ADVANCES IN HYBRID ENERGY SYSTEMS: MODERN DEVELOPMENT TOWARD GREEN ENERGY INITIATIVES

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Article History: Received: 02.10.2022 **Revised:** 23.12.2022 **Accepted:** 17.01.2023

Abstract

A hybrid energy system in India with a focus on green initiatives has been discussed in this article. The aim of the study is to examine the advancement of hybrid energy systems in the development towards the methods green technology. The rural locations can be connected by national grid extension although the current electricity access is below the demand with an average growth of GDP. Moreover, different modes of energy production in India are going on with fossil fuel, biomass, and various renewable energy sources are discussed. It is seen that Maharashtra is of particular importance in producing energy from industrial waste. Lastly, the importance of biogas as an alternative to stubble burning in India where tonnes of the residue of crops are in use is conferred.

Keywords: Hybrid energy system, green technology, importance of biogas, renewable resources, rural locations

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DOI: 10.48047/ecb/2023.12.2.015

1. Introduction of the topic

Access to energy can be considered a basic precondition to improving the lives of rural people in the form of education, healthcare, and economic growth. Presently more than 70% of Indian people are deprived of electricity where and access to ***RES*** or the renewable energy system has the potential to meet the demand (Electricalindia, 2023). It is noteworthy that the clean energy transition of India is underway which can benefit the world. As per the increase in rising income levels with urbanisation, the electricity demand has increased in the industrial and residential sectors as well where green electric and fuel vehicles come in handy.

2. Background

There are a few challenges regarding renewable energy sources in India as the energy is produced only when the wind is blowing or the sun is shining. The output is therefore limited to specific times in the day resulting in lower utilisation of electricity. As imprinted by Kiesecker et al. (2019), issues can be created in matching the power demand with rising transmission costs where gas or hydro-based power is essential. The rural locations can be connected by ***national grid extension*** although the current electricity access is below the demand with an average growth of GDP (Mohideen et al. 2021). Despite having a hydroelectric potential, the country is lagging behind owing to river weather distribution conflicts.

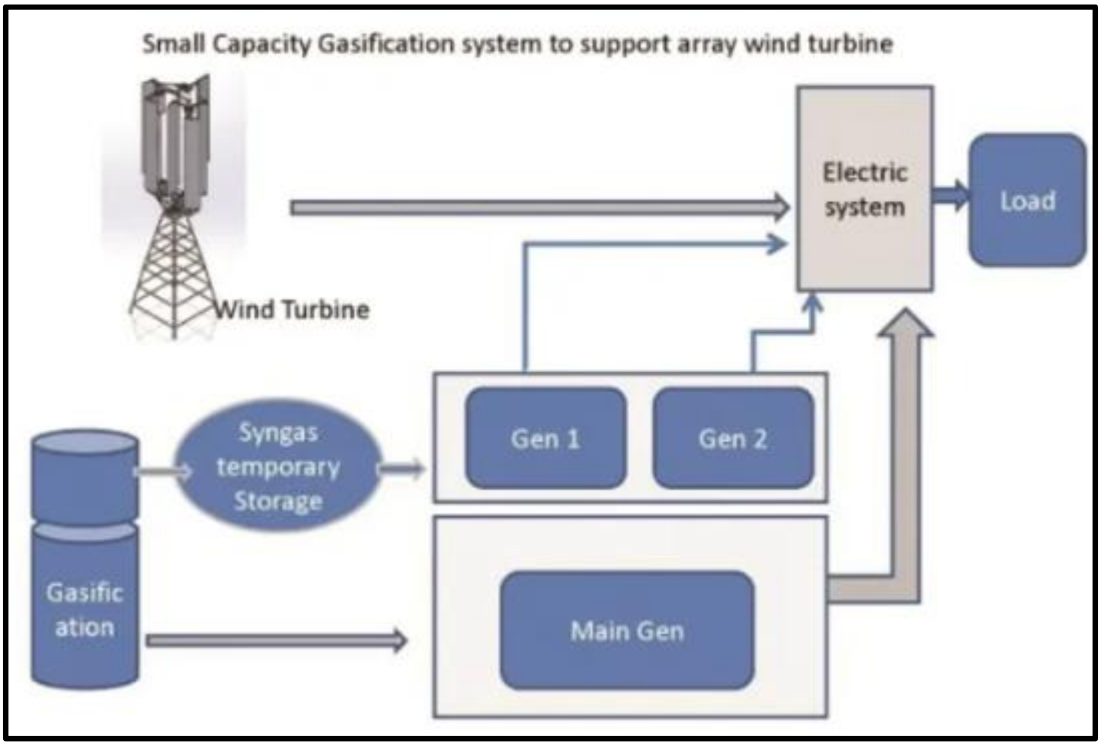


Figure 1: Hybrid hydro-wind system: *Source: Kiesecker et al. 2019*

As shown in figure 1, current approaches are taken with the utilisation of ***wind-hybrid energy*** in India. This system is able to heighten reliability and is beer than the standalone systems of wind energy. Hybrid renewable energy systems are the cutting-edge solution to mitigate many education, water supply, and electricity problems across India.

