Design and Feasibility Analysis of a Solar PV and Biomass-based Electric Vehicle Charging Station for Metropolitan Cities (India)

Venkatesh Boddapati[1], A. Rakesh Kumar[2,*],
D. B. Prakash[1] and S. Arul Daniel[2]

[1]*B.M.S College of Engineering, Bangalore, India*
[2]*National Institute of Technology, Tiruchirappalli, India*
E-mail: rakesh.a@ieee.org
[*]*Corresponding Author*

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Abstract

This paper presents the Electric Vehicle Charging Station (EVCS) design and feasibility analysis using hybrid energy sources such as Solar PV, Biomass, and Diesel generators for India's metropolitan cities. The planned EVCS is precisely modelled and simulated by using HOMER software. The performance of the EVCS is analysed by adopting different configurations, and the techno-economic performance of the proposed system is presented in detail. The system's optimum configuration is analysed by considering the different case studies, and the results are compared. Further, the design and performance of the EVCS are performed for four metropolitan cities in India, such as Delhi, Bombay, Bangalore and Chennai, and the performance parameters are compared.

Keywords: Electric vehicle charging station, solar PV, biomass, energy economy, LCOE and NPC.

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1 Introduction

The growing population and industrialization are increasing energy consumption at an alarming rate. The energy consumption is expected to increase by nearly 50% across the globe by 2050 [1] about 24% of generated energy has been utilized for transportation, and the major source of energy are fossil fuels as of 2018 [1]. The use of fossil fuels contributes to global warming, and the harmful gases emitted by burning hydrocarbon fuels will threaten public health to a greater extent. There is a need to address this global issue by incorporating a breakthrough in the production and consumption of Renewable Energy Resources [RES] which can be achieved by changing infrastructure, vehicles and mechanisms used for optimum utilization. The United Nations Framework Convention for Climate Change [UNFCCC] in 2015 has suggested the rise in atmospheric temperature to 2° by 2020 as per Parris Agreement to combat global warming. Policymakers worldwide are working towards developing a more sustainable, reliable and Zero carbon emission means of energy production by implementing stringent measure to reduce CO_2 emissions. When it comes to RES, solar energy has the highest energy generation capacity among other renewable resources because the world's annual demand can be met in less than an hour [2]. In a developing country like India, which is ranked world number two in population, most of the population is concentrated in the metropolitan cities. Effective utilization of solid waste will improve the economic stability, savings on energy production and aid in urban growth in sustained manner. One of the significant drawbacks of RES is its intermittent production which can be overcome by developing different strategies through hybridizing two or more resources for unremitted energy.

Since 29% of the CO_2 gas emission in the world is from vehicular emission [3], feeding just the electrical load with renewable resources might not be an optimal solution for sustainable green future. The air pollution due to the transport sector has increased to 254.4 Million tonnes from 231.8 Million tonnes in India in one year between 2015 to 2016 [4]. Firstly, the conventional vehicles have to be replaced with electric and hydrogen vehicles, which are eco-friendly [5]. In this paper, a feasibility analysis of Solar PV, Biomass and Diesel generators for various hybrid combinations have been designed to provide energy to electric vehicle charging stations. The analysis and the design of EVCS are performed for five major metropolitan cities of India like Delhi, Bombay, Bangalore, Chennai, and Hyderabad, and the performance parameters are compared.

Understanding the importance of electric vehicles and with new technologies emerging to manufacture more efficient eco-friendly vehicles, the worldwide electric car stocks have elevated to 63% by reaching a 5 Million mark in 2018 [6] compared with 2017. The Government of India in 2011 has approved the National Mission on Electric Mobility to accelerate the production and deployment of electric vehicles, and thus Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme has been made. The mission under this scheme is to develop a prototype connecting the demand incentives, publicizing the importance of EVCS, a good network of charging stations and improvise Information, Education and Communication (IEC) activities. With the increase in Electric Vehicles there is a need of providing efficient infrastructure to meet the energy demands without posing an extra burden on the grid for electricity. Consumer satisfaction regarding easy access to charging stations and their suitable location plays a crucial role in the successful deployment of electric vehicles in metropolitan cities.

In the literature an effective way of charging the batteries through run-out-of charge cases, and a detailed analysis was presented has improvised the Plug-in EVCS through Artificial Neural Networks for optimum energy management. The plug-in EVCS handling procedures through an intelligent Nano grid system that utilized hybrid solar power. As per [7, 8] even if the oil prices go low, the demand for electric vehicles will be competitive in the market. Another significant technology used for charging of EVs is, wireless transfer technology, in the literature many people had done work on wireless power transfer technology for a EVs charging [9–13].

