60	60
9	Desktop computer	2	100	2	400	200	200
10	LED light (toilet)	2	5	4	40	-	40
		Total				**5132**	**6831**

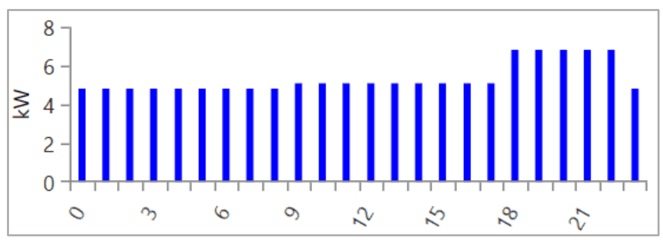

Figure 3. Daily load profile of Gurvanbulag ger camp

I. *Solar radiation data got from NASA's Atmospheric Data Center for Gurvanbulag soum. [11, 12]*

Figure 4 presents the regular monthly average of solar resource along with global horizontal irradiation data during 2023. The annual average irradiation for the area studied is 4.05 kWh/m^2/day.

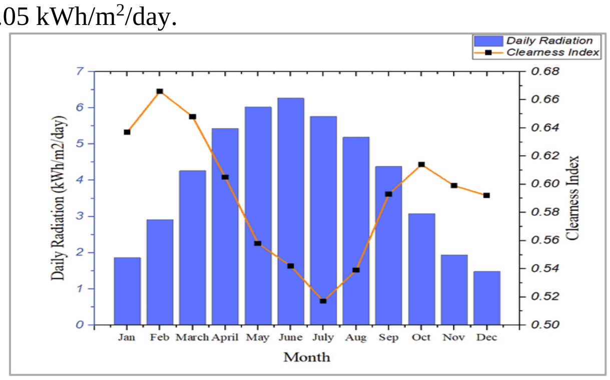

Figure 4. Gurvan Bulag soum renewable energy potential

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III. Results and Discussions

In this paper, three different types of hybrid systems are simulated and compared for supply load demand.

A. *PV and battery storage system*

To supplying camp demand, the PV system capacity has to be 3 kW and battery has 2500 Ah in shown Figure 5. The system will generate 8166 kWh/year of electricity.

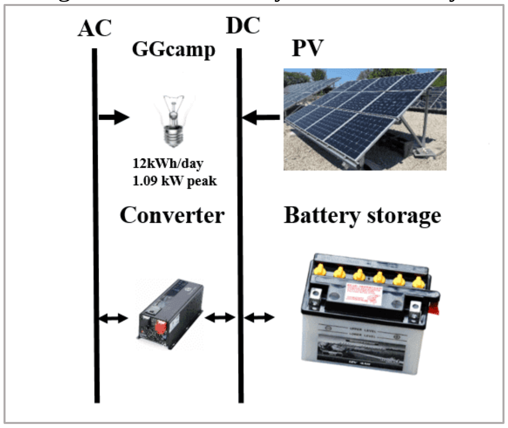

Figure 5. Schematic diagram of PV and battery

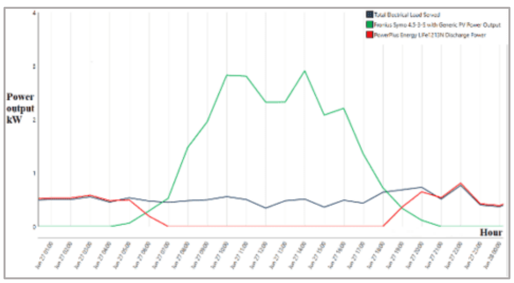

Figure 6. Power output of PV and battery system by hour

Figure 6 shows that power generation from PV, battery system and demand by hour. When sun rises at 7 am, PV system slightly generating electricity then the maximum power is 2.83 kW at 10 am. During the PV system supplies the electricity to demand, the battery does not discharge. When sunset at 19:00 pm, the battery discharges power to supply demand. Figure 7 shows that energy production from PV panels which capacity is 3kW by month.

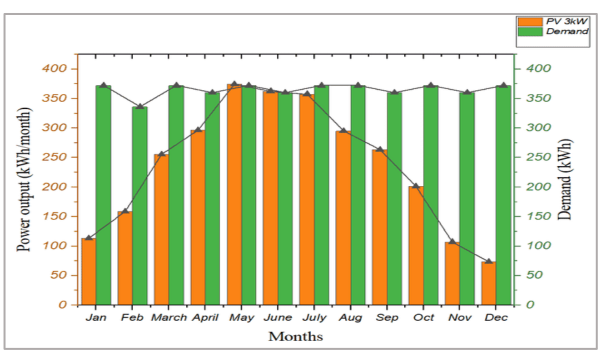

Figure 7. Energy generation from PV

The system adequately supplies electricity during the summer months, namely May, June, and July, leveraging solar radiation. However, it falls short during other months. Refer to Figure 8. Despite the camp's operational window limited to the summer months, it can employ a hybrid system like PV+wind or PV+wind+diesel to meet the electricity demand in the remaining months where adequate power cannot be generated. Alternatively, increasing the capacity of the PV system is an option, albeit a more expensive one that might be slightly unreliable during rainy days.