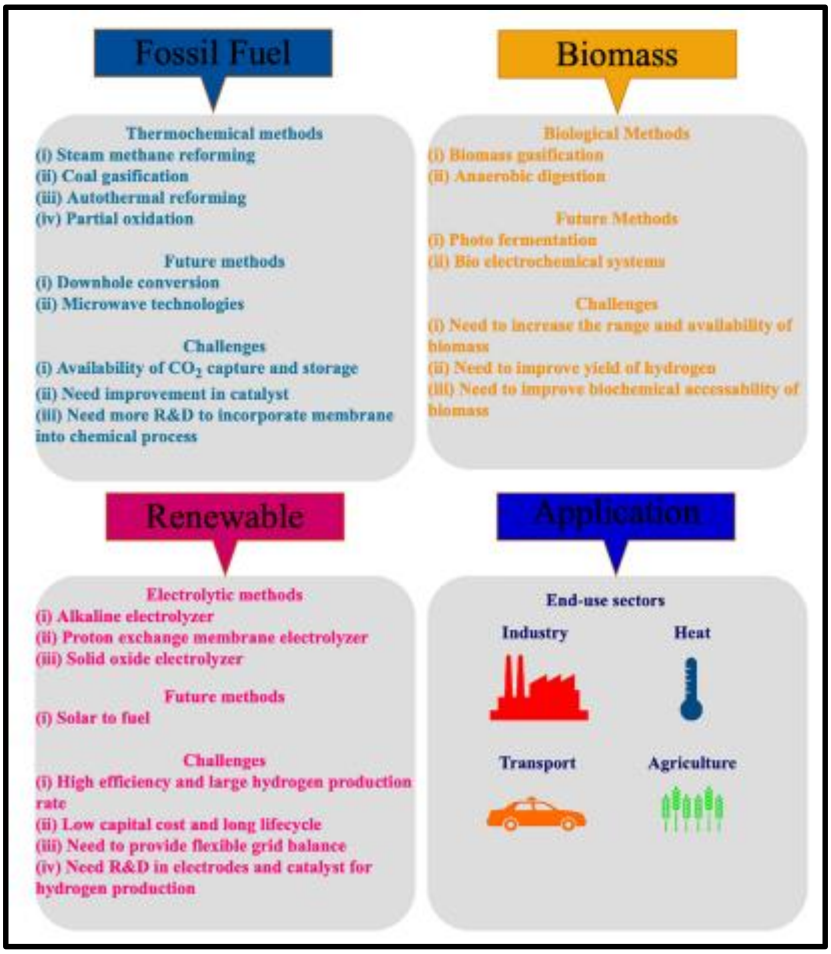


Figure 2: Hydrogen production pathways in India: Source: Mohideen et al. 2021

Different modes of energy production in India are going on with fossil fuel, biomass, and various renewable energy sources. As per the comment of Meena et al. (2019), ***HRE*** or hybrid renewable energy sources are best suited to the geographical location and pattern in many popular regions. Hence, a completely renewable ***HPP*** or Hybrid power Plant is required.

Table 1: Various well-established Hydrogen production pathways: Source: Mohideen et al. 2021

Technical process	Current status	Feedstock	Primary energy source	Emission of CO_2	Efficiency (%)	Remarks
Steam methane reforming	Mature& commercial	Natural gas	Standard fossil fuel	Without CCS- highwith CCS-low	70–85	• Works at low temperature • Doesn't require O_2 • Excellent H_2/O_2 ratio for H_2 production
Coal gasification	Mature & commercial	Coal	Standard fossil fuel	Without CCS- Highwith CCS-low	60	• Depends upon gasifier configuration • Low H_2/CO ratio
Partial oxidation	Mature & commercial	Natural gas	Standard fossil fuel	High	60–75	• Required no catalyst • Low methane slip • Works at high temperature • Low H_2/CO ratio • Complex operational process
Autothermal reforming	Mature & near-term	Natural gas	Standard fossil fuel	High	60–75	• Low operating temperature then partial oxidation. • Low methane slip required air/O_2.
Biomass gasification	Mature & commercial	Woody biomass	Internally generated steam	Neutral	35–50	• Low cost feedstock • Required O_2 and catalyst • Works at high temperature • Trace of tar and dust formation • Need R&D
Electrolysis	Mature & commercial	Water	Solar, wind	No emission	40–60	• Abundant feedstock • O_2 as byproduct • High cost and low overall efficiency

