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Optimizing Hybrid Power for Manpura Island: A Case Study in Bangladesh

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Abstract: In the remote and isolated island Manpura in southern Bangladesh, located within the Bhola district and surrounded by the Meghna River, most communities rely on farming and fishing for their livelihoods. Due to its isolation, the island is not connected to the mainland's electrical grid. In this study, a freestanding green hybrid energy system was proposed for the Manpura island using HOMER software to meet the electricity needs of its 17,016 households. The average load for the system is 9,149.87 kWh per day, with an annual peak load of 2,112.6 kW. The system would utilize PV panels, hydrokinetic energy, biogas, wind turbines, storage, and a converter, with a total Net Present Cost (NPC) of 23,796,260.00 and a Cost of Energy (COE) of $0.5515. This hybrid energy systems would provide a sustainable and cost-effective long-term power solution for the island while preserving its natural beauty.

Keywords: Hybrid Energy System, Biogas, Solar, Hydrokinetic, Wind, Manpura.

1. INTRODUCTION

Manpura, located at Bangladesh's southernmost tip, has become a popular tourist destination [1]. The coordinates for this spot are 22° 11.8' north, 90° 57.5' east. Approximately 77,000 people live in that place [4]. Farmers and fishermen make up the bulkof the population. Many people come here to marvel at the wide variety of plants and animals. With access to the grid or offshore power, this destination might become even more appealing to visitors and permanent residents alike. The dearth of convenient lodgings is hurting this otherwise stunning destination, but a new power plant could change all that. Dueto its extreme isolation from the rest of the country, this region lacks the infrastructure to connect to the national power grid and begin receiving electricity [2]. Emergency situations

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only necessitate the use of small-scale PV cells and diesel generators. In order to successfully draw attention in tourists and help out the locals, sufficient power is essential [3]. Due to its separation from the mainland, the only practical grid solution is an offshore one. Both locals and tourists can get power from our green hybrid grid. Neither locals nor tourists would feel at ease if the area's natural beauty and tranquility were sacrificed to generate electricity. Industrial emissions contribute to climate change. It's a green, carbon-free technology. Since our approach won't result in noise pollution, the island's natural charm will be preserved.

The island has great potential for renewable energy sources like sun, wind, hydrokinetic and biomass. Since there are over 17016 homes [4], it's safe to infer that the majority of them keep cows. The majority of biogas comes from discarded cattle feed. On our quest for a better society with zero carbon emissions (Fig. 1), we looked into solar panels, wind turbines, biogas generators, and batteries as potential power sources for our system, where biogas comes from discarded cattle feed. On our quest for a better society with zero carbon emissions (Fig. 1), we looked into solar panels, wind turbines, biogas generators, and batteries as potential power sources for our system. And in large or short-range networks, an optimal power assessment is needed for both operational and planning objectives. Our team used the HOMER (Hybrid Optimization Model for Multiple Energy Resources) [5] software to find the most cost-effective green hybrid system to suit the island's energy requirements. Electric loads, components to be used, solar radiation data, a wind speed profile, and technical information on the components are all inputs the program needs in order to buildthe system.

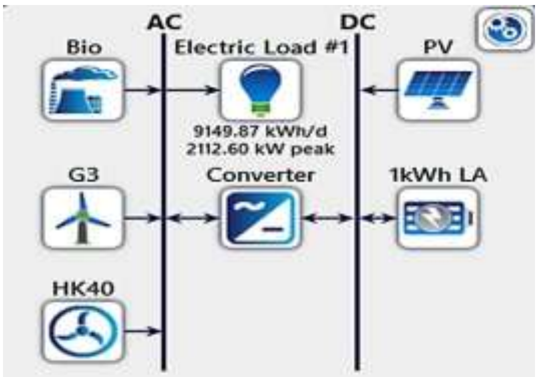

Fig. 1 Schematic of Green Hybrid Energy system

Load Modelling and Analysis

Individual people's PV cells [6] and diesel generators can't keep up with the demand for electricity because the grid isn't providing any. In order to obtain the best possible model for the island, the population of 17016 homes is taken into account [4]. In order to guarantee that all residents and guests always have access to electricity, we have suggested that load data modeling be implemented. The new thing about the proposed system is that it comes up with an optimal data solution that is completely sustainable and that model's data in a SMART way. We modeled the daily load profile for 17016 homes, considering the area's demographics and economic situation (Table 1-4).

