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A comparative study of solid waste based distributed multigeneration system between two Indian islands

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The scarcity of fossil fuels to fulfil the increasing demand of electricity and the generation of solid waste are the great concerns of the society. Presently, supply of uninterrupted electricity generation in the isolated areas particularly in the islands or in the rural areas based on available energy resources is the significant area of research. The purpose of the present work is to study the feasibility of setting up a distributed multigeneration system in the islanded area integrating with hybrid energy system and solid waste management. A comparative study of multigeneration in the form of electricity generation, heating, and hydrogen production between two Indian island areas: Hiranmoypur and Sundarban is carried out. The Hybrid Renewable Energy System (HRES) comprising of Solar PV, Biogas microturbine and Electrolyzer is used in the present study and optimisation is made by using a software HOMER (Hybrid Optimization of Multiple Energy Resources). Fuels utilized for the energy generation are mainly the solid wastes generated from the locality and also the freely available forest wastes. The results include the size of various components used, Net Present value (NPV) of the hybrid system, share of different renewable energy sources and the emissions. Biogas generator is found to be the most suitable technology to utilize the solid wastes for electricity generation that shares 99% to the total electricity generation and the rest is from Solar PV cells at Sundarban with a Cost of Electricity (COE) generation of Rs. 9.35/kWh. Whereas, at Hiranmoypur, the share of electricity generation from Biogas generator is 66.1% and the rest is from Solar PV cells with a COE of Rs.11.26/kWh generation. Moreover, the result shows that designing a multigeneration system for distributed electricity generation through the utilization of solid wastes instead of using only Solar PV at Sundarban island helps in solid waste management, sustainable electricity supply, and lower value of COE generation.

Keywords: Distributed generation, hybrid renewable energy system, multigeneration, solid waste management.

Introduction

Development of urbanization, industrialization, and growth of population resulted in increase of the energy consumption in general and electricity in particular. About 33.33% of the total fossil fuel utilized is consumed by the urban centers resulting in about 80% of the total carbon dioxide (CO_2) emission[1]. CO_2 is emitted not only by energy consumption but also generated from many of the solid and liquid wastages.The relationship between civilization and energy demands can be well understood from the works by Appiah *et al.*[2]. Biodegradable waste handling and CO_2 emissions from the domestic sector are still found unsustainable and create lot of problems[3].

The development of the renewable energy sector is the way to overcome the issue of increasing global emission through fossil fuel. Development of sustainable system using different renewable energy sources, available optional fuels for catering energy of buildings, transportation, and various industrial purposes[4]. Energy consumption of residential and commercial buildings has exceeded the energy demand for other areas like industrial and transportation[5]. A grid-connected distributed hybrid energy poly-generation system has been a favored approach for community-based energy requirements like electricity, transportation, and cooling/heating. Moreover, this approach can reduce the loss of energy due to the transmissions and distributions as it includes approx. 26% of total energy production[6]. Security is also an advantage of the distributed generation.

A solar assisted wind-based generation has become sustainable and environmental-friendly alternative to supply power in rural, off-grid, and isolated, locations[7]. Limitation of the stand-alone system is the need for a storage system as they are not continuous production sources of electricity. Moreover, the energy conversion ratio and cost of production depends on the climatic condition. Hence, there is a need for development of storage devices which ultimately increases the cost of generation and storage, complexity, and maintenance cost. Diesel generator as a back-up device fulfills mostly the requirement of continuous power supply. Techno-economic optimization of a distributed poly-generation system with renewable resources locally available at a remote location of India is carried out by Ray and De[8]. From the preceding research work it can be understood that individual renewable sources may not be economical and technically viable for the building or to meet the community-based energy demand. Hence, there is a need of hybridization of the renewable energy sources but this may make the system more complicated. Solar and wind based hybrid energy system have been studied by different researches to estimate the cost of production when the hybrid system operates with stand-alone or in grid connected manner[7–12]. Feasibility study is also conducted for an islanded micro grid set-up in the island and rural areas combining PV, wind, biomass, and battery storage system[11].

