Feasibility Assessment of distributed generation systems in the Sundarban area; a Case Study for the Sagar Island

Partha Sarothi Sikder[1], Nitai Pal[2*]
[1]Research Scholar, [2]Associate Professor, Department of Electrical Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand - 826 004, India.
Email address: [1]parthasarothi.sikder@gmail.com, [2]nitai_pal@rediffmail.com

Energy is one of the basic needs of socioeconomic development of an area. The conventional way of generation of electricity and grid-connected transmission and distribution system is costly for the remote rural areas of India which consequences lower per capita energy consumption. On an island, the grid connectivity or establishing new power plant using conventional energy sources is more difficult and expensive. The depletion of conventional energy sources is also another reason for searching alternative energy sources. Regardless of the cost and depletion of conventional energy resources, the environmental issue is much more concern in the island. The pollution created by the conventional energy sources destroys the biodiversity and ecological health in the island. In this consequence, the aim of the paper is to study the distributed generation system using different renewable energy sources from the available meteorological data of the largest island of Sundarbans deltaic complex named Sagar Island. Here an attempt has been made to study a vast number of renewable energy sources available in this island and discussed the possibility of generation of electricity. Moreover, the possible per unit cost is also estimated using Levelised Cost of Energy (LCOE).

Keywords: Island Energy Scenario, renewable, solar, wind, biomass, hydal, ocean energy, Cost.

1. Introduction

At present, the energy utilization is one of the prime indicators of the civilization and sustainable development. India is a developing country where the generated electrical energy is approximately 3, 29,205 MW with a 0.8 % energy deficit [1]. Due to rising population and increasing load demand, the energy deficit is difficult to compensate. In India, the per capita energy consumption per person is around 1075 kWh, which is below the world's average the per capita energy consumption and very much lower than the worlds developed countries which indicates the poorer sustainable development of our country. The problem related to energy deficit mainly faced by the remote rural area due to difficult and cost-effective grid connectivity which minimizes the sustainable development. In India, 67% of the energy produced from the fossil and it is very difficult to increase the generation capacity due to depletion to compensate future energy demand [2]. At present, instead of the depletion of fossil fuel, the environmental pollution is the prime concerned. All the primary energy sources damage our environment which begins a new era to generate electricity from renewable energy sources to compensate future energy demand and initiate sustainable development.

The problem related to energy deficit is major at the far end of the country's mainland where the grid connectivity is difficult due to topographical constraints. The Indian islands face great difficulty to access the reliable electricity. The environmental issue is much more predominant in the Sagar Island, where the contamination in the environment destroys the biodiversity and ecological balances. Therefore, to reduce the pollutant, reduce grid dependency at the far end of the country and the distributed generation policy is encouraged by the government and international corporations. In this circumstance, the renewable energy resource management is very much essential to generate pollution-free electricity for sustainable development of a particular area of the Sundarban named Sagar Island.

The Sagar Island is located in the Sundarban areas of West Bengal. The Sundarban region is the world's largest delta formed by the Ganges

(Hugli in this region), Brahmaputra, and Meghna. About 40000 families inhabit 47 villages of the Sagar Island spread over 504 sq. km of area. Due to premature reclaim, parts of Sagar remain three meters below sea level hence the environmental imbalance is dangerous to the existence of the Sagar Island [3]. Most of the places of Sundarban area are separated from the mainland by the rivers and creeks which make the grid-connected electricity supply system difficult. The Sagar Island is like other parts of the Sundarbans is characterized by the mangrove swamps, waterways and small rivers, which is isolated from the mainland by the Indian Ocean and the Hugli River, which restrains the grid connectivity and suppresses sustainable development [4]. Due to insufficient electrical energy, sustainable development of the Sagar Island is not up to the mark and future development is also difficult. Due to lack of electricity, the majority no of families retained in the ancient age and depends on the kerosene lamp for emergency lighting purposes.

