Environ. Eng. Res. 2025; 30(3): 240340
https://doi.org/10.4491/eer.2024.340

Supplementary Materials

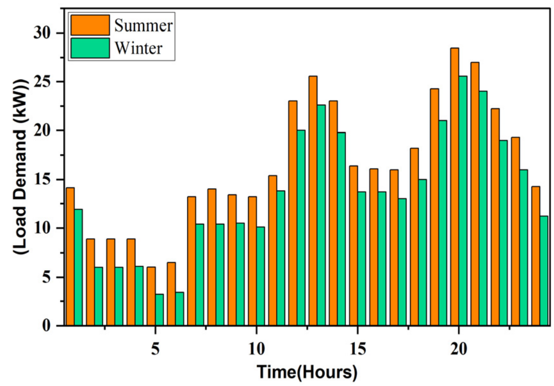


Fig. S1. The winter and summer day-to-day load profile.

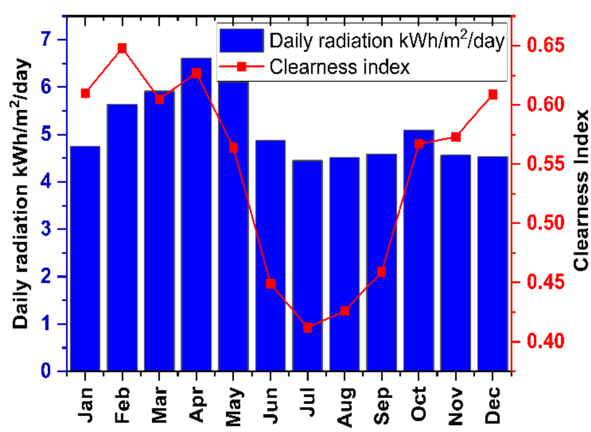


Fig. S2. Monthly per-day solar irradiation and clearness index.

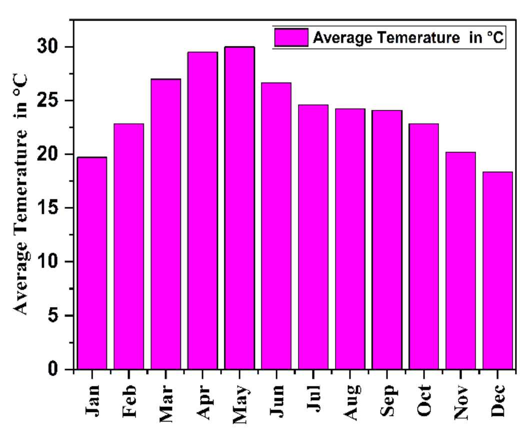


Fig. S3. The annual average temperature.

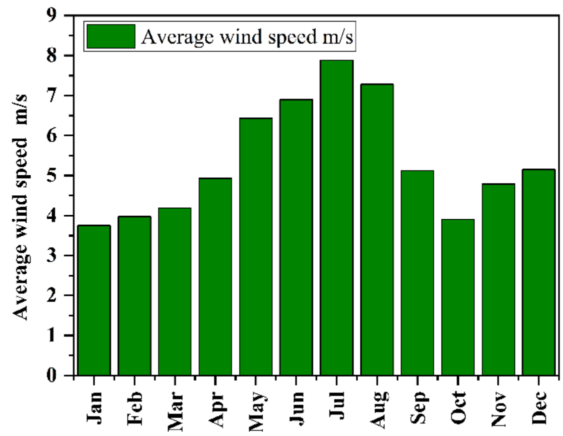


Fig. S4. Average monthly wind speed data.

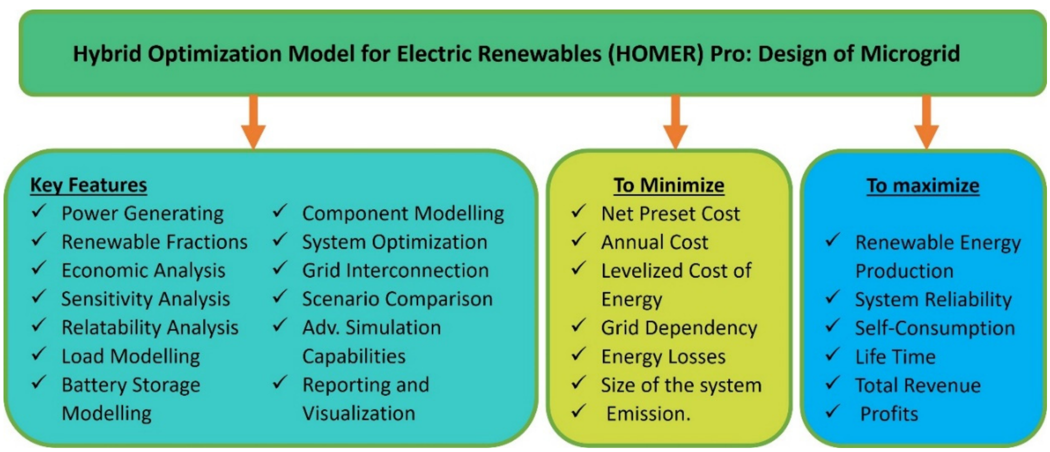


Fig. S5. Illustrates the key features and potentials of HOMER pro software.

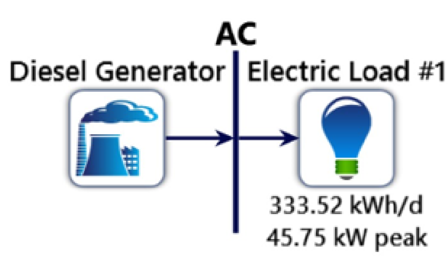


Fig. S6. Simulation diagram of scenario-1.