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Table 1: Load Profile for Higher-Class Family

Appliances	Capacity(Watt)	Rural Area (247)		Urban Area (2)	
		Quantity	Average Work hour per Day	Quantity	Average Work hour per Day
LED Bulb	20	490	6	20	7
Ceiling Fan	80	294	14	15	14
TV	55	98	4	5	4
Fridge	55	98	24	5	24
Mobile Phone	5	294	2	15	2
Total Power Consumption per Day (kW)		**541.94 (Summer) 212.66 (Winter)**		**27.45 (Summer) 10.65 (Winter)**	

Table 2: Load Profile for Middle-Class Family

Appliances	Capacity(Watt)	Rural Area (247)		Urban Area (2)	
		Quantity	Average Work hour per Day	Quantity	Average Work hour per Day
LED Bulb	20	1235	6	6	7
Ceiling Fan	80	494	14	6	10
TV	55	247	3	2	3
Fridge	55	125	24	2	24
Mobile Phone	5	500	2	4	2
Total Power Consumption per Day (kW)		**912.235 (Summer) 358.955 (Winter)**		**8.65 (Summer) 3.85 (Winter)**	

Table 3: Load Profile for Lower-Middle Class

Appliances	Capacity(Watt)	Rural Area (13317)		Urban Area (185)	
		Quantity	Average Work hour per Day	Quantity	Average Work hour per Day
LED Bulb	15	26634	6	370	6
Ceiling Fan	80	13317	7	185	7
Mobile	5	13317	2	185	2
Total Power Consumption per Day (kW)		**9987.75 (Summer) 2530.23 (Winter)**		**138.75 (Summer) 35.15 (Winter)**	

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Table 4: Load Profile for Lower-Class Family

Appliances	Capacity(Watt)	Rural Area (3145)		Urban Area (17)	
		Quantity	Average Work hour per Day	Quantity	Average Work hour per Day
LED Bulb	15	3145	6	17	6
Mobile	5	3145	2	17	2
Total Power Consumption per Day (kW)		**314.5 (Summer) 314.5 (Winter)**		**1.7 (Summer) 1.7 (Winter)**	

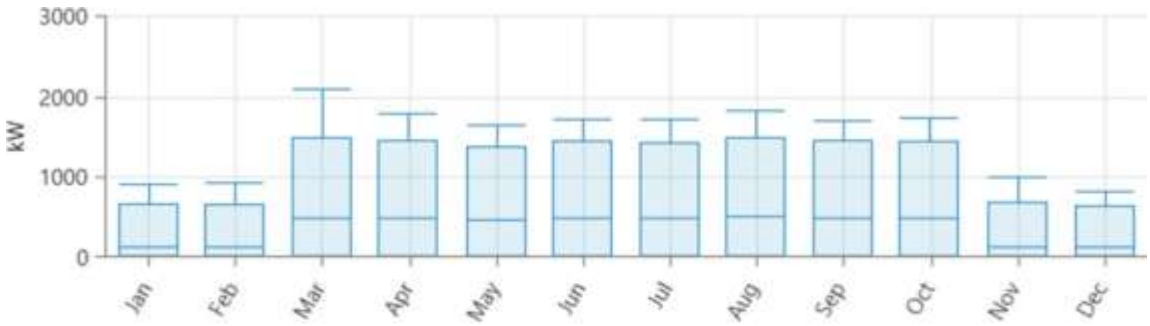

Fig. 2 Monthly Load Profile of Manpura Island

From the figure 2, we obtained that maximum load is 2112.6 kw in March and minimum load is 834.63 kw.