A comparative analysis of H2 production pathways is depicted in table 1 with analysation of ***CCS*** or carbon capture storage technology. In this case, the cost of H2 can range from $1.5–3/kg whereas Carbon dioxide accounts for 50/tCO2e. The versatile energy carrier, Hydrogen can easily be produced in different regions of Europe as well (Burke et al. 2019). In Table 1, it is crystal-clear that sans Biomass gasification, all the processes are highly efficient.

Table 2: Solar and GW (Gigawatt) goals in India: Source: Kiesecker et al. 2019

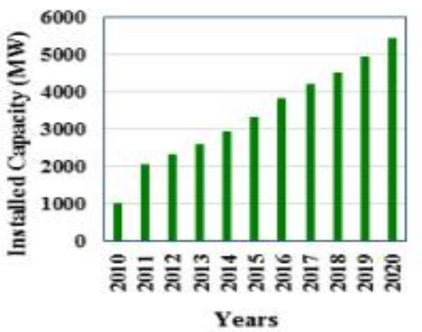
Name	2022 Vision Targets (GW)			2017 Installed Capacity (GW)		
	Solar Rooftop	Solar Ground-Mounted	Wind	Solar Rooftop	Solar Ground-Mounted	Wind
Lakshadweep	0.010				0.001	
Madhya Pradesh	2.200	3.475	6.200	0.017	1.193	2.498
Maharashtra	4.700	7.226	7.600	0.152	0.620	4.778
Manipur	0.050	0.055		0.001		
Meghalaya	0.050	0.111		<0.001		
Mizoram	0.050	0.022		<0.001		
Nagaland	0.050	0.011		0.001		
Odisha	1.000	1.377		0.003	0.076	
Puducherry	0.100	0.146		<0.001	<0.001	
Punjab	2.000	2.772		0.078	0.836	
Rajasthan	2.300	3.462	8.600	0.053	2.259	4.282
Sikkim	0.050			<0.001		
Tamil Nadu	3.500	5.384	11.900	0.110	1.712	7.970
Telangana	2.000		2.000	0.027	2.963	0.101
Tripura	0.050	0.055		<0.001	0.005	
Uttar Pradesh	4.300	6.397		0.056	0.495	
Uttarakhand	0.350	0.550		0.018	0.231	
West Bengal	2.100	3.236		0.023	0.017	

Name	2022 Vision Targets (GW)			2017 Installed Capacity (GW)		
	Solar Rooftop	Solar Ground-Mounted	Wind	Solar Rooftop	Solar Ground-Mounted	Wind
Andaman & Nicobar	0.020	0.007		0.001	0.011	
Andhra Pradesh	2.000	7.834	8.100	0.022	2.143	3.835
Arunachal Pradesh	0.050			0.004	<0.001	
Assam	0.250	0.413		0.002	0.010	
Bihar	1.000	1.493		0.004	0.138	
Chandigarh	0.100	0.053		0.014	0.005	
Chhattisgarh	0.700	1.083		0.013	0.166	
Dadar & Nagar Haveli	0.200	0.249		0.003		
Daman & Diu	0.100	0.099		<0.001	0.010	
Delhi	1.100	1.662		0.067	0.003	
Goa	0.150	0.208		0.001		
Gujarat	3.200	4.820	8.800	0.092	1.262	5.537
Haryana	1.600	2.542		0.086	0.130	
Himachal Pradesh	0.320	0.456		0.001		
Jammu & Kashmir	0.450	0.705		0.001	0.001	
Jharkhand	0.800	1.195		0.007	0.017	
Karnataka	2.300	3.397	6.200	0.085	1.717	3.793
Kerala	0.800	1.070		0.038	0.050	0.052

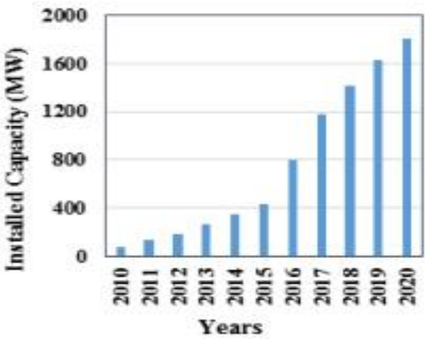
In an aim to reduce conflicts, with degradation and loss of human lands, the projection of India based on the 2022 vision of GoIs in utilising wind and solar energy is depicted in table 2. A detailed forecast for a temporal and spatial roadmap is highly dependent on the GW (Bhuvaneshwari et al. 2019). Table 1 summarised the technical potential for ground-mounted solar for energy generation which is sector specific. Lastly, the proliferation of various rooftop solar-energy is shown in the table which is slightly slowed down in India where the development involves ground-mounted solar energy.