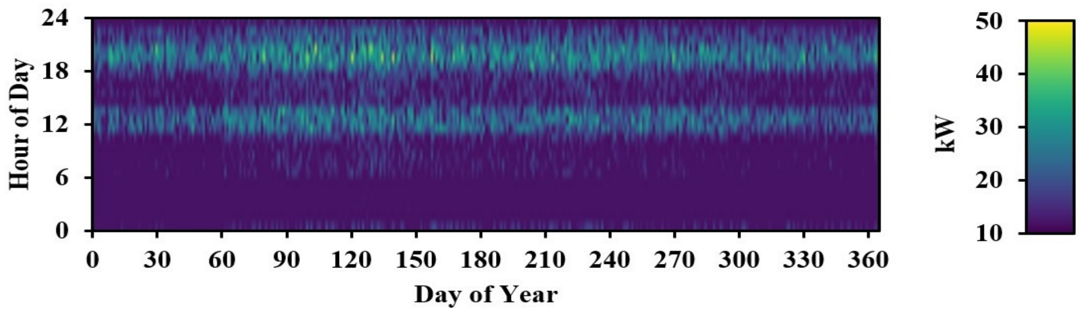


Fig. S7. Annual energy production heat map of diesel generator.

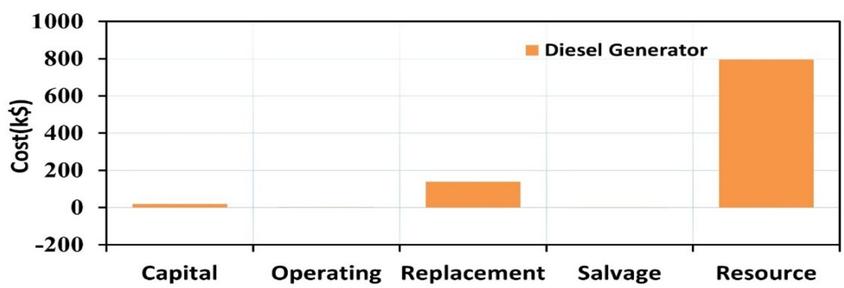


Fig. S8. Cost summary of the diesel generator.

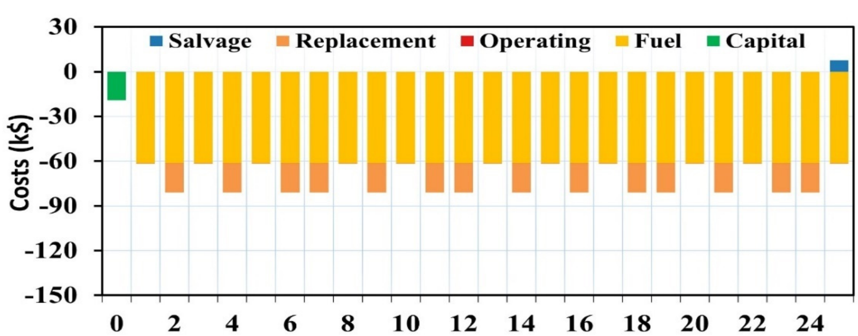


Fig. S9. Cash flow of diesel generator cost type.

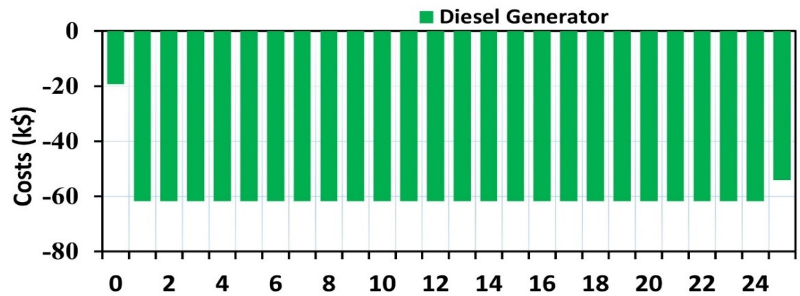


Fig. S10. Cash flow of stand-alone diesel generator component type.

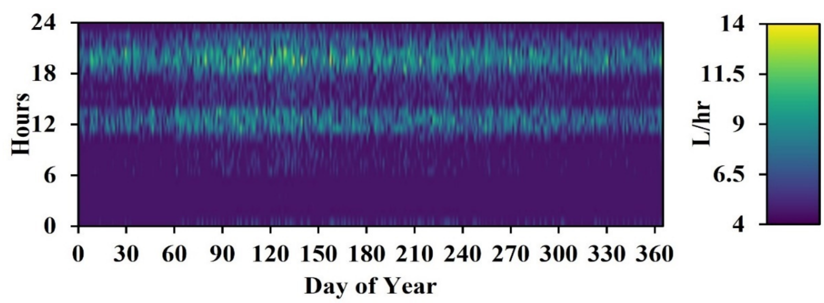


Fig. S11. Diesel consumption statistics of the stand-alone diesel generator.

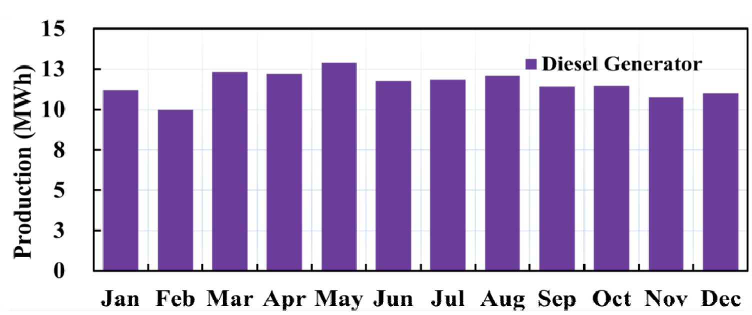


Fig. S12. Average electrical power generation of diesel generator.

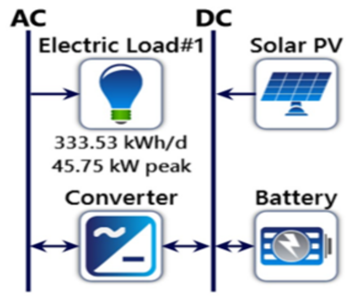


Fig. S13. Simulation diagram of scenario-2.