At present, a lot of research has been done related to distributed generation system worldwide. Some of them studied the different renewable energy sources and its impact on the environment for future demand [5]. Some of the studies mainly concentrate on the optimization of renewable energy sources for a predicted load consumed in a particular area for sustainable development [6-7]. The researchers also optimize the minimum cost for renewable energy sources combined with some diesel generator to compensate a particular load [8-10]. In Sagar Island, the research only concentrated on the solar energy and the biomass energy to generate electricity [11-14]. The hybrid generation system with diesel generator is also studied here with details the technological development and practical implementation, data analysis and optimization [15]. But the feasibility of generation of electricity using tidal and the ocean energy sources left open for research to study the feasibility of generation of electricity. In this present study, the different topology of generation of electricity in Sagar Island using different renewable energy sources and their possibility has been studied with comparative cost analysis. The possible energy mix to construct a hybrid system to increase reliability and generation capacity without increasing the storage devices is also discussed here without compromising the environmental effect. The present study will open the option for energy researcher for further studies for new energy generation technology in Sagar Island, where wide varieties of renewable energy sources are available.

2. Sagar Island and its Renewable Energy Sources

The geographical location of Sagar Island in the Sundarban area is shown in Figure 1.

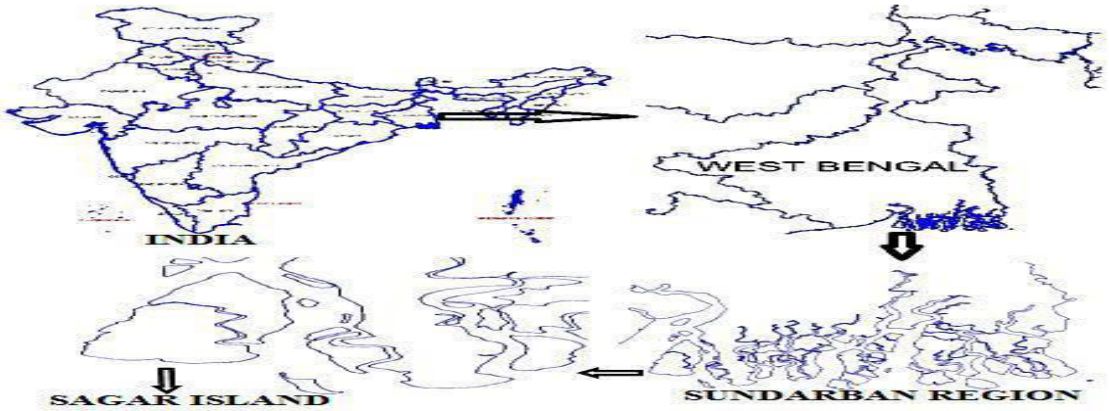

Fig-1. Location of Sagar Island in the Sundarban area of India [16]

The Sagar Island is located between the Tropic of Cancer and the Equator where adequate solar energy is available throughout the day [17]. Availability of solar energy and barren coastal area indicates the availability of wind energy. There are the hydal energy sources based on the Hugli river (local name is the Muri Ganga) to generate electricity. Besides the above, the other renewable sources are biomass, tidal energy and

blue energy which is discussed in this present studies.

2.1 Feasibility of electricity generation from Solar Energy

Solar energy is one of the promising energy resources in the world due to the availability of the solar energy, noiseless operation, and less maintenance during the generation of electrical energy [18]. As per the NASA surface metrology in Sagar Island the Sun provides promising solar energy with an average 13.6 h solar hour round the year indicated in Fig 2 [19].

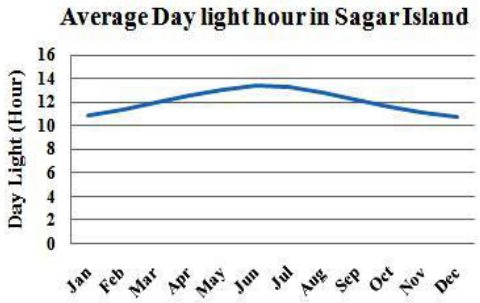

Fig-2. Average daylight hour on the Sagar Island during different month of the year