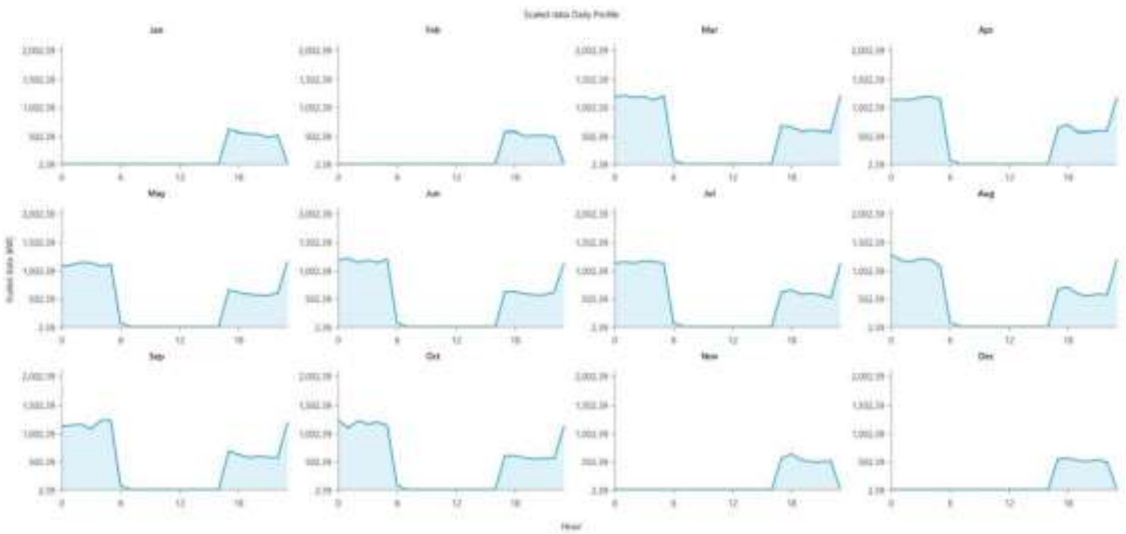
Fig. 3 Monthly individual daily load profile

Figure 3 shows monthly individual daily profile in kwh.

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Possible Sources of Clean Power

Solar and wind power generation are both highly feasible in Manpura. As eco-conscious people, we haven't given any thought to carbon-emitting power sources. Only solar panels, wind turbines, a biogas generator, hydrokinetic and batteries are truly useful to us.

Solar Energy

Homer [5] derives solar radiation from clearness indices based on Manpura's position and vice versa. The average monthly global radiation levels for Manpura are provided by NASA [7]. Using this information, HOMER generates 8760 hours of synthetic solar radiation using the Graham method per year. As can be seen in Figure 4, HOMER provides monthly average solar irradiance data for Manpura.

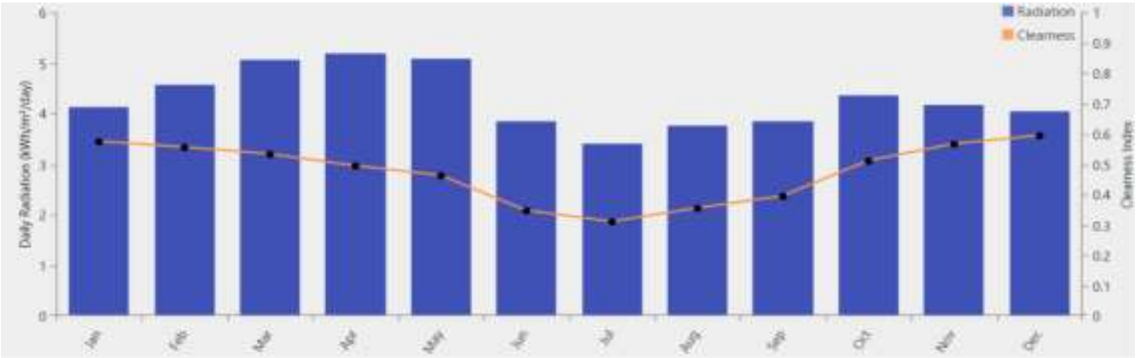

Fig. 4 Manpura's monthly solar GHI

Wind Energy

Monthly averages can be used to synthesize hourly wind speed data in this case. The HOMER [5] Synthetic Wind Speed Data Generator requires four inputs. For the Weibull distribution: This paper uses Weibull's [8] k to assess the seasonal stability of wind speeds. In this study, it is assumed that k = 2. The autocorrelation factor is that the degree of randomness in wind speeds and directions is measured. If the factor is low, the wind speed is more erratic. We use the value of 0.78 here. The significance of the diurnal cycles the amount by which wind speed varies during the day can be quantified by the diurnal pattern's intensity. The diurnal pattern has been set at a strength of 0.3.

Time of maximum wind speed: On a yearly basis, this is the hour with the most wind. At 1400, the wind was at its strongest. The average monthly wind speeds on Manpura island are shown in Figure 5, which was made by HOMER from NASA's surface meteorology and solar energy database.

Fig. 5 Monthly average wind speed of Manpura Island

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Biomass Energy

Animal feces are made up of a wide array of components, some of which are water, others are burned rubbish, and organic detritus that has decomposed [9]. In environments with low oxygen levels, carbon dioxide and other naturally occurring chemicals become more flexible and exert less of an impact. On the other hand, methane, carbon dioxide, and a variety of other chemical compounds that are stable are formed in anaerobic conditions. Figure 6 shows monthly available biomass in Manpura island.