Continuous progress in technology it is found that biomass, biogas, small-hydro, and fuel cell are combined with solar and wind sources[13]. Biomass integrated power plants have higher load factor and conversion efficiency[14]. Resulting biomass and biogas became a more feasible option, specifically in agriculture rich countries. Conversion of biomass can be done into heat, electricity and bio-fuel etc.[15,16]. The integration of biomass and concentrated solar power system in transcritical organic Rankine cycles: A micro combined heat and power generation is under development[17]. Techno-economic analysis is carried out of off-grid solar PV assisted by Fuel cell system for a community in the desert region[18]. Off-grid and grid-connected PV- biomass with or without storage seems to be a viable and cost-effective option for electricity generation in the developing countries[19,20]. Thermodynamic optimization of a Solar-powered multigenerational system to meet the needs of residential building and syngas generation has been made[21].

Now-a-days, municipal solid waste management is also a big concern of the society as well as the government. Due to the population growth, there is a growth in domestic waste which resulting in increase of pollution. Handling of biodegradable waste is still unstable in many European countries, and carbon emission through domestic biodegradable waste is very high[22], whereas it has been observed that the correct treatment of solid waste can generate some amount of biogas which is a low calorific value fuel. Now-a-days new technology and methods have been developed in European countries to reduce residential waste and production of energy from it[23]. Mass-burn incineration technology converts one tone of biodegradable waste into 550 kWh of electricity[24]. The biogas concept is not new. Previously, its utilization was limited to the cooking gas, but development of micro-turbine helps in production of electricity and heat from biogas, which can be reutilized for steam generation, heating requirement, water desalination or in vapor absorption system to fulfill the requirement of cooling. In recent report solar assisted biogas energy system's feasibility in terms of their cost-effectiveness has also been reported with grid-connected network or standalone solar PV system for electrification[25,26].

The present work aims to model, design and optimize a distributed hybrid energy system using solar PV, micro-turbine running by biogas and electrolyzer for the generation of electricity and heat load of a residential building. Moreover, some amount of hydrogen can also be produced which can be further reutilized by methanation reaction to make methane and some amount of hot water. The optimization technique is utilized to enhance the renewable penetration and depreciate the cost of energy, CO_2 emission and a comparison is made to for system potential, price, and effect at two different sites of India viz. Hiranmoypur and Sundarbans. Furthermore, the work is compared with previous research for one of the locations selected for using solar PV for electricity to the community.

Material used and methodology adopted

(A) Hybrid renewable energy system (HRES) modeling:

The proposed biogas integrated HRES includes solar PV, biogas micro-turbine, converter, and electrolyzer which is modeled by HOMER Pro software. The input parameters of the load and solid waste availability have been taken from the existing literature[27,28].

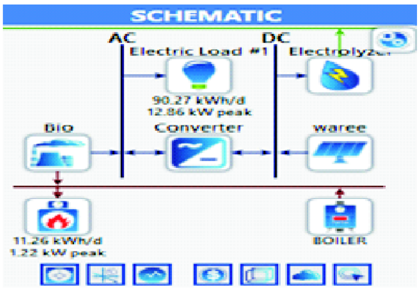

Fig. 1. Schematic of HRES.

Fig. 1 shows the schematic of the correct configuration of the components drawn by HOMER software to the respective AC/DC terminals and other configuration of the HRES. As the figure shows the load of the building, biogas based micro-turbine are on AC bus and the PV and electrolyzer are on the DC bus hence it is clear that the power generated from the PV should be converted into AC so that it can be fed to building load.This requires a converter/inverter whereas the electrolyzer can directly utilize it. Biogas micro-turbine is assumed to operate through the local domestic waste, local forest waste such as the leaves of different trees. Solid waste through domestic waste and stable renewable power supply through this HRES is the primary purpose of using other local resources. The HOMER software has taken solar irradiation, and other whether data by setting up the location within the software.

Weather data for a long period of time has been collected and analyzed by National Renewable Energy Lab (NREL) over the past few years to estimate the resources locally available at the locations used by the HOMER software. Micro-turbine operates on the waste generated biogas, and, anaerobic digestion process is utilized for the biogas generation. The modeled system is standalone and it is not considered any storage system as the storage system increases the system cost and complexity during operation and maintenance.

All the components have been assumed to be located within the same premises, forming a small power generation micro grid within the boundary of the building. Inverter is needed for conversion of DC power generation into AC power which is mostly required by all the electric equipment. Since the system is not in the connection of any grid, it is considered to be a type of distributed generation system which eliminates the losses due to the transmission and distribution (~26% of total production) and reduces a considerable amount of electricity during the DC to AC conversion as the size of the PV component is tiny[6].