*Table 3: Renewable energy production in Maharashtra**:** Source: Kumar et al. 2020*

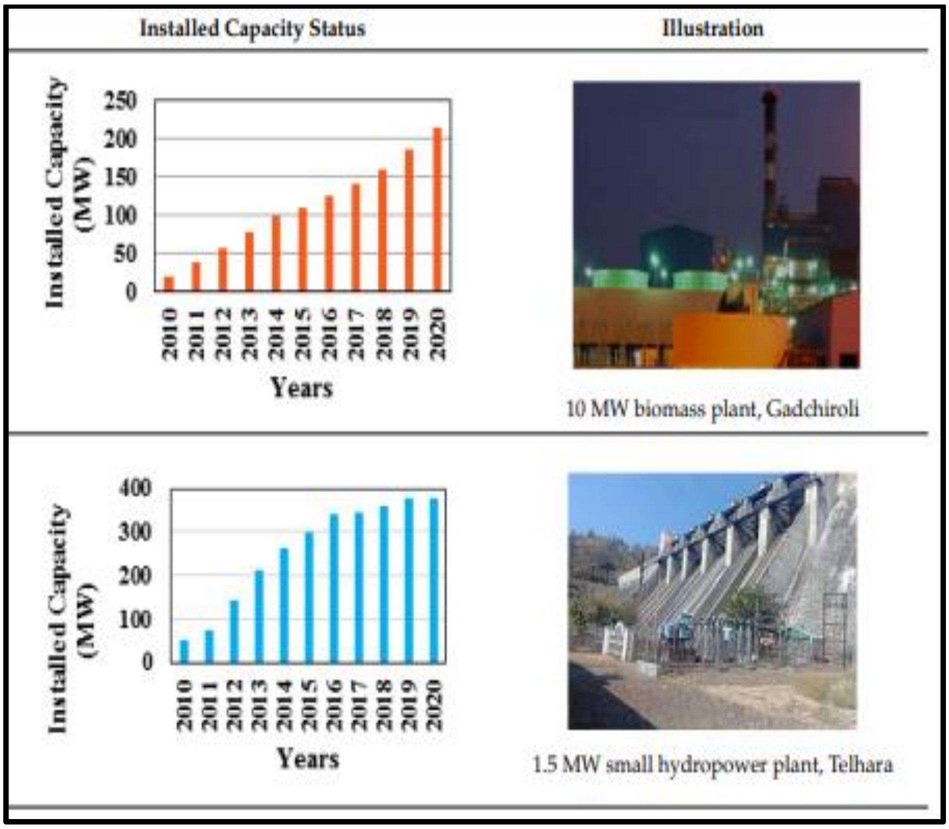
Installed Capacity Status	Illustration



100 MW Chand-Bibi Mahal Wind turbine plant, Ahmednagar



3 MW Tata solar power plant, Mulshi, Male



Maharashtra is of particular importance in producing energy from industrial waste. As per the data obtained from Tata Energy Research Institute, Maharashtra has the potential of energy production of 350 MW from wastes as shown in table 3. Under the 2012 prospective plan of MEDA, 200 MW remains fixed as the power generation to generate renewable energy (Karuppiah et al. 2020). In the production of wind energy, solar energy, and biomass energy, Maharashtra has excelled in many cases in the last decade (Kumar et al. 2020).

3. Research aim

The aim of the research is to analyse the ***advancement in hybrid energy systems in India along with the development of green energy initiatives***

4. Research objectives

The key objectives of the article are outlined below:

- To assess the importance of green energy initiatives and hybrid and renewable energy systems in India.
- To identify various challenges faced by the states in generating renewable energy sources.
- To provide feasible recommendations for the generation of renewable energy to eradicate the existing issues.
- To examine the different tactics used for the improvement of the usage of renewable energy in the society

5. Research questions

- What is the importance of green energy initiatives and hybrid and renewable energy systems in India?
- What kind of challenges is faced by the states in generating renewable energy sources?
- What types of recommendations can be made for the generation of renewable energy to eradicate the existing issues?
- What are the different tactics used for the improvement of the usage of renewable energy in the society?