Fig. 6 Monthly available biomass energy of Manpura island

Hydrokinetic Energy

Hydrokinetic energy, also known as tidal and wave energy, is a term that refers to the same renewable resource [10]. Because it does not produce any greenhouse gases or other harmful emissions, it is an excellent choice for people who are concerned about their impact on the environment. Because tides and waves are predictable and occur at regular intervals, it is possible to rely on hydrokinetic energy to provide a reliable and consistent source of power. In addition, as long as the oceans of the planet continue to exist, this type of energy source will always be available as a renewable resource. Figure 7 shows Monthly average water speed of Manpura Island.

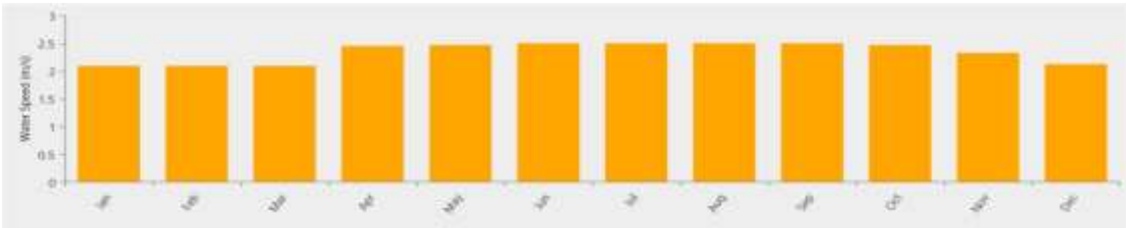

Fig. 7 Monthly average water speed of Manpura Island

Element of the Proposed Hybrid Energy System

Our proposed system takes into account a PV array, wind turbines, storage batteries, hydrokinetic energy, a biogas generator, and a converter to ensure its entire sustainability [11]. In the event that renewable energy sources like solar panels and wind turbines are unable to meet demand, the power grid is backed up by batteries and a biogas generator. In order to do economic analysis with HOMER, users must first enter technical ratings, capital costs, replacement costs, and O&M (operation and maintenance) costs.

Simulation and Optimization Result

Optimization and Modelling Over the course of many hours, HOMER ran numerous simulations with different values for solar radiation, wind speed, and other factors to determine the best course of action [12]. This hybrid system's optimization outcome is

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depicted in Figure 8.

Architecture							Cost			
PV (kW)	G3	Bio (kW)	1kWh LA	HK40	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
315	191	500	16,555	1	1,403	CC	$23.8M	$0.552	$838,195	$13.0M
	350	500	18,849	1	1,837	CC	$26.1M	$0.604	$932,843	$14.0M
845		500	18,847	1	2,737	CC	$26.5M	$0.615	$889,026	$15.0M
3,021	673		42,750	1	2,642	CC	$71.1M	$1.65	$1.56M	$50.9M
7,434			77,175	1	3,811	CC	$118M	$2.72	$2.42M	$86.3M

Fig. 8 Optimization result for the hybrid system

The optimization table estimates that the NPC (net present cost) of the PV, wind turbine, biogas generator, hydrokinetic, storage, and converter hybrid energy systems will be $23.8 million. NPC is $26.1 million without PV and with only wind turbines, biogas generators, hydrokinetic storage, and converters. The NPC rises to $26.5 million if the wind turbine is removed and to $71.1 million if the biogas generator is taken out of the equation as well. Including everything in the hybrid energy system is the most cost-effective solution. We received a total NPC (net present cost) of $23,796,260.00 and a COE of $0.5515 for that type of hybrid energy system. The total cost summary of the hybrid energy system is given in Figure 9.