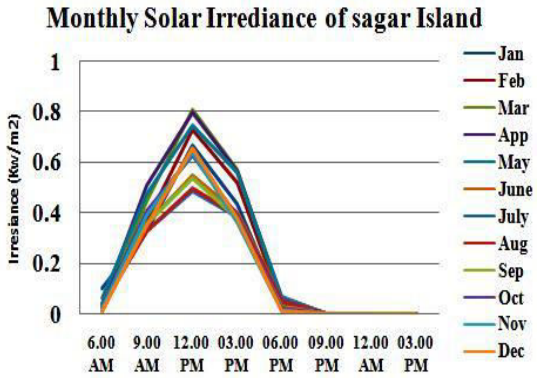

Fig-3.Monthly solar irradiance variation in different month in Sagar Island

Fig-3 indicates the average monthly solar irradiance of Sagar Island. In the different month, the solar irradiance and the solar hour is quite promising and very much impressive to generate energy from Solar Photovoltaic (SPV) as well as Concentrating Solar Thermal (CST) technology or combination of the both. The only difficulty related to solar energy is less energy density compared to other energy sources. The efficiency to convert solar energy is around 17% for CST and 15 % for SPV technology. Compared to CST, SPV system is more acceptable due to the less maintenance during operation. Due to less energy density, the area required to establish the solar power plant is very large. The other difficulty to utilize the solar energy to generate electricity depends on the seasonal variation of clear sky irradiance level. During monsoon, the solar irradiance is hardly available in the Sagar Island. The maximum estimated maximum NO SUN days on the Sagar Island is 8.75 which indicate the large no of storage devices makes the power supply system costly and bulky.

2.2 Wind Energy Resources on Sagar Island

The wind turbine attaches to the generator converts the kinetic energy of wind into electricity. Normally at 3 m/sec to 15 m/sec speed is the optimum wind speed to generate electricity using wind energy. At present, due to developed technology and material science built the lower speed wind turbine to generate electricity [20].

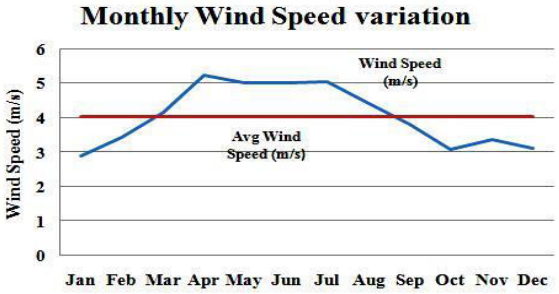

Fig-4. Monthly wind speed variations in the Sagar Island

The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The Sagar Island provides a low, but moderate wind speeds indicated in Fig. 4 [19]. The island has plenty barren land in the coastal area indicates uninterrupted wind flow and provides adequate space for construction of the tower and other accessories to generate electrical energy from wind energy.

2.3 Hydel Energy Resources on Sagar Island

The potential energy of water is converted into electricity using turbine generator set in the range of a few watts to kilowatt is called the small-scale hydro-power. The system is based on run-of-river schemes or implemented in existing water infrastructure. The small-scale hydropower plant is normally installed in the hilly areas, where the water speed is very high. The total small-scale hydro energy is very much essential and beneficial in terms of low-cost

electricity, quick start, and nil environmental impact. The Sagar Island encircles with the Hugli River but due flat geographical surface the water speed does not fulfill the requirement to generate electricity.

2.4 Biomass Energy Resources on Sagar Island

As the Sagar Island surrounded by the natural forest and plenty barren land covered with weeds which considered as a biomass. As the Sagar Island's main occupation is the cultivation so the agricultural by-product is also considered as biomass. The rice husk, crop residue, jute stick, wood, animal waste, municipal waste etc all are available at Sagar Island. To extract the energy from biomass, normally the biomass is burnt in the boiler to generate electricity using a gas turbine. Due to the burning of the biomass, some pollutant gases are generated during generation of electricity but as the biomass resources regenerate within few years it is considered as a renewable energy source. Using recent technology the biomass is converted to biofuel and directly utilized for the transportation and pumping operation. Using developed technology the production of hydrogen energy from biomass is also possible. The produced hydrogen utilized for vehicle or can be used to generate electricity using fuel cells. The direct estimation of biofuel or biomass is not possible as because it's directly related to the field survey and other variables [21-22].

2.5 Ocean Energy Resources on Sagar Island

The available various forms of energies from the Ocean to generate electricity are the tidal energy, Wave energy, Ocean Thermal Energy Conversion (OTEC) and salinity gradient. Due to the gravitational force by the Sun and the Moon, the level of the earth's surface water is changed in a cyclic order which is known as the tidal energy [23]. To convert the tidal energy into electricity, tidal-barrages technology, and tidal-current technologies are there. In the former case, a dam has been built to store the water during high tides and the stored water then discharge through the water turbine during ebb tides. The attached generator generates electricity by converting the potential energy of the water due to the tide. In the latter case, the water-current due to tide is utilized to generate electricity. The kinetic energy of the water stream is converted to electricity using underwater turbine attached to a generator similar to the wind energy conversion system. The Sagar Island has a higher value of tide ranges around 6 meters (Maximum) to 1.5 meters (Minimum) which is shown in Fig-5 which indicates the prospects the generation of electrical energy from tidal energy sources [24].