(B) Case studies:

The hybrid system performance evaluated at Hiranmoypur and Sundarban depending on the accessibility of their local resources like solar irradiance, solid waste from the local residences and their premises, geographical area, ambient temperature, and local government policy. Latitude and longitude of Hiranmoypur and Sundarban 22°7.4′N/88°40.8′E and 21°50.2′N/88°53.1′E, respectively. Both the places consist of more than 5 million inhabitants and have comparable solid waste generation potential. Both the sites also have a potential of massive range of forest waste available locally. The rest of the input data has been taken from the NASA surface meteorology and solar technology for temperature, irradiance and wind speed. Both the places have almost the same biomass availability, but variation exist in the irradiance, temperature, rain, and wind speed due to their geographical locations.

The annual average temperature at Hiranmoypur is 25.66°C, and solar irradiance is 4.67 kW//day whereas the same at Sundarban are 26.08°C and 4.80 kW//day, respectively. The resource availability is shown in Table 1.

Table 1. Average resource and domestic energy demand for buildings per year at Hiranmoypur and Sundarban

Resources availability	Hiranmoypur	Sundarban
Location	22°7.4′N, 88°40.8′E	21°50.2′N, 88°53.1′E
Average solar irradiance	4.67 kW/day	4.80 kW/day
Average temperature	25.66°C	26.08°C
Wind velocity (at 20 m from ground)	2.20 m/s	2.20 m/s
Biomass availability	650 tonne/day	630 tonne/day

Energy profile for the two locations used for the present study is adopted from existing literature. Optimal design and implementation of Solar PV-VRFB (Vanadium Redox Flow Battery) storage based hybrid microgrid shows nearly zero loss of power probability obtained from Sarkar *et al.*[29]. To create the energy consumption demand profile it is assumed that the usage patterns on weekdays and weekends follows the same profile of energy consumption. It is further assumed that the time spent by the residents in their buildings reaches the peak between 12:00 am to 8:00 pm whereas; minimum

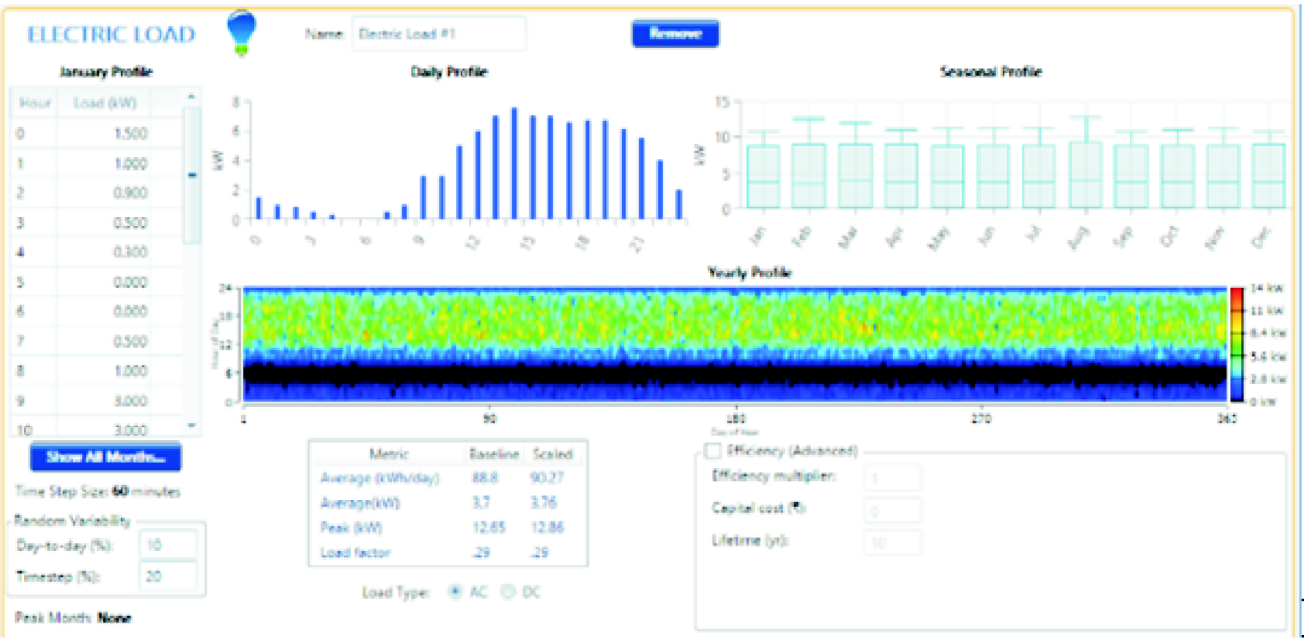

Fig. 2. Electric load profile of both the places.