6. Scope of the research

The research is extremely valuable in delving into the key areas of hybris energy systems in India. The research paper is advantageous in assessing the key areas where the states are supposed to take initiatives in rural development as well as green energy production system. As claimed by Ansari (2022), Maharashtra has been doing a great job of utilising waste to generate energy. Moreover, it is important to note that Andhra Pradesh and West Bengal are well behind in grid-scale storage systems of batteries to produce solar energy.

7. Methodology

The methodology is considered a theoretical and systematic discussion of all the methods, which are applied by the researcher. As stated by Javed et al. (2019), the effective utilisation of several appropriate tools is beneficial to assess the methods. All the authentic journals have been taken from ***ProQuest*** with the maintenance of authenticity. The research methodology is an efficient process of accumulating, analysing, as well as utilisation the data in order to achieve profound conclusions (Newman & Gough, 2020).

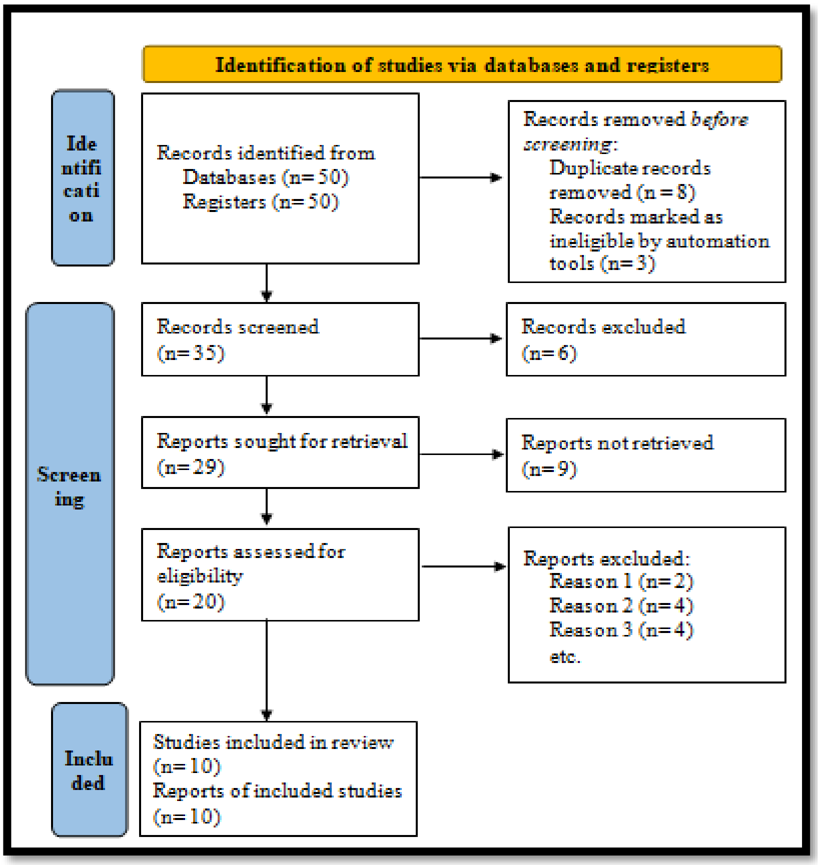


Figure 3: PRISMA diagram: Source: Newman & Gough, 2020

The Prisma diagram, depicted above is of particular interest as it shows how the entire process has been carried out in a suitable fashion. Here out of 50 journals, only 10 journals have been chosen to frame the systematic review table. The 40 journals were brushed aside as there was duplicate information plus they were deprived of authenticity. The systematic review table is of immense significance as various themes would cater to the intelligibility of the research topic in a significant way (Alzahrani, 2020).

8. Findings and analysis

Quality review of chosen articles

Table 3: CASP table

Serial no.	Title	Author	Year	Citation in the name of the author	Clearly focused research questions	Clearly mentioned aim	Meeting of the research objectives	Appropriateness of the participant recruitment strategy to meet the aim	Rigorous data analysis	Application of the results	Consideration of ethical issues	Collection of data to meet the research issues	Usage of relevant studies
1	Journal of Energy Chemistry	Mohamedazeem M. Mohideen a , Seeram Ramakrishna b , Sivaprasath Prabu c , Yong Liu	2020	Mohideen et al. 2020	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Biogas as an alternative to stubble burning in India	Preseela Satpathy 1 & Chinmay Pradhan1	2020	Satpathy and Pradhan (2023)	✓	✓	✓	X	✓	✓	✓	✓	✓
3	Hybrid Renewable Energy Microgrid for a Residential Community: A Techno-Economic and Environmental Perspective in the Context of the SDG7	Ansari, M. S.	2022	Ansari (2022)	✓	✓	✓	✓	✓	✓	X	✓	✓