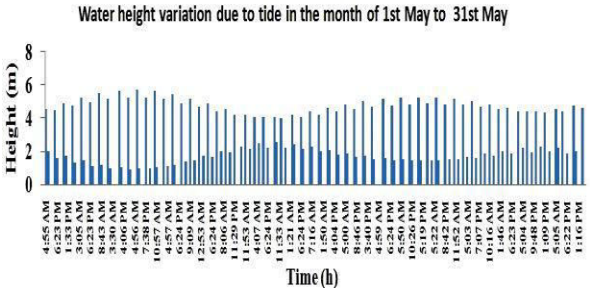

Fig-5. Monthly water height variation in Sagar Island due to Tide

The wave energy is a by-product of the solar and wind energy. The other factor affected for the wave energy is the distance of open water over which the wind blows, Width of an area affected by the wind, the duration which the wind blows and the water depth [25]. The Sagar Island, located at the Bay of Bengal with huge coastal area massive solar energy around the year with a maximum solar hour around 13.6 hours. Due to geographical location, the Sagar Island has a huge potential of wave energy which is estimated based on the data provided by a station of the Bay of Bengal (Wave energy estimation station 23223 of Bay of Bengal) nearer to the Sagar Island which is shown in Fig-6 [26]. The data obtained from the Wave station indicates the huge potential of wave energy to generate electricity, but the difficulties are highly costly equipment and advanced technology.

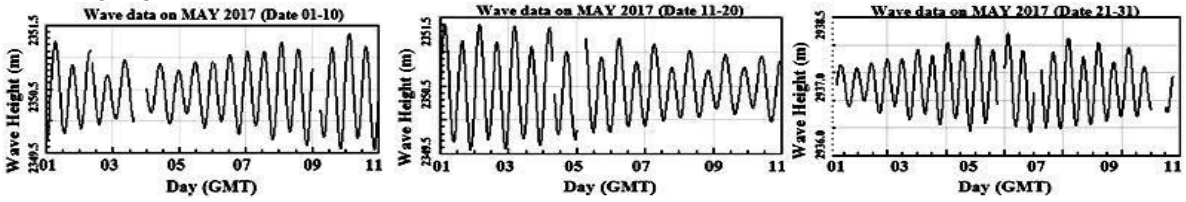

Fig-6 Wave energy in Indian Ocean near to the Sagar Island

In OTEC the temperature difference between sea surface water and sea deep-water can be harnessed to generate electricity [27-28]. The surface water of the Ocean consumes the heat energy from the sun and traps it into the surface. The trapped heat energy is consumed by the working fluid using a heat exchanger. The working fluid evaporates easily by the trapped energy and provides kinetic energy to the turbine. The condensation of the working fluid is done using pumping the cold water from the deep ocean. Due to the availability of the solar energy, the Sagar Island has a huge difference in temperature from the surface of the ocean and the deep water. Normally a 20^0 difference of temperature is optimum for the OTEC processes which is available in the Sagar Island. Fig-7 indicates the temperature difference between the surface to the deep water at a different surface water temperature. The advanced technology and costly apparatus are the barriers to generate electricity using this process.

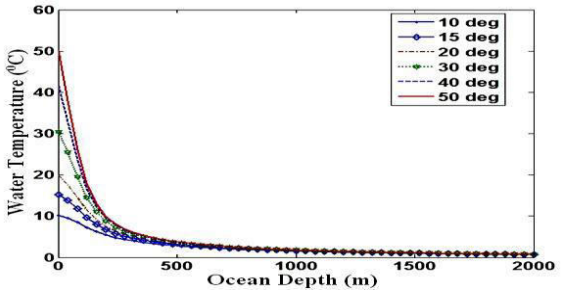

Fig-7 Variation of temperature from Surface to deep water

The salinity difference between the fresh water and the ocean water has a huge potential to generate electricity is called the Salinity energy or Blue energy [29]. Using advanced membrane science and technology the blue energy is converted to electricity. There are two Methods of harvesting energy from the salinity difference which are the pressure-retarded osmosis (PRO) and Reverse electrodialysis (RED). In PRO processes the pressure difference between river water and seawater is about 23 atm under ordinary conditions, equivalent to the hydrostatic head of 231 m dam. In PRO processes semi-permeable membranes are utilized to transfer the static energy of the fresh water to the high concentration draw solution (seawater or brine). The high-pressure seawater extracts more energy from the fresh water than utilizing to rotate the turbine attached to the generator and produces the electrical energy like the hydroelectric generation plant.