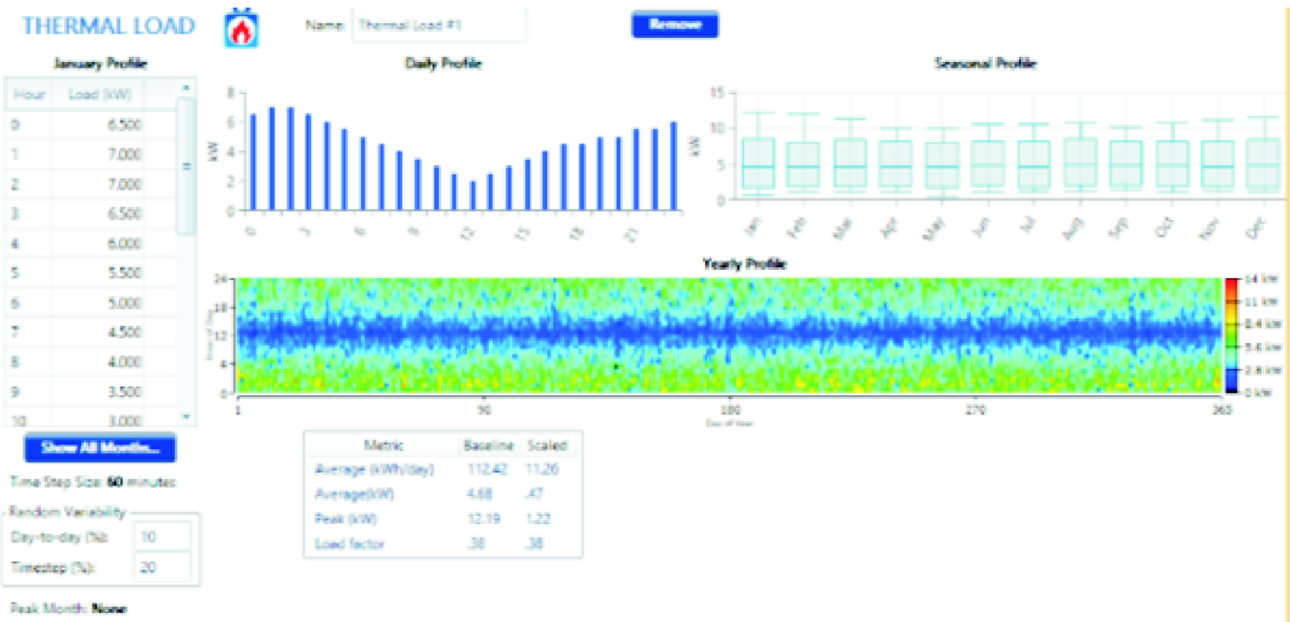

Fig. 3. Thermal load profile of both the locations.

is in between 2:00 am to 7:00 am. The electricity consumption profile is shown is Fig. 2. Apart from these assumptions a small increment of load demand during the lunchtime is also considered.

The thermal load profile is also same over weekdays and weekends with higher consumption at the night-time and less at the day-time, especially between 10:00 am to 12 noon which is shown in Fig. 3.

(C) HOMER software tool and operation:

National Renewable Energy Laboratory (NREL), USA has developed the software 'HOMER' used as a tool for optimizing the multiple energy resources. HOMER is used widely in the past few years as an accurate tool for the techno-economic analysis of hybrid energy system including sensitivity analysis in a microgrid connected system[29]. Moreover, HOMER includes wind speed, temperature data, inbuilt solar radiation, and clearness index which can be imported with the help of the location coordinates of different places available in the internet. Monthly average data for both the locations considered in the present study are shown in the Figs. 4, 5, 6 and 7. The tool also consists of two microgrid controllers viz. load following and cycle following controllers. Load following controller is mainly used for the optimization of the distributed generation through HRES because it does not contain any grid to export and as a result minimum excess energy is provided.