However, none of the author so far presented the feasibility analyses of a EVCS design for an India. In this research feasibility analysis of different metropolitan cities is presented in details and its techno economic performance assessment is presented. Homer pro is used for designing and performance assessment.

2 System Description

The system is designed to produce electricity for charging stations located across five major metropolitan cities in India. The system is built exclusively to provide for charging EVs and is not connected to the grid so that demand can be effectively met. As shown in Figure 1, energy generation is achieved through hybrid Solar PV panels, Biomass and Diesel generators. Hybrid Optimization Model for Electric Renewables (HOMER) simulation tool from National Renewable Energy (NREL), US, is used to design the hybrid

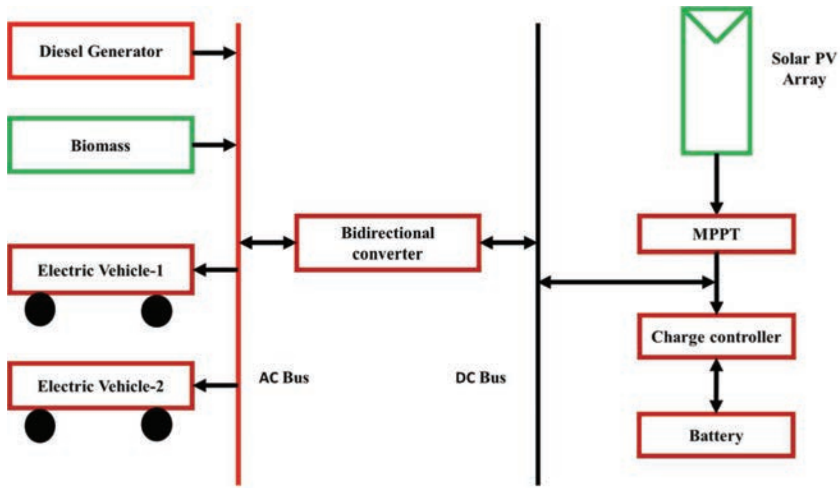

Figure 1 Schematic of proposed hybrid energy generation system in India.

system's technical and economic feasibility study. This paper determines the optimal feasibility model through qualitative and quantitative analysis of various combinations of energy sources like solar, biomass, and diesel generators. The produced power is fed into the battery system located at EVCS. The system is planned to be set up in the following five stations:

1. Delhi at Gail No.1, pocket 6, Mango apr Kalan, Rohini, 28°41.9 N, 77°.0 E
2. Mumbai at 28°54.50 N, 77°.1926 E
3. Hyderabad at 17°59.47 N, 78°.1230 E
4. Bangalore at 12.9410° N, 77.5655° E

3 Resources

Solar radiation variation in four metropolitan cities is as shown in Figure 2; Delhi has the most negligible solar radiation in December with 3.52 kWh/m^2/day and 3.8 kWh/m^2/day in January. Bombay faces the highest solar radiation of 7.33 kWh/m^2/day in May followed by 6.72 kWh/m^2/day in Chennai for April month, Bangalore has the most negligible solar radiation 6.38 in April and Delhi with 6.42 kWh/m^2/day in May.

Wind speed in four metropolitan cities are as follows: wind speed is the least in Delhi with 1.83 m/s in November, and the highest speed is attained in

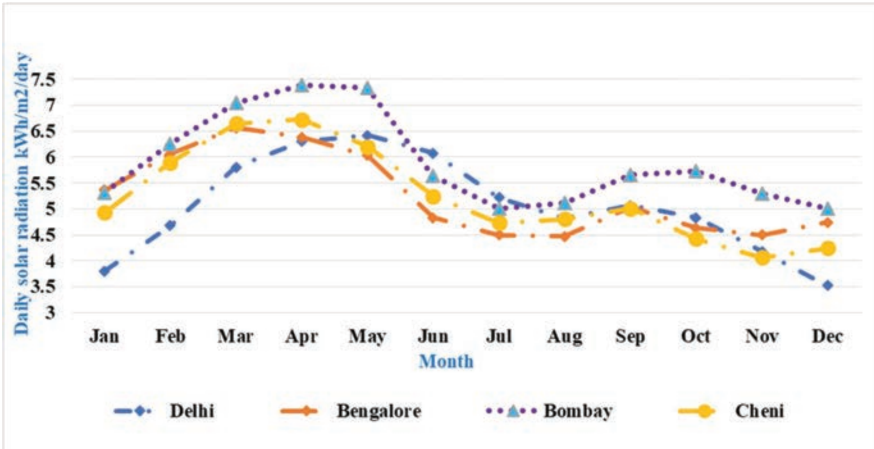

Figure 2 Daily Solar Radiation at four major cities in India.