4	A Holistic Review of the Present and Future Drivers of the Renewable Energy Mix in Maharashtra, State of India	Rajvikram Madurai Elavarasan , Leoponraj Selvamanohar , Kannadasan Raju , Raghavendra Rajan Vijayaraghavan , Ramkumar Subburaj , Mohammad Nurunnabi , Irfan Ahmad Khan , Syed Afridhis , Akshaya Hariharan , Rishi Pugazhendhi , Umashankar Subramaniam and Narottam Das	2019	Elavarasan et al. (2019)	✓	✓	✓	X	✓	✓	X	✓	✓
5	Cost optimization of a stand-alone hybrid energy system with fuel cell and PV	Shakti Singh , Prachi Chauhan , Mohd Asim Aftab , Ikbal Ali and S. M. Suhail Hussain and Taha Selim Ustun	2020	Ansari (2020)	✓	✓	✓	✓	✓	✓	✓	✓	✓

6	Renewable Energy and Land Use in India: A Vision to Facilitate Sustainable Development	Joseph Kiesecker , Sharon Baruch-Mordo , Mike Heiner , Dhaval Negandhi , James Oakleaf , Christina Kennedy and Pareexit Chauhan	2019	Kiesecker et al. (2019)	✓	✓	X	✓	✓	✓	✓	✓	✓
7	Optimal Planning of Hybrid Energy Conversion Systems for Annual Energy Cost Minimization in Indian Residential Buildings	Nand K. Meenaa, Abhishek Kumarb, Arvind R. Singhc , Anil Swarnkard , Nikhil Guptad , K. R. Niazid , Praveen Kumare , R. C. Bansal	2019	Meena et al. (2019)	✓	✓	X	X	✓	✓	X	✓	✓
8	A State-of-the-Art Review on the Drive of Renewables in Gujarat, State of India: Present Situation, Barriers and Future Initiatives	Elavarasan, R. M., Shafiullah, G. M., Manoj Kumar, N., & Padmanaban, S.	2019	Elavarasan et al. (2019)	✓	✓	✓	✓	✓	✓	✓	X	X

9	Techno-economic analysis of a hybrid renewable energy system for an energy poor rural community	Krishan, O., & Suhag, S.	2019	Krishan & Suhag (2019)	X	X	✓	✓	✓	✓	✓	X	X
10	Augmented Reality: A Systematic Review of Its Benefits and Challenges in E-learning Contexts	Alzahrani, N. M.	2020	Alzahrani (2020)	✓	✓	✓	✓	✓	✓	✓	X	X

Status of BIPV and BAPV systems in India considering hybrid energy systems

The BIPV or Building Integrated PV and BAPV or Building attached PV is the going concern across India. As viewed by Gyamfi et al. (2021), climate change issues and the share of electricity generation have been increasing of late. For this reason, bearing in mind the global renewable energy scenario, India is planning to harvest renewable energy and maximise it whereas Gujarat is proactive (Gyamfi et al. 2021).

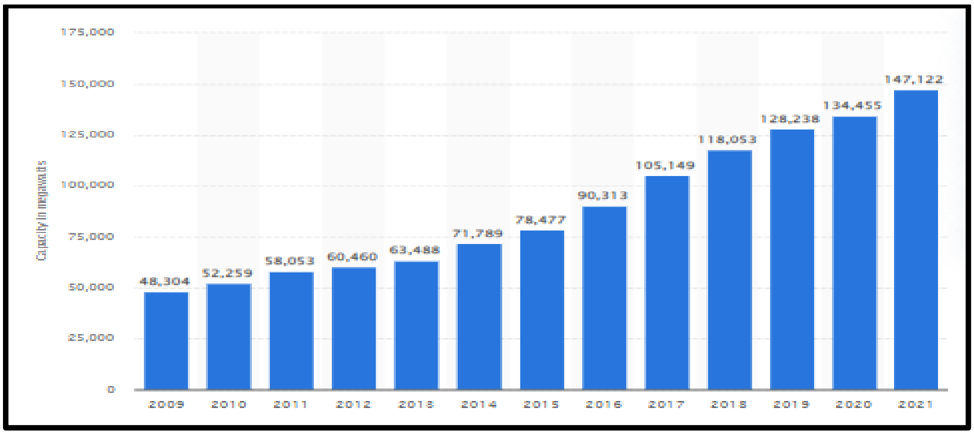


Figure 4: Renewable energy capacity in India: Source: Statista, 2023

It is clear from figure 4 that the energy capacity in the South Asian countries is more than 147 GW in 2021 which is a notch higher than 134 GW in 2020. This has been beneficial for India to become the PV or the photovoltaic country with meeting the IEA targets. Silicon solar cells, ***CDTE*** solar cells, and organic solar cells are of immense use in recent days which are low-cost materials with high advantages.