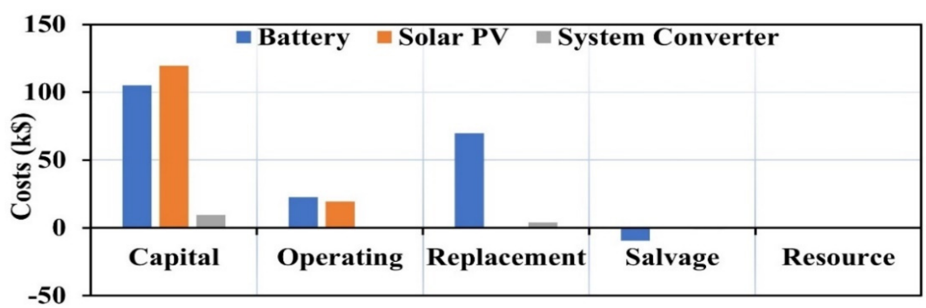


Fig. S14. Hybrid PV, BAT, CONV microgrid system cost summary.

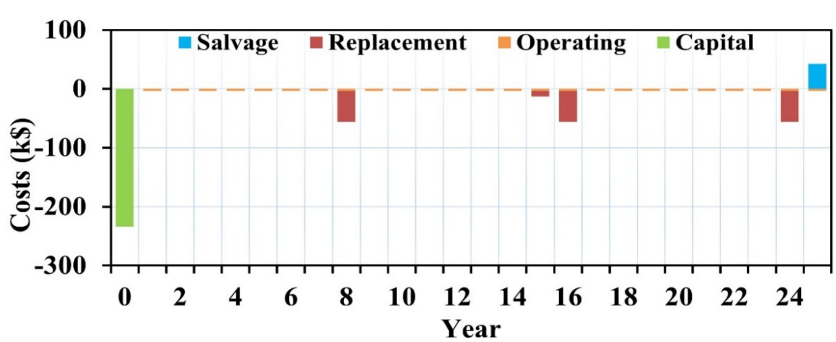


Fig. S15. Cash flow of PV, BAT, and CONV systems by cost type.

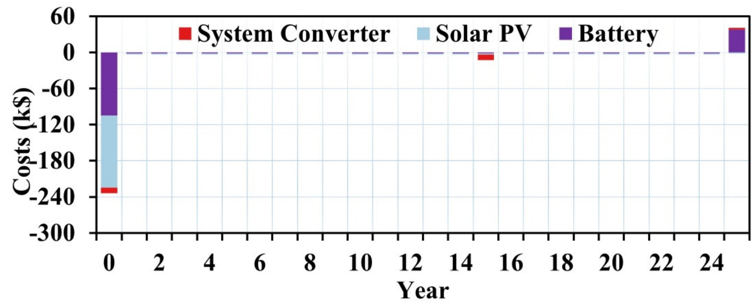


Fig. S16. Cash flow of PV, BAT, and CONV systems by component type.

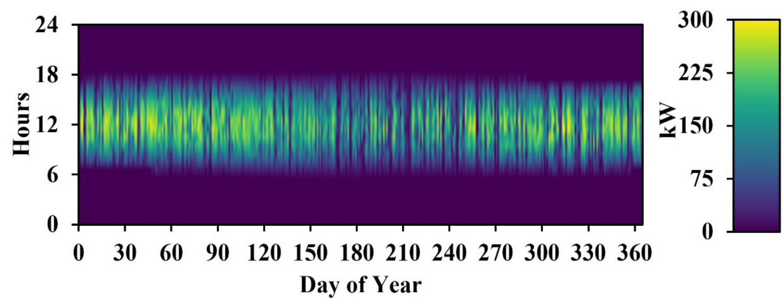


Fig. S17. Annual energy production summary heat map of the solar PV.

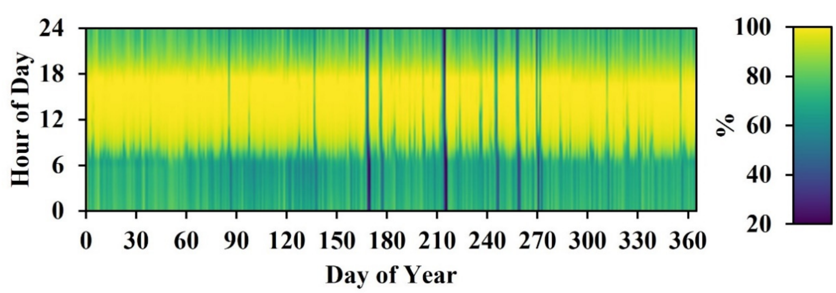


Fig. S18. Batteries state of charge.

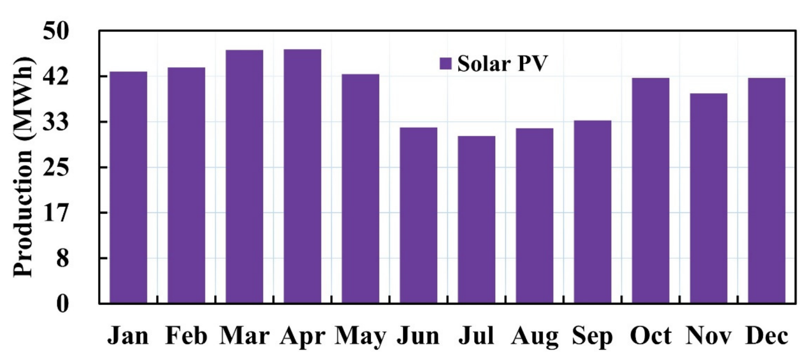


Fig. S19. Average electrical production of the solar PV system.

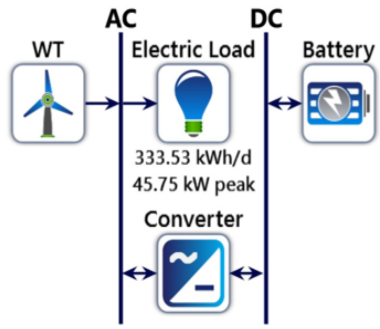


Fig. S20. Simulation diagram of scenario-3.