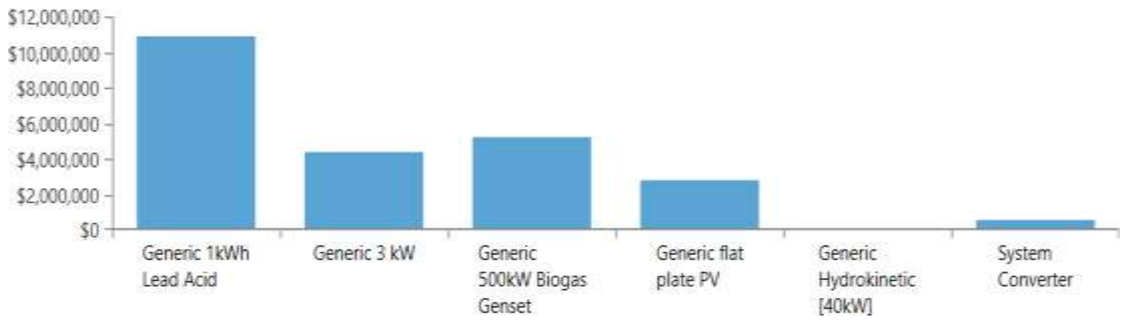

Fig. 9 Cost summery of the hybrid energy system

The term "cumulative cash flow over the life of the project" refers to the total amountof cash received or expended up to a given point in time during the life of the project [13]. Having a complete picture of the cash inflows and outflows that have occurred over the lifetime of the project is useful for evaluating its financial performance as a whole. Figure 10 shows cumulative cash flow over the life of the project.

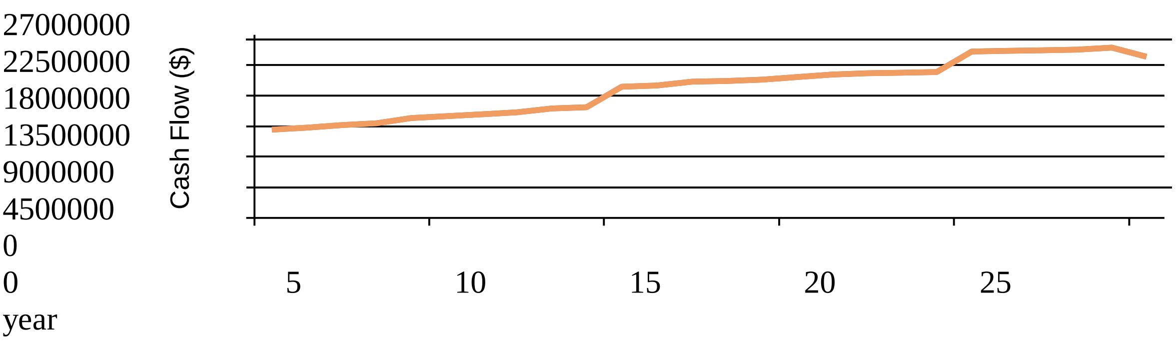

Fig. 10 Cumulative Cash Flow over Project Lifetime

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This microgrid has a peak demand of 1882 kW and needs 9105 kWh per day. All of the following types of electrical generation are used to supply the proposed system's electrical load. Figure 11 depicts the average monthly electricity output.

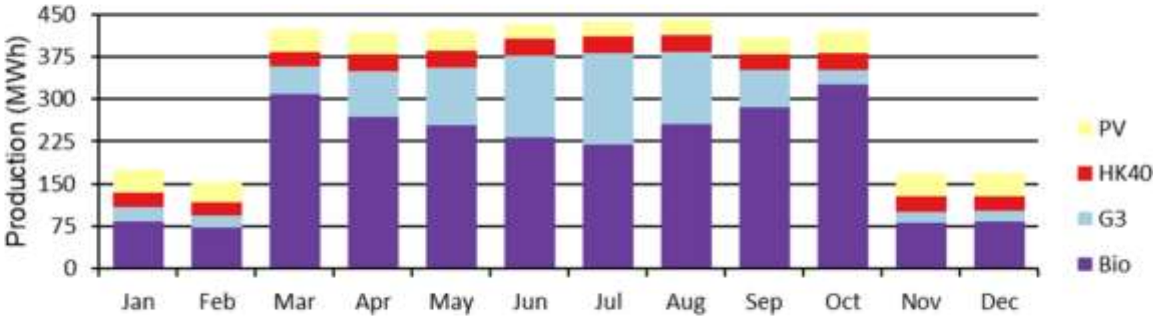

Fig. 11 The average monthly electricity output

Generic flat plate PV output

The Generic PV system has a nominal capacity of 315 kW. The annual production is 424,307 kWh/yr.

Rated Capacity	315 kW
Capital Cost	$2.62M
Specific Yield	1,349 kWh/kW
PV Penetration	12.7 %
Total Production	424,307 kW
Maintenance Cost	10,484 $/yr
LCOE	0.503 $/kWh

Wind Turbine output

Power output from the Generic wind turbine system, rated at 573 kW, is 838,266 kWh/yr.