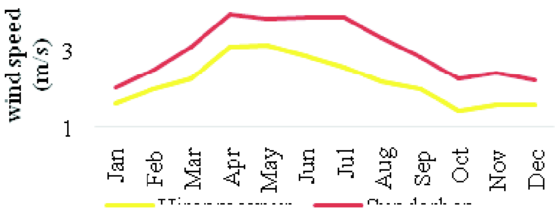

Fig. 4. Monthly average wind speed.

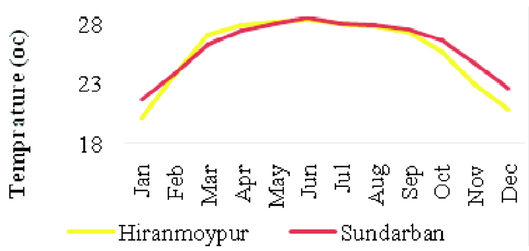

Fig. 5. Monthly average ambient temperature.

HOMER has the capability to size the different forms of energy sources like solar PV, wind turbine, energy storage devices, biomass, hydro plants. The optimization analysis helps in finding out the optimal size of the individual components, capital requirement against each component, and minimizing the net present cost and cost of electricity of the

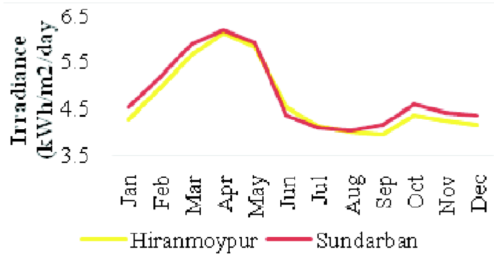

Fig. 6. Monthly average irradiance profile.

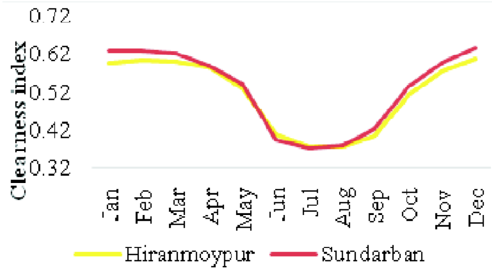

Fig. 7. Monthly average irradiance clearness index.

HRES based on including the details of component price on kW basis. Economic data and specification of each component used for the study is shown in Table 2.

Table 2. Components cost and specification

Item	Capacity (kW)	Capital cost (INR)	Replacement cost (INR)	O and M cost (INR)	Lifetime
Solar PV	1	30,500	22,500	1.00	20 years
Converter	1	3,500	3,500	0.00	15 years
Biogas micro-turbine	12	26,500	22,050	40.00	20,000 h
Electrolyzer	1	80,150	60,015	2,000	15 years
Generic boiler	1	0	0	0	20 years

Results and discussion

(A) Optimized HRES configuration:

The life span of the optimized biogas integrated solar PV system is considered as 20 years for both Hiranmoypur and Sundarban. System configuration for both the places are taken similar for doing optimization in HOMER except the size of solar PV used. At Sundarban the size of solar PV is considered as 0.240 kW whereas, at Hiranmoypur it is 13.6 kW. The converter size is 1.07 kW, 5.99 kW; biomass micro-turbine of 10 kW and 7 kW, and equal electrolyzer size of 10 kW for both the places are considered and is shown in Table 3. The system architecture for both the locations is shown in Fig. 8.

Table 3. Optimal design of biogas integrated solar PV hybrid system

Component	Type	HRES Size-Hiranmoypur	HRES Size-Sundarban
Solar PV	Flat plat photovoltaic	13.6 kW	0.240 kW
System converter	DC to AC converter	5.99 kW	1.07 kW
Biogas generator	Generic biogas micro-turbine	10 kW	7 kW
Boiler	Generic boiler	1.0 unit	1.0 unit
Electrolyzer	PEM electrolyzer	10.0 kW	10.0 kW
Dispatch strategy		Load following	

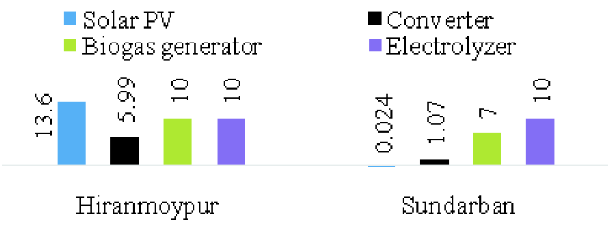

Fig. 8. HRES architecture at both the location.