In the RED process, the seawater and the fresh water are pumped into arrays or stacks of membranes with alternating anion-exchange and cation-exchange membranes. Due to the concentration difference between high concentrations draw solution (salt water or brine) and the low concentration solution (fresh water) the ion-selectivity of these membranes an electrochemical potential is generated directly. The difference in electrochemical potential due to movement of ions converted to an electrical current in the stack.

The Sagar Island is located in the mouth of the ocean where the Hugli River, which meets with the Indian Ocean. Hence the Sagar Island has a huge prospect of the generation of electricity using blue energy. The only difficulties to generate electricity using blue energy are the technological development and huge cost.

3. Cost analysis of the different distributed generation system

The feasibility study of the generation of electricity is incomplete without considering the cost analysis. To calculate the per unit generation cost of the different power supply system possible in the Sagar Island the LCOE method is applied and compare the diesel based power supply system. Equation 1 indicates the LCOE to estimate the generation cost of individual power supply system [30-31].

LCOE= Annual Fixed Cost per Unit + Annual Variable Cost per Unit+ Fuel Cost Per Unit (1)

To calculate the Annual fixed cost the capital recovery factor (CRF) should be multiplied by the overnight generation cost per unit for different power supply system. Equation 2 indicates the mathematical equation of CRF

$$CRF = \frac{r(1-r)^{i}}{(1-r)^{-i}-1} \quad (2)$$

Where,

CRF=Capital Recovery Factor, r is the rate of interest of the weighted average cost of capital (WACC) (in the case of this study this is 11% as assumed), i is the investment life (normally the life cycle of the power supply system).

Table 1 Calculated per unit generation cost for the different distributed generation system

Sl. No	Technology	Overnight cost ($/100 kW)	Fixed operation and maintenance (O&M) costs (%)	Expected lifetimes (year)	Per Unit Generation Cost ($/kWh)
1	Diesel	30000	15	5	0.2351
2	Solar PV	264400	5	25	0.2783
3	Solar Thermal	345900	15	25	0.5358
4	Onshore Wind	1877 00	5	25	0.1567
5	Offshore wind	3 95300	15	25	0.5073
6	Biomass	216850	15	30	0.1242
7	Tidal	261100	15	20	0.5117
8	Wave	378100	5	20	0.6671
9	Battery	281300	15	5	0.2437

It is more realistic and more appropriate to estimate the per unit generation cost for a particular area using the SCOE. In case of SCOE the environmental and social benefit is included with the per unit generation to evaluate the generation cost and the impact of the power generation to society [32]

SCOE = LCOE + cost of climate change damage + cost of air pollution damage + system integration costs (3)

The calculation of Society's Cost of Electricity (SCOE) is based on the available data and the detailed experiment related to the environmental effect is required.

The diesel generator is the good option for distributed generation system as it has a wide range of generating capacity from few kilowatts to megawatt range with little overnight cost. But the per unit generation cost is high compared to wind and biomass-based distributed generation system and its environmental effect also increase the SCOE compared to the other distributed generation system. Among the solar PV and the solar thermal, the solar PV required less overnight cost, less per unit generation cost and it has the ability to construct in different generating capacity. To reduce the per unit generation cost in case of a solar thermal system the capacity should increase which introduces the concentrated grid connected system. Among the onshore wind and the offshore, the onshore wind has less overnight cost, less maintenance cost, and less per unit generation cost. But the offshore wind distributed generation system as the wind speed is less fluctuating compared to onshore wind the penetration level to the other electrical system is less in case of the offshore wind distributed generation system. The biomass-based distributed generation system provides minimum per unit generation cost compared to the other distributed generation system but the SCOE is high due to the generation of harmful gases during generation of electricity. The other problem related to the biomass-based distributed generation system is a large capacity to minimize generation cost, cost related to maintain the quality of the biomass during winter and the rainy season. The tidal and wave energy based distributed generation system the former has less per unit generation cost compared to the later. The size of the generation system in case of wave energy is huge which is similar to the concentrated distributed generation system. The battery is the inevitable unit of the distributed generation system which stores the surplus generated energy and supplied to the consumer whenever the primary source of energy is fade.