Quantity	191
Wind Turbine Total Production	838,266 kWh/yr
Capital Cost	$3.44M
Wind Turbine Lifetime	20.0 years
Rated Capacity	573 kW
Hours of Operation	6,988 hrs/yr
Maintenance Cost	34,380 $/yr

Generic 500kW Biogas Genset (Biogas) output

Power output from the Generic generator system, rated at 500 kW using Biogas as fuel, is 2,477,263 kWh/yr.

Capacity	500 kW
Operational Life	3.95 yr
Capital Cost	$1.50M
Fuel Consumption	7,439 tons/yr
Hours of Operation	5,057 hrs/yr
Fixed Generation Cost	61.3 $/hr
Generator Fuel	Biogas
Generator Fuel Price	1.00 $/kg

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Maintenance Cost	151,710 $/yr
Electrical Production	2,477,263 kWh/yr
Marginal Generation Cost	0 $/kWh

Generic 1kWh Lead Acid Battery output

The Generic storage system's nominal capacity is 16,568 kWh. The annual throughput is 1,246,444 kWh/yr.

Rated Capacity	16,568 kWh
Annual Throughput	1,246,444 kWh/yr
Maintenance Cost	165,550 $/yr
Autonomy	26.1 hr
Expected Life	10.0 yr
Capital Costs	$4.97M
Losses	278,691 kWh/yr

Generic Hydrokinetic [40kW] output

The Generic Hydrokinetic [40kW] has a total rated capacity of 40.0 kW. The total annual production is 331, 510 kWh/yr.

Rated Capacity	40.0 kW
Capital Cost	$14,000
Maximum Output	40.0 kW
Hydrokinetic Penetration	9.93 %
Total Production	331,510 kWh/yr
Hours of Operation	8,760 hr/yr
Levelized Cost	0.00576 $/kWh
Capacity Factor	%

System Converter output

Capacity	1,403 kW
Mean Output	121 kW
Minimum Output	0 kW
Maximum Output	1,346 kW
Capacity Factor	8.64 %
Hours of Operation	2,664 hrs/yr
Energy Out	1,062,145 kWh/yr
Energy In	1,118,048 kWh/yr
Losses	55,902 kWh/yr

Implementation Challenges

Despite the numerous advantages of electrifying rural areas, achieving this through a hybridized energy system in off-grid areas is not a simple task. It will be necessary to overcome numerous technical, political, economic, and sociocultural obstacles for this endeavor to be successful. Hybridized power system design and implementation is complex and relatively difficult due to the system topology [14, 15]. Furthermore, the hybrid system hashigher capital requirements than the diesel-only system. Insufficient market infrastructure and resources exist to support the hybrid system's components. In remote locations [16], the maintenance and availability of a large number of batteries and spare components can be difficult. In developing nations like Bangladesh [17], policy and regulation are significant obstacles, and they can be a determining factor in a project's success or failure. Access to sustainable and inexpensive energy is vital for eliminating poverty in these nations. Bangladesh has established renewable energy regulations that include financial incentives such as a 15% value-added tax (VAT) exemption on equipment and raw material purchases, as well as a 10% higher purchasing price from the private sector [18]. The implementation of a hybrid system may be impossible without changes to existing laws and regulations, but new ones could make it possible. Government endorsement is required for the use of renewables [19] in rural electrification. To obtain authorization in a timely manner, however, the current institutional system requires approval from multiple government agencies and departments, necessitating cooperation with these institutions. To overcome this problem, Government and private organizations must work together to find solutions to the difficulties associated with implementing a hybridized system that operates independently. The incorporation of renewable energy sources into a conventional system not only reduces greenhouse gas emissions by 22% compared to a diesel-based system, but also increases the dependability of electricity supply and satisfies load demand. [20]

2. CONCLUSIONS

This research combines wind, hydrokinetic, solar, and biomass energy sources in order to develop a novel method for storing renewable energy for use in remote locations. Changing from conventional fossil fuel energy sources to renewable sources of energy such as wind, solar, and biomass is one way to lessen one's impact on the environment. Not only does it lack the capacity to meet the growing demand for electricity in rural regions, but it also failsto promote the necessary energy transition in those areas. This research proposes a more realistic grid-connected non-sales operation mode based on the actual system. This mode has the potential to effectively reduce wind and solar abandonment and lower the impact of system grid connection on the grid.

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