B. *The hybrid system of PV, Wind turbine, and Battery storage*

The hybrid system consists of a 3 kW capacity of PV, 5 kW capacity of Wind turbine, and batteries. The system will generate 19,303 kWh/year of electricity.

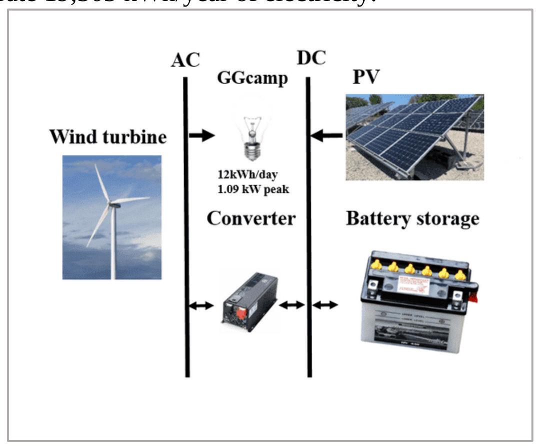

Figure 8. Schematic diagram of PV, wind and battery

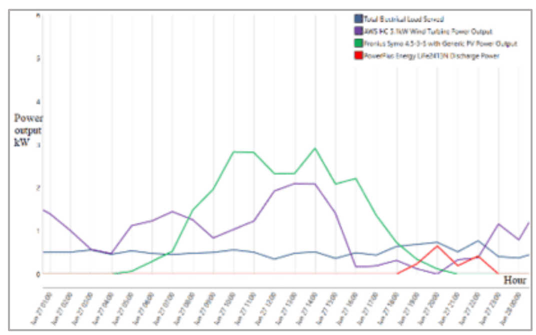

Figure 9. Energy generation by hour of PV, wind and battery

Compared to a system solely reliant on PV and batteries, a hybrid system incorporating PV, wind turbines, and batteries functions throughout all months. Particularly noteworthy is the higher energy production during spring months, primarily due to the presence of wind resources in the case study area. Moreover, implementing the hybrid MPPT (Maximum Power Point Tracking) method in the photovoltaic/wind turbine/battery system aids in controlling and reducing stress on the storage batteries [13]. From Figure 9, the camp can meet the necessary demand from the hybrid system. When the solar radiation and wind speed are low, the demand can be supplied from batteries.

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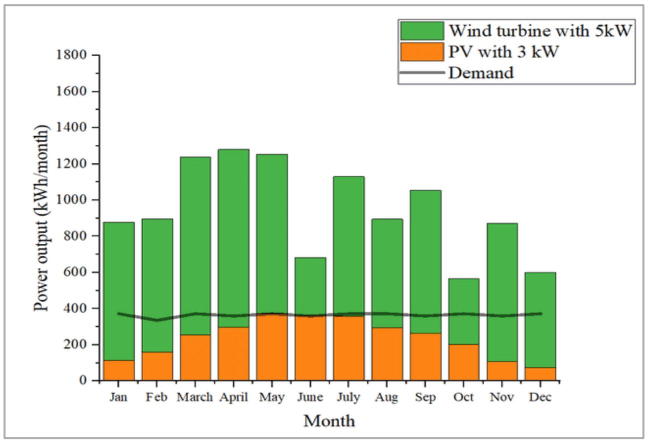

Figure 10. Energy generation from PV/wind

Figure 10 shows the power outputs of month. The wind turbine output power and PV cell output power are much higher than the total demand. It can be seen wind turbine and PV cell can supply the total demand and possible to charge batteries.

C. The hybrid system of PV, Wind turbine, diesel, and Battery storage

The schematic diagram of the hybrid system is shown in Figure 11. The hybrid system consists of wind power generator (5kW), diesel generator (2kW), converter, storage system and PV (3kW). The PV module is expected to operate for 25 years. [14] The system will generate 19,303 kWh/year of electricity. Therefore, most expensive part of economic is PV panels and diesel generator.

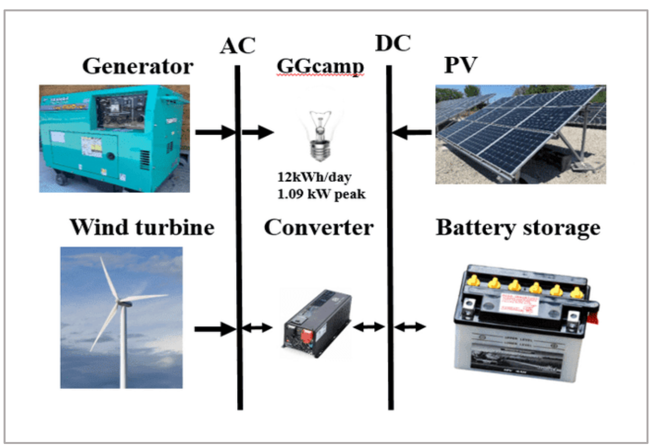

Figure 11. Schematic diagram of hybrid system

Figure 12 depicts the 24-hour power output at Gurvanbulag Ger Camp (GGC). Due to the nature of PV cells being reliant on solar irradiance, it's evident that PV power is available between 7 am and 5 pm. The power output of the wind turbine shows a slight increase from 5 am to 7 am before experiencing a dramatic decline at 3 pm. Although renewable energy sources primarily generate power during the daytime, there is a gap in power availability between 7 pm and 9 pm, during which a diesel generator can be utilized to compensate for the power load.