Net Present Cost (NPC), Cost of Electricity (COE) and other cost-related data for each component are shown in Table 4. The NPC of the system includes capax, opax, maintenance, fuel, and salvages cost. No fuel cost is considered to the system as the system run with the local available resources. The highest NPC is for electrolyzer, followed by biogas micro-turbine and solar PV.

NPC at Hiranmoypur is Rs. 4.18 Million (M) and the Levelized Cost of Electricity (LCOE) is Rs.11.26/kWh, whereas for Sundarban the NPC is Rs. 3.78 M and LCOE is Rs. 9.35/kWh. The difference is coming due to the difference in the size and price of solar PV.

(B) Output energy from the current HRES:

The optimal system suggested by the HOMER software derives highest electricity generation from the biogas micro-turbine followed by the solar PV and values are more at Hiranmoypur than that of the Sundarban. The production of electricity exceedes the requirement and is found more at Sundarban whereas loss of electricity is more in Hiranmoypur. In case of solar PV, it is notable that Sundarban is having almost negligible amount of electricity production compared to Hiranmoypur as the system consist of a 1.07 kW solar plant which is due to the clearness index and solar irradiance. But the most effective cause is speed is high which reduces the PV production. Also it can be seen that the solar PV are less effective for the Sundarban area due to its geographical location. All the electricity data are shown in the Fig. 9.

The proposed HRES system not only generates electricity but also produce considerable amount of heat, which

Table 4. Component-wise NPC of the HRES [all costs in Rs. (M-Million)]

Component	Capital	Replacement	O and M	Resource	Salvage	Total
NPC by component - Hiranmoypur						
Solar PV	415,150	0.0	175.96	0.0	0.0	415,326
Converter	20,954	–1,673	0.0	0.0	–1,673	28172
Biogas micro-turbine	22,083	75,286	3.00 M	0.0	–1,310	3.10 M
Boiler	0.0	0.0	0.0	2,675	0.0	2,675
Electrolyzer	801,500	254,628	258,550	0.0	–47,924	1.27 M
System	1.26 M	338,805	3.26 M	2,675	–50,906	4.18 M
NPC by component - Sundarban						
Solar PV	7,307	0.00	3.10	0.00	0.00	7,310
Converter	3,761	1,596	0.00	0.00	–300.31	5,056
Biogas micro-turbine	15,458	63,824	2.42 M	0.00	–2,966	2.50 M
Boiler	0.0	0.00	0.00	1,335	0.00	1,355
Electrolyzer	801,500	254,628	258,550	0.00	–47,924	1.27 M
System	828,026	320,047	2.68 M	1,355	–51,190	3.78 M

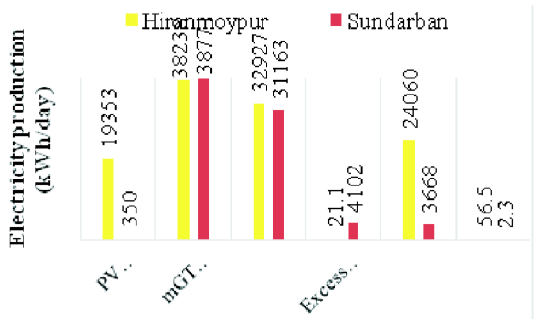

Fig. 9. Electricity share of each component.

can be utilized for the building heating or some other purposes and can indirectly save the requirements of the electrical energy in terms of reducing heating or other loads. Heat production from the optimal HRES is shown in the Fig. 10, which shows that the amount of heat generated from the biogas micro-turbine is comparatively higher. In both the locations, requirement of heat load is comparatively smaller and as the system is designed for Indian condition where heating load is not as important as cooling load. Moreover, heat generation is higher in both the cases and the excess heat can be utilized for water desalination, water heating or for cooling purpose by integrating a vapor absorption refrigeration cycle or it can be utilized in the Kalina cycle for electrical and cooling load addition.