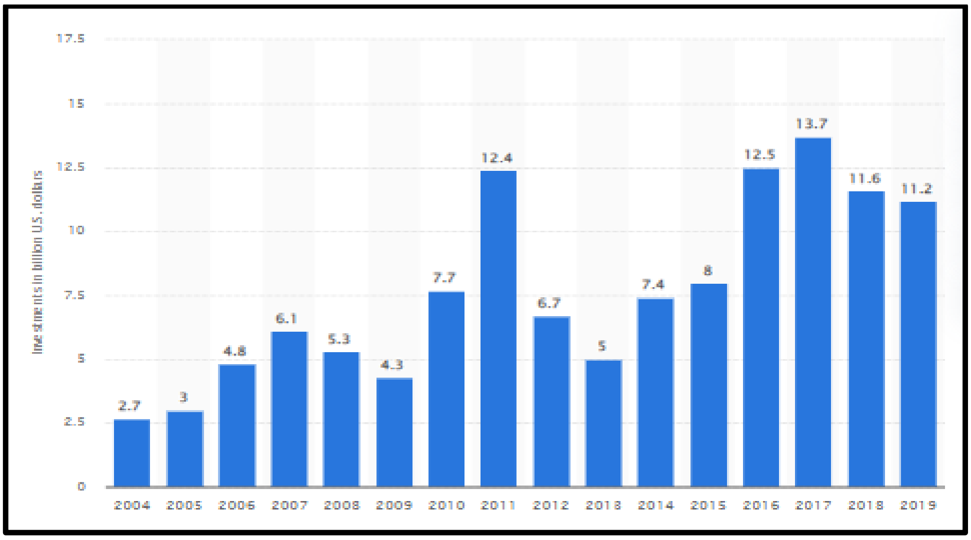


Figure 5: Investments in renewable energy in India: Source: Statista, 2023

Figure 5 describes that 11.2 billion USD has been done as expenditure in India to produce renewable energy which is commendable. Thus investment is helpful in making several BIPV windows, and building blocks

Techno-economic analysis of Biogas in India as a green energy initiative

Biogas is an alternative to stubble burning in India where tonnes of the residue of crop are in use. For example, paddy straw burning results in the loss of 4 million organic carbon, 20,000 tonnes of P, and 59,000 tons of N2 (Satpathy & Pradhan, 2023). Hence, to reduce the effects of greenhouse gases, VOC or volatile organic compounds, and OM or particulate matter, biogas is highly essential.

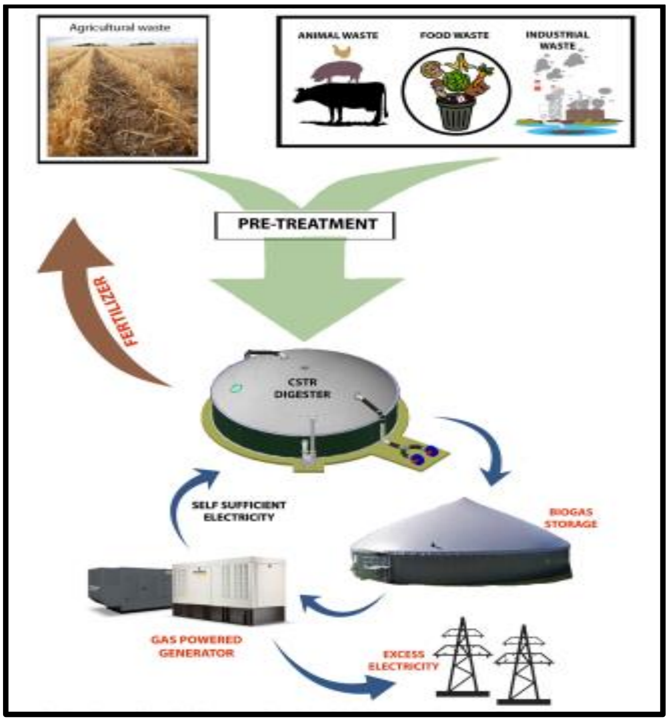


Figure 6: Co-digestion of crops in biogas generation: Source: Satpathy & Pradhan, 2023

The production of biogas is making a significant aspect across India. In this regard, the *waste-to-energy mission* is trending across various rural regions of India. 9. Discussion and conclusion

Discussion

A cumulative electricity generation area-wise has been mentioned in this article which is fruitful. Hydrogen production pathways and hydro-wind technology are advantageous in the Indian context with the development of hybris systems (Krishan & Suhag, 2019). Besides, an analysis of excluded water bodies and terrestrial lands is of immense importance for green energy production. The ***LULC*** or the land use land cover system of India is highly relevant where ground-mounted solar and wind technology development is discussed (Elavarasan et al. 2019). The consumption and production of electricity per year are significant to assess the economic growth of the country where India is supposed to play a pivotal role.