From the overview of the different distributed generation system, the SCOE is higher in case of diesel and biomass-based distributed generation system as this generation system contaminates our

environment during generation of electricity. All the other distributed generation systems are environmentally friendly. The problem related to the renewable energy sources is the intermittence nature. By analyzing the available data the solar energy is the most promising energy sources. The available technology also supports to generate electricity successfully but the problem related to the solar energy is highly intermittence nature. The energy is not only unavailable in the night but also unavailable during the monsoon. The intermittency increases the size of the storage devices and hence cost increases. The intermittency of the wind energy is lower at the Sagar Island but the wind speed is moderate which indicates lower energy output with a high capacity wind turbine. The biomass energy sources are also promising as per availability but a problem arises to maintain the quality of the biomass during monsoon which introduces high cost and large energy storage devices. The tidal and wave energy sources intermittency does not affect much due to seasonal variation but the wave energy need a huge time and huge cost to generate electricity compared to the tidal energy. The blue energy and the OTEC are new technology which introduces huge cost and the current need more research works to make the energy sources at the utility level.

4. Conclusion

The various energy sources at a particularly rural area of Sagar Island have been discussed and studied the feasibility studies. Due to intermittence nature, the single energy sources are unable to maintain the reliable energy sources so the battery may maintain the required reliability of energy but the problem with the battery is poor life cycle and high maintenance. Instead of a large battery bank, the hybrid system may introduce at the Sagar Island to maintain the reliability using solar and wind-based hybrid system is an effective one to generate electricity as the wind energy does not vary during monsoon. The biomass-wind based distributed generation system also has the feasibility but the environmental issue related to biomass-based electricity generation is harmful to the environment. At present, the generation of electricity using tidal energy sources is higher but in future due to improved technology the per unit generation cost may reduce and the tidal-wind hybrid system may be utilized for generation of electricity.

REFERENCE

1. Government of India Power Sector Feb-2017 Ministry of Power Central Electricity Authority New Delhi *http://www.cea.nic.in/reports/monthly/executivesummary/2017/exe_summary-02.pdf*
2. All India power sector at a glance *http://powermin.nic.in/en/content/power-sector-glance-all-india*
3. Mitra, I., Optimum utilization of renewable energy for electrification of small islands in developing countries. *Kassel: Kassel Univ. Press*, 2009.
4. Mitra, I., A renewable island life: Electricity from renewables on small islands, *Refocus* , 2006, 7(6), pp. 38-41.
5. Lanfranchi, Maurizio, and Carlo Giannetto. **"**A Feasibility Study for a Project of Alternative Energy Production in an Agritourism Business in Sicily.**"** *International Journal of Environmental Studies*, 2017, **75(2)**, pp. 334–342.
6. Benli, Hüseyin. **"**Potential of Renewable Energy in Electrical Energy Production and Sustainable Energy Development of Turkey: Performance and Policies.**"** *Renewable Energy*, **50**, 2013, pp. 33–46.
7. Shafiullah, G.M., Amanullah, M.T.O., Shawkat Ali, A.B.M. Dennis Jarvis, D. And Wolfs, P., Prospects of renewable energy – a feasibility study in the Australian context, *Renewable Energy*, 2012, **39(1)**, pp 183-197.
8. Beluco, A., Benevit, M., Gewehr, A., Silva J., Subtle Influence of the Weibull Shape Parameter on Homer Optimization Space of a Wind Diesel Hybrid Gen Set for Use in Southern Brazil, *Journal of Power and Energy Engineering*, 2016, **4**, pp. 38-48.
9. Ramdhane, I. B. et al., **"**Optimization of Electrical Production of a Hybrid System (solar, diesel and storage) Pilot Using HOMER in Biret, Southern Coast of Mauritania,**"** *International Journal of Physical Sciences, 2017.* **12**, pp. 211-223.
10. [f] Sen, R. And Bhattacharyya, S. C., Off-grid electricity generation with renewable energy technologies in India: An application of