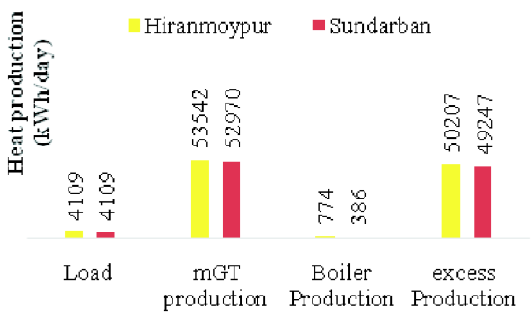

Fig. 10. Heat production by each component.

(C) Fuel consumption and H_2 production:

The optimal HRES developed by the optimization tool using biogas and methanol as fuel does not consider any fuel cost but restriction is there in solid waste generation and in availability of methanol. It is consider that Hiranmoypur uses about 207 tonne/year of meathanol whereas, the same is 113 tonne/year utilized at Sundarban. The biogas consumption is considered same at both the locations. As methanol is used in the boiler and its utilization can be replaced by the excess amount of heat generated by the biogas micro-turbine. Fuel consumption at the boiler and micro-gas turbine is shown in Fig. 11.

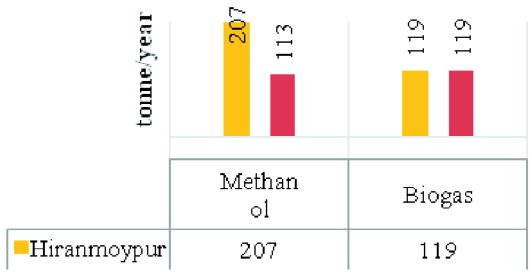

Fig. 11. Fuel consumption.

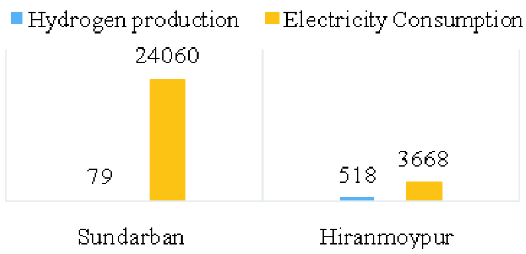

Fig. 12. Electrolyzer performance.

From the study it is observed that the consumption of electricity is low and hydrogen production is high at Hiranmoypur. On the other hand, the reverse scenario for electricity generation and hydrogen production are found at Sundarban. Hydrogen as produced is a very clean form of renewable energy which can be further utilized for the production of other fuels and to generate electricity with the help of fuel cells. The byproduct of fuel cells can provide water and heat. Since the energy consumed by the electrolyzer is the excess energy available from the proposed system therefore, it is economical too as the excess energy is sent to different stand-alone micro grid systems.

(D) Emission through the system:

In the present study it is observed that HRES uses biogas which comprises of CH_4, CO_2 and H_2S. As a result there is always some amount of emissions. Fig. 13 shows that Sundarban emits lower CO_2 emission of 177 kg/yr whereas; Hiranmoypur emits 334 kg of CO_2 per year. Other emissions like CO, SO_2 and NO_2 is observed negligible at both the locations. Higher value of CO_2 emission can be mitigated by methanation reaction to produce methane by mixing with H_2. Methane is used as biofuel and produce the byproduct in the form of hot water. The emission data is shown in Fig. 13.

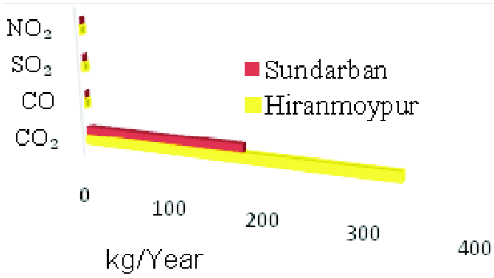

Fig. 13. Emission from the HRES.

(E) Comparison of present work with existing literature:

The present work is compared with the research paper by Nosakhale *et al.* where the system consists of Solar PV, Wind turbine and Storage system[31]. NPC of this system is considered as \$ 29.9 M and COE is \$ 0.131/kWh (Rs. 9.29). The present study is further compared with Maulik[32] where the system consists of Solar PV only for the basic fulfilment of electrical energy demand at Sundarban on distributed generation basis. The total annual cost of the system is Rs. 12,39,958 and the COE is Rs. 11.11/kWh. Moreover, this system provides only 8 h of electricity to that place. It indicated that the system is not sustainable as well as reliable. Whereas, in the present the optimized HRES shows the NPC of Rs. 4.18 M with COE of Rs. 11.26 for Hiranmoypur and NPC of Rs. 3.78 M with COE of 9.36 for Sundarban. Moreover, HRES also provides heat, hydrogen, negotiable amount of emission with more reliable and sustainable system configuration. The COE data is shown in Fig. 14.