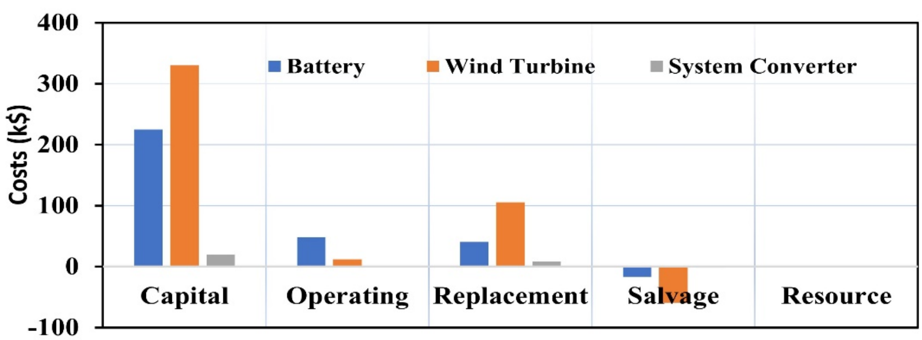


Fig. S21. Cost summary of hybrid WT/BAT/CONV microgrid.

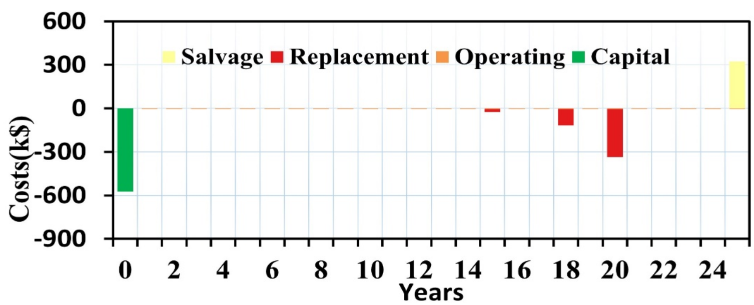


Fig. S22. Cash flow of WT, BAT, and CONV systems by cost type.

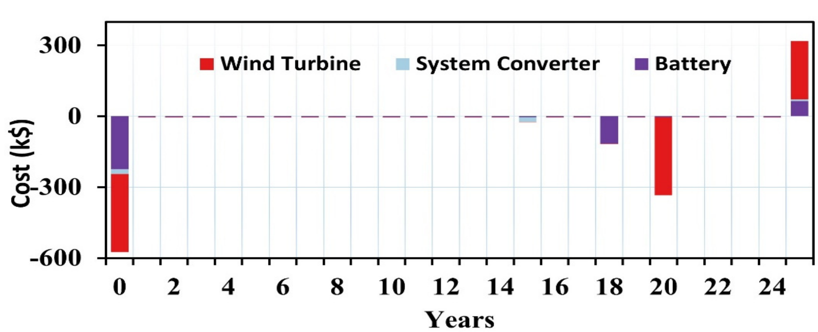


Fig. S23. Cash flow of WT, BAT, and CONV systems by component type.

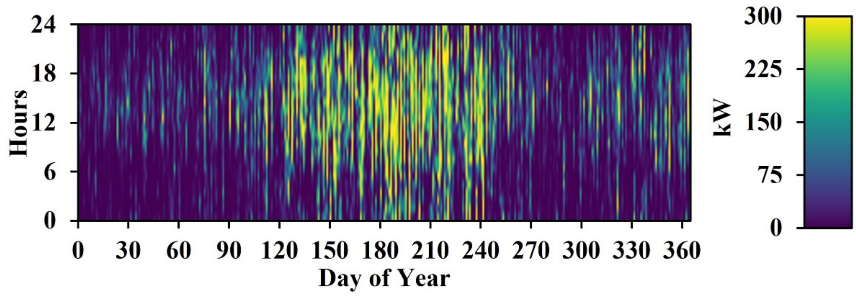


Fig. S24. Annual energy production summary of the WT.

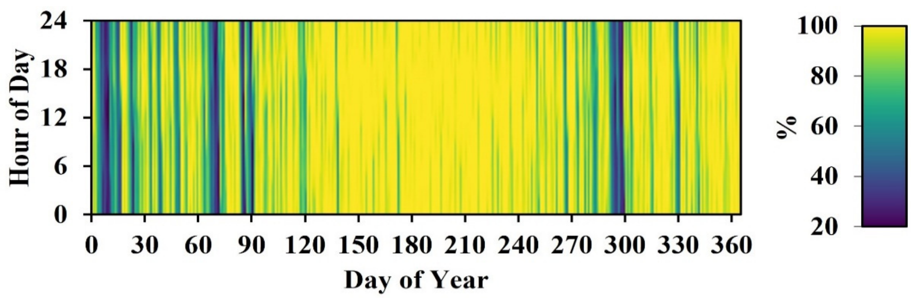


Fig. S25. Batteries state of charge.

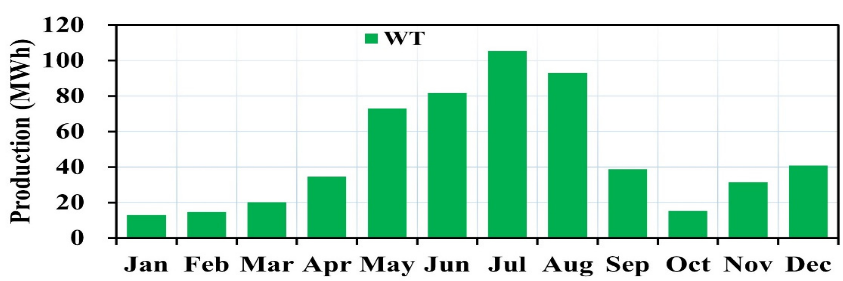


Fig. S26. Annual energy production summary of the WT.

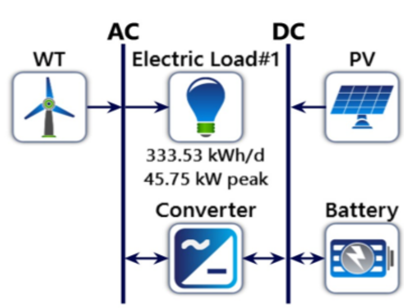


Fig. S27. Simulation diagram of scenario-4.