HOMER, *Renewable Energy*, 2014, **62**, pp. 388-398

11. [g] Moharil, R. M., and Kulkarni P. S. **"**A Case Study of Solar Photovoltaic Power System at Sagardeep Island, India.**"** *Renewable and Sustainable Energy Reviews*, **13(3)**, 2009, pp. 673–681.
12. [h] Hiremath, R.b., et al. **"**Decentralised Renewable Energy: Scope, Relevance and Applications in the Indian Context.**"** *Energy for Sustainable Development*, 2009, **13(1)**, pp. 4-10.
13. [i] Mondal, M. and Mandal, S., Remote Village Electrification through Renewable Solar energy: a Case Study of Sagar Island, West Bengal, India, *The International Journal of Engineering and Science (IJES)*, 2013, **2(1)**, pp. 201-205.
14. [j] Palit, D. and Sarangi, G. K., Renewable Energy based Mini-grids for Enhancing Electricity Access: Experiences and Lessons from India, *International Conference and Utility Exhibition on Green Energy for Sustainable Development (ICUE 2014), Thailand, 2014*
15. Roy, P. C., et al. **"**Optimization of a Stand-Alone Solar PV-Wind-DG Hybrid System for Distributed Power Generation at Sagar Island.**"** AIP Conference Proceedings, **1298**, (1), India, 2010.
16. Map of India, West Bengal, Sundarban and Sagar Island, The official maps released by the Survey of India. *http://www.surveykshan.gov.in/.*
17. Mandal, S., choudhury, B. U., Mondal, M., BEJ S., , Trend analysis of weather variables in Sagar Island, West Bengal, India: a long-term perspective (1982–2010), *Current science*, 2013, **105(7)**, pp. 947-953.
18. Seelam, P., K., and Giribabu, L., Recent advances in perovskite-based solar cells, *current science*, 2016, **111(7)**, pp. 1173-1181.

19. Surface meteorology and Solar Energy - NASA. (n.d.). Retrieved May 19, 2017, from *https://eosweb.larc.nasa.gov/sse/*

20. Tummala, A., Velamati, R. K., Sinha D. K., Indraja, V. and Krishna, V. H., A review on small scale wind turbines, *Renewable and Sustainable Energy Reviews*, 2016, **56**, pp. 1351–1371.
21. Gebreegziabhera, T., Oyedunb, A. O., Lukb H. T., Lamb, T. Y. G., Zhangb, Y. and Huib, C. W., Design and optimization of biomass power plant, *chemical engineering research and design*, 2014, **9(2)**, pp. 1412–1427.
22. Nixon J.D., Dey, P. K. and Davies, P. A., The feasibility of hybrid solar-biomass power plants in India, *Energy*, 2012, **46**, pp. 541-554.
23. Deshmukh, S. P. And Goswami, P., An overview of Ocean Energy in the World and its Potential in India, *Water and Energy International*, 2016, 59 (5), pp. 62-68
24. Tidal energy details in Sagar Island. *https://www.tide-forecast.com/locations/Sagar-Island-India/tides/latest.*
25. Sharma, R.C. and Sharma, N., Energy from the ocean & scope of its utilization in India, *International Journal of Environmental Engineering and Management*, 2013, **4(4)**, pp. 397-404.
26. Ocean wave energy resources in National Data Buoy Center *http://www.ndbc.noaa.gov/.*
27. Emdadi, A. E. A., Afshar, O. A. and Emami, Y., Electricity Generation by the Ocean Thermal Energy, *Energy Procedia*, 2011,**12**, pp. 936-943.

28. Fujita, R., Markham, A. C., Diaz, J. E. D., Garcia, J. R. M., Scarborough, C., Greenfield, P., Black, P. and Aguilera, S. E., Revisiting ocean thermal energy conversion, 2012, *Marine Policy*, **36(2)**, pp. 463-465.

29. Ross, R. and Krijgsman, J., New ionomer membranes for blue energy - making water trees useful, *International Conference on Future Power Systems***,** 2004**, 2**, pp. 780 – 783.
30. M. Y. Roche, Comparison of Costs of Electricity Generation in Nigeria - Technical Report, Abuja, 2017.
31. Kulkarni*,* P. S., Patil, A., Kothari, S., Pohnekar, E., Bharambe, K and Doshi, K., Captive Power Generation, *National Power Systems Conference* (*NPSC*), Madras. 2004, pp. 528-531

32. **"**Annual Energy Outlook - Energy Information Administration**"**, *www.eia.gov/outlooks/aeo/pdf/0383(2016).pdf*

.