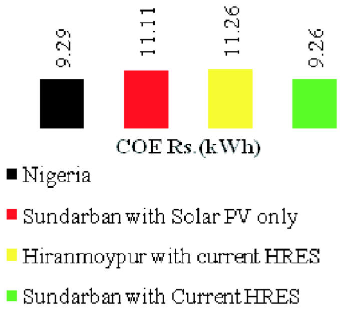

Fig. 14. Comparison of economics with previous work.

(F) Potential for additional benefits from the proposed HRES:

The proposed HRES is designed to produce electricity and heat. Moreover, some benefits in terms of space cooling, compost (fertilizer), desalination water can be obtained if heat is not required at the facility center. In addition, the hydrogen produced by the electrolyzer can further produce another renewable fuel, methanol by undergoing through a reaction with CO_2, a byproduct produced at the micro-turbine end exhaust flue gases. The reaction which can be taken place to form methanol from the CO_2 and hydrogen is as follows:

$$CO_2 + 3H_2 \longleftrightarrow CH_3OH + H_2O \qquad (1)$$

where, $\Delta H_{298} \longrightarrow$ 40.9 kJ/mol

From eq. (1), it is understood that the byproduct of this reaction produces small quantity of hot water by considerable amount of heat utilization. Moreover, significant amount of CO_2 emission can be reduced with methanol formation. The potential of these additional benefits is shown in the Table 5.

Table 5. Additional benefits potential from the proposed HRES

Sl. No.	Additional product	Potential	
		Sundarban	Hiranmoypur
1.	Space cooling (VARS with COP of 44) in ton/year	6283.01	6162.87
2.	Desalination (FSMED from heat of 382.5 kWh/1000 gallons of sea water) in gallons	128750.32	131260.10
3.	Methanol (CH_3OH) gm-mol/lit	214375	876753.84
4.	H_2O (Due to reaction) gm-mol/lit	120586.10	493174.04
5.	Additional heat generation (due to reaction) kJ/mole	164493.67	310401.14
6.	Compost (taking average of 20%/kg of biomass) kg/day	160.5 for both the locations	

Conclusions

The scarcity of fossil fuel, increasing demand of energy and solid waste management, increasing level of pollutant are great concern for any society. Electrification at rural and islands are very complex in present scenario. It is clear that at Sundarbans central grid connectivity is absent and local grid is not providing sufficient energy with higher cost of the energy supply. The present study is an attempt to propose a hybrid energy system to overcome all the said difficulties. Moreover, locally available waste is used as a feed to the hybrid energy system so that the costs of fuel and solid waste disposal can be saved and a clean, hygienic, and aesthetic for residential area can be improved.

The proposed system decreases the requirement of the storage by providing a solid waste based distributed multigeneration HRES with COE of Rs. 11.26/kWh at Hiranmoypur and is lower than the previous study made at Sundarban by an amount of Rs. 0.15/kWh. The present study shows that the COE at Sundarban is Rs. 9.26/kWh which is lower than the COE at Nigeria (from literature) by about Rs. 0.03/kWh and Sundarban (from literature) by about Rs. 1.85/kWh. Moreover, the present study also generate heat of 50207 kW and 49247 kW at Hiranmoypur and Sundarban, respectively with hydrogen generation of 518 kg/year at Hiranmoypur and 79 kg/year at Sundarban.

Solid waste management and implementing renewable system are the necessities for the saving the environment. Proper social and economic development of such localities is the commitment of government but due to the lack of awareness, peoples don't adopt such system. Moreover, due to huge capital cost of developing such system, government needs to take more initiatives include more number of awareness camps, sanctioning subsidy or incentives so that the social and economic barriers can be removed in these localities.

Nomenclature

(a) NPC – Net Present Cost

(b) COE – Cost of Electricity

(c) HOMER – Hybrid Optimization in Multiple Energy Resources

(d) HRES – Hybrid Renewable Energy System

(e) LCOE – Levelized Cost of Electricity

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