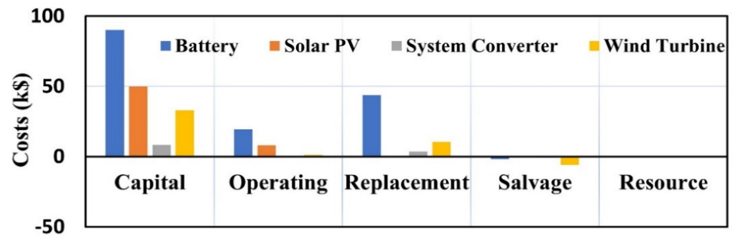


Fig. S28. Hybrid PV-WT-BAT-CONV microgrid cost summary.

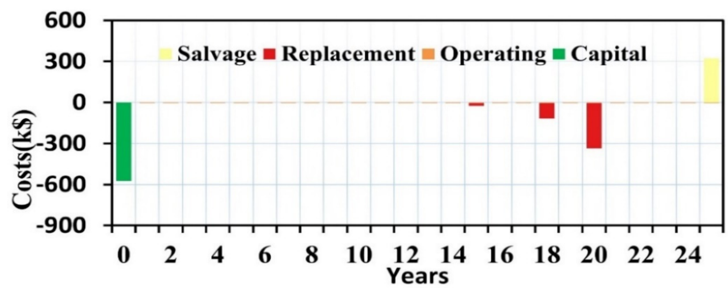


Fig. S29. Cash flow of hybrid PV/WT/BAT/CONV microgrid by cost type.

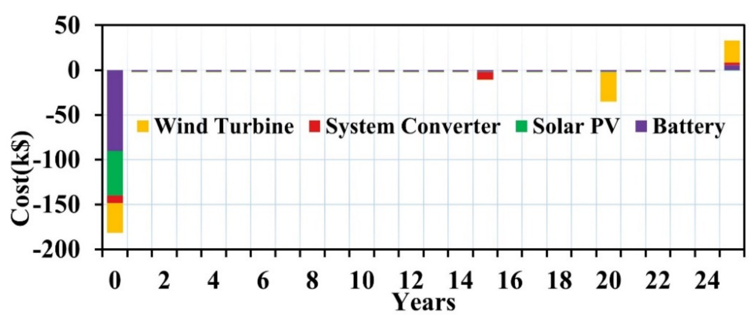


Fig. S30. Cash flow of hybrid PV/WT/BAT/CONV microgrid by component type.

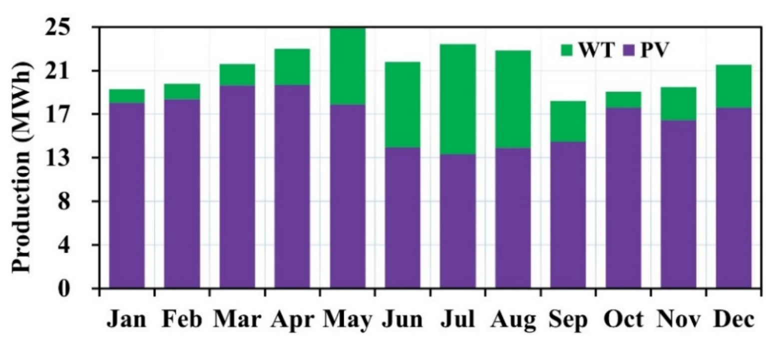


Fig. S31. The combined monthly average of PV and WT output.

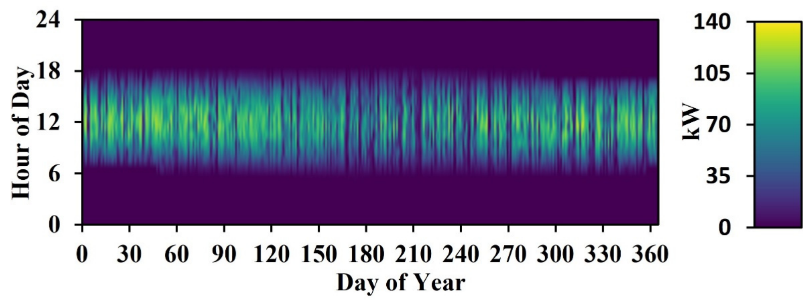


Fig. S32. Annual energy production summary of the solar PV.

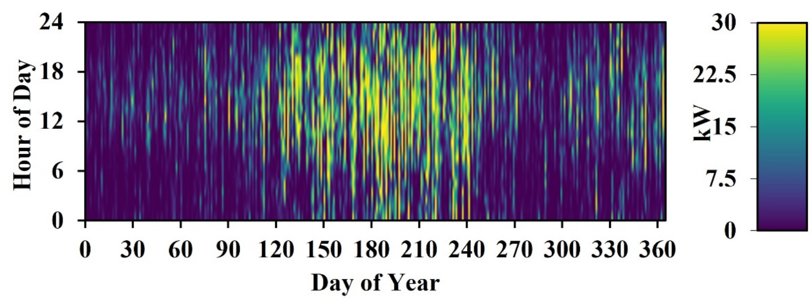


Fig. S33. Annual energy production summary of the wind turbine.

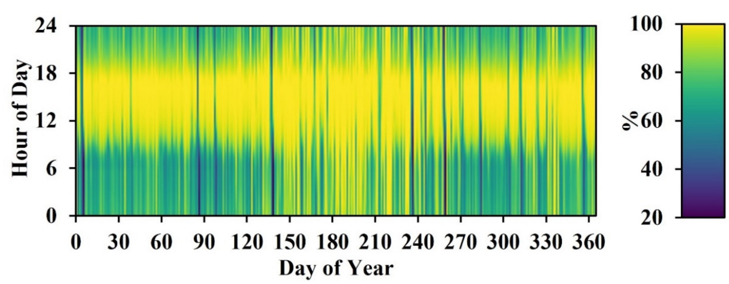


Fig. S34. Batteries state of charge over a year.