The energy which is produced from PV panels is more than 90% of the total energy production whereas rest 9% is produced by fuel cells (Diemuodeke et al. 2019). Of late, a major part of the population of India is residing in rural areas where electricity is highly required for being the second most populous country. It is seen that almost 70% of the 1.4 billion inhabitants of India in rural areas are deprived of reliable and affordable access to electricity (Nijhawan et al. 2021). The southern sector has been doing explicitly well in generating renewable energy followed by the western regions contributing to ***88,945 MU*** electricity production in 2019. ***[Refer to Appendix 1]***

Conclusion

For effective maintenance of green energy and renewable energy production, investment is the need of the hour. Additionally, there must be a special focus on electricity generation in rural areas so that the have-not families can make the full utilisation of the same. In addition, the Co-digestion of crops in biogas production is highly advantageous in terms of pollution control. Karnataka and Gujarat are leading in the production of ***clean energy*** whereas Bihar and Odisha are lagging behind. In industrial, and residential actors, the electricity demand is soaring day by day. ***[Refer to appendix 2]***

10. Limitation

One of the principal limitations of the study is this article has not been successful in suggesting the most suited measure of energy production. Moreover, the article could recommend a few effective technical tools which are required for meeting financial operations. Along with these, governing and monitoring of technologies has not been mentioned which is an important aspect of the generation of energy (Meena et al. 2019). In addition, proper sources of green energy production to get rid of the perils of pollution are missing in this article too. Lastly, only a few states are mentioned in the entire article with their initiatives and a few more pieces of information could be beneficial to analyse the importance of renewable energy (Reddy et al. 2020).

11. Future scope

A huge scope of study relies on the fact of the utilisation of wastes in generating renewable energy. On the other hand, government investment has been discussed in a fruitful manner that affects electricity production (Madurai Elavarasan et al. 2020). In addition, the importance of biogas augurs well for the future development of energy and electricity production across India. The hydro-production pathways and the hydro-wind system can go far in the path of achievement in India.

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Appendices

Appendix 1: Region-wise electricity generation in India

Cumulative generation achieved during the year up to the reporting month (MU)	2018–2019 (April–November 2018)	2017–2018 (April–March)	2016–2017 (April–March)	2015–2016 (April–March)
Northern	16,055.27	21,388.22	18,184.54	15,917.51
Western	26,124.98	31,564.48	27,603.54	22,958.91
Southern	44,768.78	46,077.26	33,137.87	24,162.83
Eastern	1779.46	2516.78	2611.19	2425.30
North-Eastern	216.85	292.75	331.55	316.30
Grand Total	88,945.34	101,839.48	81,868.69	65,780.85

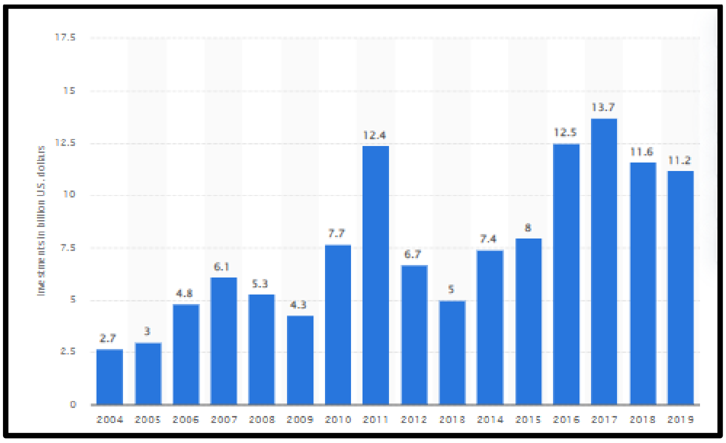
(Source: https://energsustainsoc.biomedcentral.com/articles/10.1186/s13705-019-0232-1/tables/14)

Appendix 2: Sector-wise electricity demand

TWh	2012	2022	2030	2047
Industry	336	494	703	1366
Residential	175	480	842	1840
Commercial	86	142	238	771
Agriculture	136	245	336	501
Others	29	71	121	233
Total	762	1433	2239	4712

(Source: https://energsustainsoc.biomedcentral.com/articles/10.1186/s13705-019-0232-1/tables/5)

Appendix 3: Renewable installed capacity in India



(Source: https://www.statista.com/statistics/567724/new-investments-worldwide-in-sustainable-energy-in-india/)