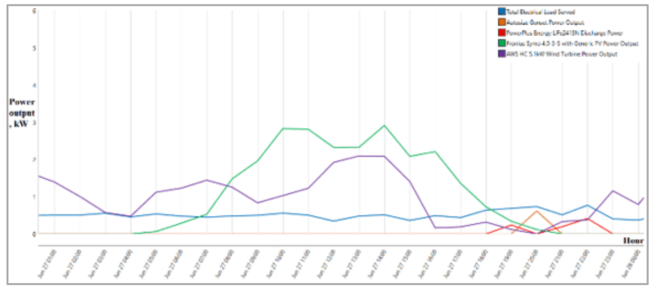

Figure 12. Power output from hybrid system of PV/wind/batteries/diesel

Thus, employing a hybrid system comprising PV, wind, batteries, and a diesel generator renders the off-grid system more reliable. The input power of the batteries fluctuates during the night, resulting in a slight decrease in their state of charge. During daytime, the batteries can reach their peak charge, which is subsequently utilized during the night. However, in the absence of sunlight at night, reliance shifts to the wind turbine to replenish the battery charge. Therefore, it's crucial to alternate between renewable energy sources capable of charging the batteries. One notable drawback is its reliance on environmental conditions.

The cost of a solar PV system is initially more expensive than grid extension. However, the current cost of PV modules is decreasing due to the development of renewable energy technologies. Table 2 presents the cost of NPC (Net Present Cost), operating costs, and initial capital of the optimal system for different configurations obtained from simulations. These configurations include PV panels with a capacity of 10.4 kW, 33 generic 1 kWh lead acid-12V batteries, PV panels with a capacity of 3 kW, a 5 kW wind turbine, a 2500 Ah battery, and a combination of 3 kW PV panels, a 5 kW wind turbine, and a 2 kW diesel generator.

Table 2. The comparison of cost for hybrid systems

Type of hybrid systems	Net present cost (NPC)	Operating cost	Initial capital
PV (10.4kW)+Battery	$37,505	$1622	$16,538
PV(3kW)+ Wind(5kW)+Battery	$15,960	$669,91	$7300
PV(3kW)+ Wind(5kW)+Diesel(2 kVA)+Battery	$13,593	$697,98	$4570

D. Environmental consideration

The fossil fuel-based electricity generation approaches are among the major sources of anthropogenic carbon dioxide emissions into the atmosphere [15]. Using HOMER (Hybrid Optimization of Multiple Energy Resources) software, the emissions of pollutants produced by a diesel generator are simulated. The hybrid system comprises a 2kVA diesel generator, 3 kW Solar PV, 5 kW wind turbine, and 12V batteries. Table 3 displays the results of pollutant emissions

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from the diesel generator, batteries, and the solar PV and wind hybrid system. It's evident that the amount of pollutant emissions decreases with an increase in the installed capacity of the solar PV and wind turbine.

Table 3. GHG emissions from PV-diesel-wind-battery system (kg/year)

Pollutant	PV+Wind+Diesel+Bat
Carbon dioxide (CO_2)	519
Carbon Monoxide (CO)	3.27
Unburned Hydro carbons (UHC)	0.143
Particulate Matter (PM)	0.0198
Sulfur Dioxide (SO_2)	1.27
Nitrogen Oxides (NOX)	3.08

IV. CONCLUSIONS

In this study aimed to show to techno-economic viability and optimal size model of the off-grid hybrid energy system for tourism camp in Mongolia Tourism significantly impacts our country's economy, making reliable and environmentally friendly electricity supply vital for its development. This paper simulates three different types of hybrid systems. The results indicate that a hybrid system can reliably and sufficiently meet electricity demands. From the results, most cost-effective and more reliable configuration of the off-grid hybrid system would be PV(3kW)+Wind(5kW)+Battery+converter, which could generate about 19,303 kWh/year of electricity to meet the camp independent from main grid. Most of users who live in remote area connected to the National Grid to use electricity. Because Mongolian electricity's cost is very low around 0.105 dollars/kWh. But solar and wind resources are significantly high in remote areas, the utilization of hybrid renewable energy system can be suitable to supply electricity whilst achieving environmental benefits. Nevertheless, the Net present cost of PV/Wind/Battery hybrid system is higher than PV/Wind/battery/diesel, long time will be use free electricity from renewable energy due to lifetime year of RE. Small-size consumers could not supply reliable renewable energy hybrid systems because of the cheap cost of electricity, but for the sake of global warming and the environment, it is necessary to start with small consumers little by little.

ТАЛАРХАЛ

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