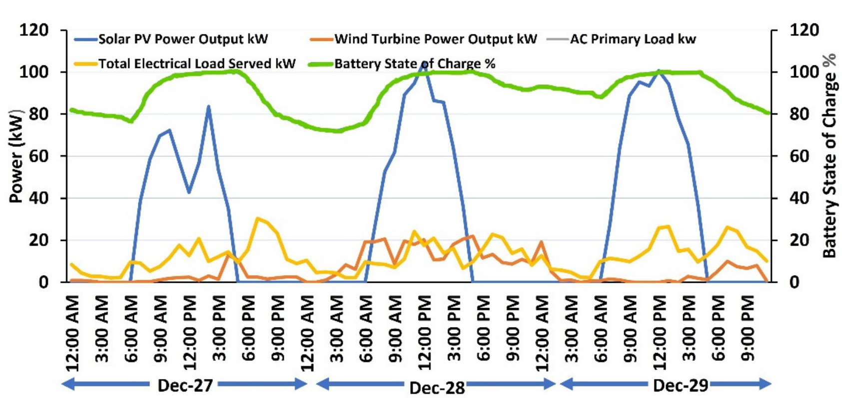


Fig. S35. Microgrid's energy dispatch on three consecutive days (27th, 28th, and 29th December).

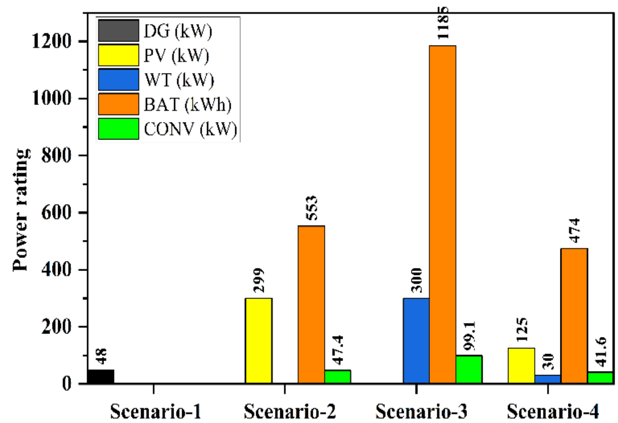


Fig. S36. Optimal design capabilities.

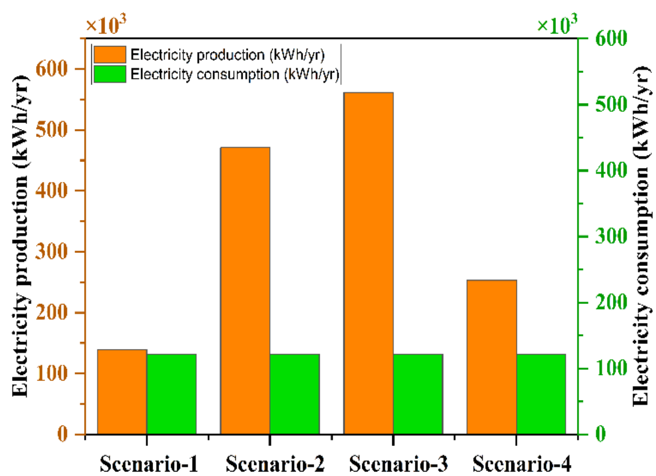


Fig. S37. Electricity production and consumption.

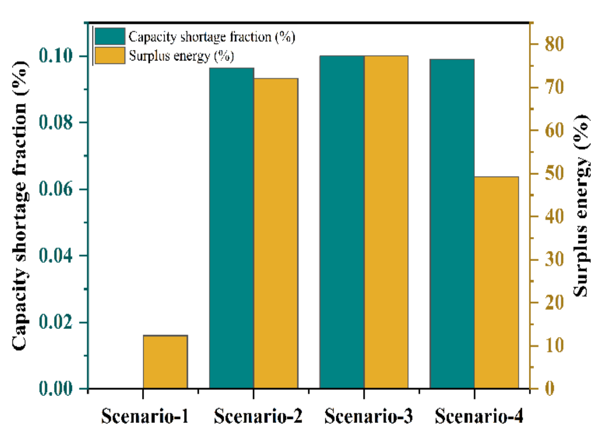


Fig. S38. CSF and SE.

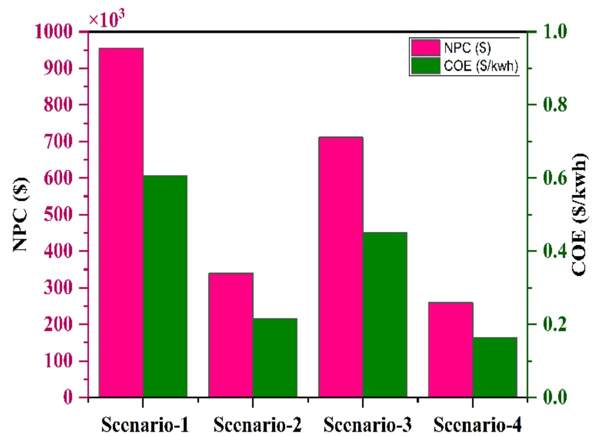


Fig. S39. NPC AND COE.

Table S1. Electrical load sharing of the study area.

Type of load	Daily load in kWh/day
Domestic load	165.4
Community loads	49.5
Agriculture load	118.63
Total loads	333.53

Table S2. Details of the microgrid system.

Microgrid system	Scenario
Stand-alone Diesel Generator	1
Solar PV, Battery, and Converter	2
Wind Turbine Battery and Converter	3
Solar PV, Wind Turbine, Battery, and Converter	4

Table S3. Technical details of microgrid components.

Component	Parameters	Value
Diesel generator (Kohler 48 kW Standby)	Rated Power	48 kw
	Fuel curve slope	0.267 L/hr/kW
	Intercept coefficient	1.35 L/hr
	Lifetime	87,600 hr
	Minimum load ratio	25%
	Fuel density	820 kg/m3
	Carbon content	88%
	Sulfur content	0.40%
	Carbon Monoxide	16.34 g/L
	Nitrogen Oxides	15.359 g/L
	Lower heating value	43.2 MJ/kg
	Price of diesel fuel	1.26 $/L
Converter	Efficiency	95%
	Relative capacity	100%
	Lifetime	15 years
Solar PV (PV Sun 330)	Rated power	0.33 kW
	Nameplate voltage	46.20 V
	Nameplate current	9.38 A
	Temperature coefficient	-0.4294
	Efficiency at STC	13%
	Derating factor	85%
	Ground reflectance	0%
	Lifetime	25 years
Wind turbine (Eocycle EO10)	Rated power	10 kW
	Cut-in velocity	2.75 m/s
	Cut-off velocity	20 m/s
	Rated velocity	6.5 m/s
	Hub height	23 m
	Lifetime	20 years
Battery (BAE SECURA SOLAR 12 V 2 PVV 140)	Nominal voltage	12 V
	Nominal capacity	1.58 kWh
	Maximum capacity	132 Ah
	SOC limits	20~100%
	Roundtrip efficiency	95%
	Capacity ratio	0.265
	String size	50
	Max charge current	45.2 A
	Max discharge current	255
	Lifetime	18 years

Table S4. Cost data of microgrid components.

Component	Capital	Replacement cost	O&M
DG [1]	400$/kW	400$/kW	0.020$/Op.hr
PV [2]	400$/kW	400$/kW	5$/kW/yr
WT [2]	11,000 $/turbine	10,000 $/turbine	30/turbine/yr
CONV [2]	200$/kW	200$/kW	0$/kW/yr
BAT [3-4]	300$/Bat	150$/Bat	5$/Bat/Yr

Table S5. Illustrates the various types of loads employed in the remote study area.

S. No	Category of load	Quantity	Power (Watts)	Summer (Feb-July)		Winter (Aug-Jan)	
				Hrs./day	Watt-hrs./day	Hrs./day	Watt-hrs./day
Type A. Domestic load (Lighting Load, Fan loads, etc.⋯,)							
1	Compact Fluorescent Lamps	5	20	10	1,000	7	700
2	Compact Fluorescent Lamps	1	11	8	88	11	121
3	Ceiling fans	2	100	20	4,000	0	0
4	Radio	1	40	3	120	3	120
5	Charging lamps	2	50	4	400	4	400
6	Mobile phone chargers, etc.	2	50	2	200	2	200
	Total demand (One house)	--	--	--	5808	--	1,541
	No. of Houses	45	--	--	261,360	--	69,345
	Total demand (Type A) in (kWh/day)	--	--	--	261.36		69.34
					165.4		
Type B. Community loads (Medical center, school, and street loads)							
1	Medical Centre	1	1,500	9	13,500	9	13,500
2	Elementary school	1	500	11	5,500	11	5500
3	Community shops	4	500	3	6,000	5	10,000
4	Community center	1	1,000	9	9,000	9	9,000
5	Flour Mill	1	3,000	4	12,000	3	9,000
6	Street lights	10	30	9	2,700	11	3,300
	Total demand (Type B) in (kWh/day)	--	--	--	48.7	--	50.3
					49.5		
Type C. Agriculture load (water pump, irrigation pump, well, etc.)							
1	Water storage tanks and pumps	1	5,500	6	33,000	4	22,000
2	Electric motors for pumping water from the river	4	5,500	4	88,000	3	66,000
3	Irrigation sprinkler systems	3	750	3	6,750	2	4,500
4	Drip irrigation systems	2	750	3	4,500	2	3,000
5	Electric Fencing to Protect Crops	1	500	9	4,500	10	5,000
	Total demand (Type C) in (kWh/day)	--	--	--	136.75	--	100.5
					118.62		
	Total demand (A + B + C) (kWh/day)		333.52				
	Peak demand (kW)		45.75				

Table S6. Illustrates the electrical energy consumption survey form used in the remote study area.

Electrical Energy Consumption Survey Form		
House number		
Type of house		
No. of people living		
No. of units consumed in last month		
Name of the Electrical Appliances	Power Rating in Watts	No. of Hours Used
Bulbs (Main lamps) (High power rating)		
Bulbs (Bed lamps) (Low power rating)		
Ceiling fans		
Radio and Television		
Charging lamps		
Mobile phone chargers		
Electric motors		
Mixers and grinders		
Any other appliances		
Total Energy consumption		

Table S7. Illustrates the technical aspect comparisons of various types of batteries [5].

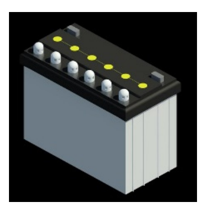
Technical Aspect	Lithium-Ion Batteries	Lead-Acid Batteries	**Nickel-Metal Hydride (NiMH) Batteries**	**Sodium-Sulfur (NaS) Batteries**
Images				
Energy Density (Wh/kg)	150-250	30-50	60-120	100-150
Cycle Life (cycles)	500-2000	300-500	500-1000	2000-4500
Charge Time (hours)	1 to 4	6 to 8	2 to 6	4 to 6
Discharge Depth	Up to 80-90%	50-60%	Up to 80%	Up to 90%
Operating Temperature(℃)	-20 to 60	-20 to 50	-20 to 60	300 to 350
Efficiency in percentage	90-95	70-85	70-80	75-80
Environmental Impact	High impact.	Lower Impact.	Moderate impact.	Lower impact.
Cost ($/kWh)	150-400	100-200	300-600	200-500

Table S8. Illustrates the nomenclatures.

Symbol	Definition	Dimension
A	Swept area	m^2
CAPC	Capital of the microgrid system	$
CSF	Capacity shortage fraction	-
$C_{Tot,an}$	Total annualized cost	$/year
DOD	Battery depth of discharge	Percentage (%)
d_r	Annual real discount rate	Percentage (%)
d'_r	Nominal interest rate to borrow money	Percentage (%)
E_L	Average daily load	kWh
E_g	Annual useful electrical energy generated by the microgrid	kWh/year
$E_{BAT,r}$	Rated storage energy of the battery	VA
Fc	Fuel consumption	L/h
f_{go}	DG fuel curve slope	-
f_{gr}	DG fuel curve intercept coefficient	-
FLC_n	Fuel cost in n year	$
f_r	Expected inflation rate	Percentage (%)
FC(t)	Fuel consumption of the diesel generator	Liters
G	Solar radiation on the panel	W/m^2
G_{ref}	Solar irradiance at standard temperature conditions (STC)	W/m^2
H_{1hf}	Lower heating value of diesel	kJ/kg
OPECn	Operation cost in n year	$
P_g	Power generation	kW
P_{pv}	Power of the PV module	kW
Pr	Rated capacity of the utilized DG	kW
Prated	Rated power at reference condition	kW
p_f	Density of fuel	kg/L
p	Density at sea level	kg/m^3
P_{PV}	Power of the PV module	kW
P_{CONV}	Converter capacity	kW
P_{diesel}	DG output power	kW
PL	Total annual load served	kWh/year
PL	Load Demand	kWh
RPCn	Replacement cost in n year	$
$	United States Dollar	USD
SECO2	Litre diesel's specific emission of CO2	kg CO2/liter
SOC	State of charge	Percentage (%)
$SOC_{BAT,min}$	Minimum state of charge of battery	Percentage (%)
$SOC_{BAT,max}$	Maximum state of charge of battery	Percentage (%)
η_{gn}	Efficiency of the DG set	Percentage (%)
η_{pv}	Photovoltaic conversion efficiency	Percentage (%)
η_{bat}	Battery efficiency	Percentage (%)
η_{inv}	Inverter efficiency	Percentage (%)
$\eta_{DC/AC}$	Converter efficiency from DC to AC	Percentage (%)
$\eta_{AC/DC}$	Converter efficiency from AC to DC	Percentage (%)
Ƭ	Gamma function	-
Y_{pv}	Derating factor	-

Table S9. List of abbreviations.

AC	Alternating current;
ALA-QPSO	Adaptive local attractor-based quantum-behaved particle swarm optimization;
APSIM	Remote area power simulator;
AQO	Aquila optimizer;
ARES	Autonomous renewable energy Systems;
BAT	Batteries;
BESA	Bald eagle search algorithm;
BG	Bio-gas;
BSPSO	Butterfly particle swarm optimization;
BT	Battery;
CO2	Carbon dioxide;
COE	Cost of energy;
CONV	Converter;
CSF	Capacity shortage fraction;
DA	Dragonfly algorithm;
DC	Direct current;
DE	Differential evolutionary algorithm;
DERs	Distributed energy resources;
DG	Diesel generator;
DHRES	Distributed hybrid renewable energy system;
DOD	Depth of discharge;
ESS	Energy storage system;
FA	Firefly algorithm;
FC	Fuel cell;
GA	Genetic algorithm
GOA	Grasshopper optimization algorithm;
GRG	Generalized reduced gradient method;
GWO	Gray wolf optimization;
HGWOSCA	Hybrid gray wolf optimizer-sine cosine algorithm;
HOMER	Hybrid optimization model for electric renewables;
HT	Hydrogen tank;
HybSim	High altitude balloon simulator;
HySim	Hybrid energy simulation model;
HySys	The Hybrid Power System Balance Analyser;
iGRHYSO	Improved grid-connected renewable hybrid systems optimization;
iHOGA	Improved hybrid optimization by genetic algorithms;
IHS	Improved harmony search;
INSEL	Integrated simulation environment language;
IPSYS	Integrated power system tool;
LCOE	Levelized cost of energy
LF	Load following;
LLP	Load loss probability;
LS	Load shifting;
MCDM	Multi-criteria decision-making approach;
MFO	Moth flame optimization;
MG,	Microgrid;
MHT	Micro hydro turbine;
NPC	Net present cost;
NSGA-II	Non-dominating Sorting Genetic Algorithm II;
P-GA-PSO	Parallel hybrid genetic algorithm-particle swarm optimization;
PSO	Particle swarm optimization;
PV	Photovoltaic;
RES	Renewable energy systems;
RF	Renewable friction;
SA	Simulated annealing;
SCA	Sine cosine algorithm;
SDG7	Sustainable development goal 7
SE	Surplus energy;
SMA	Slime mold algorithm;
SOA	Seagull optimization algorithm;
SOC	State of charge;
SOMES	Simulation and optimization model for renewable energy systems;
SSA	Salp swarm algorithm;
STC	Standard test conditions;
TAC	Total annual cost;
TCE	Total carbon emission;
TLBO	Teaching learning-based optimization;
TRNSYS	Transient energy system simulation program;
UL	Unmet load;
VCS	Virus colony search;
WCA	Water cycle algorithm;
WOA	Whale optimization algorithm;
WHO	Wild horse optimizer;
WT	Wind turbine;

References

1. Kohler power. Diesel Generator cost details from Kohlerpower [Internet]. Kohler power; c2024 [cited 15 May 2024]. Available from: http://www.kohlerpower.in/manuals/generators/specification/40_50_63kVA%20spec%20sheet.pdf.
2. Elmorshedy MF, Elkadeem MR, Kotb KM, et al. Feasibility studyand performance analysis of microgrid with 100% hybrid renewables for a real agricultural irrigation application. *Sustain. Energy Technol. Assess.* 2022;53:102746. https://doi.org/10.1016/j.seta.2022.102746.
3. BAE Secura. PVV Block Solar 12V 137Ah Battery 12V 2PVV140 battery cost [Internet]. BAE Secura; c2024 [cited 15 May 2024]. Available from: https://www.batterycentralbrisbane. com.au/cat/solar-batteries/?category[c]=off-grid- battery-banks-solar-batteries.
4. Kushwaha PK, Bhattacharjee C. Integrated techno-economic-enviro-socio design of the hybrid renewable energy system with suitable dispatch strategy for domestic and telecommunication load across India. *J. Energy Storage.* 2022;55:105340. https://doi.org/10.1016/j.est.2022.105340.
5. Nyamathulla S,Dhanamjayulu C. A review of battery energy storage systems and advanced battery management system for different applications: Challenges and recommendations. *J. Energy Storage.* 2024;86:111179. https://doi.org/10.1016/j.est.2024.111179.