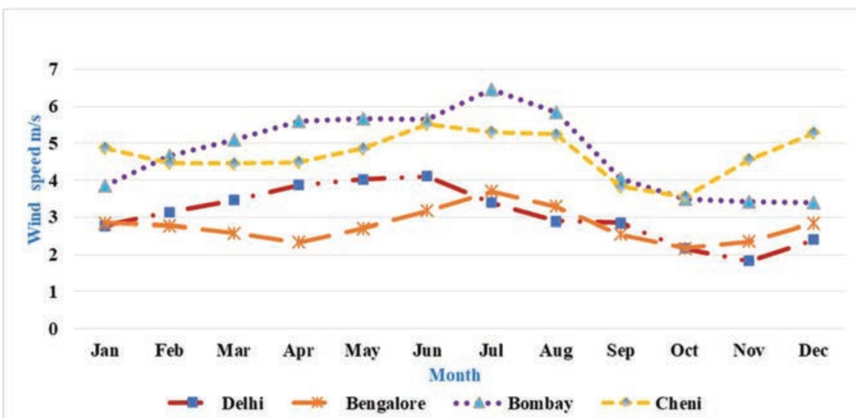

Figure 3 Daily Wind Speed measurement in Delhi, Bangalore, Bombay and Chennai.

Bombay at 6.46 m/s in July, as shown in Figure 3. Chennai has the least wind speed of 3.8 m/s in September and the highest with 5.28 m/s in December. Bombay has the least speed of 3.41 m/s in November and highest at 6.46 m/s in July. Delhi has the least speed of 1.83 m/s in November and the highest of 4.11 m/s in May and June. Bangalore has the most minor speed of 2.33 m/s in April and 3.7 m/s in July.

From Figure 4, it is seen that the highest temperature is recorded in Chennai with 30.12°C in June and least in Bangalore with 21.92°C.

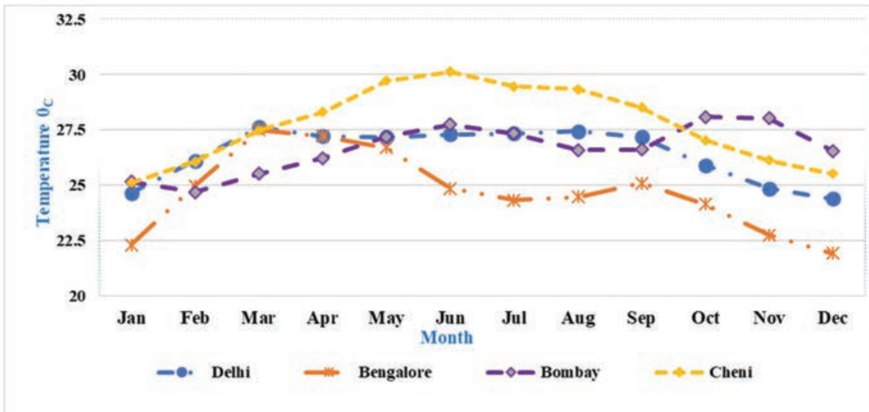

Figure 4 Measurement of daily temperature in four metropolitan cities.

4 Result and Discussions

4.1 Delhi

Gail No. 1, pocket 6, Mango apr Kalan, Rohini, Delhi, India location is considered for designing the EVCS. The longitude and latitude of the location are 28°41.9 N, 77°.0 E. Different cases were analysed for the performance.

Case-1

When Solar PV and biomass sources are supplying, and battery storage is available, the energy produced from the solar PV energy is estimated at 98,864 kWh/yr, and energy produced from the Biomass generator is estimated as 155,120 kWh/yr. The energy produced from the solar PV is 38.9%, and biomass contributes 61.6% of the total energy produced. The EVCS load served is estimated as 227,332 kWh/yr, and the excess energy available is estimated as 22,258 kWh/yr. i.e., 8.37% of the total energy produced. Figure 5 represents the amount of energy produced from the different sources.

A 60 kW solar PV is used to design an EVCS the estimated average output of the solar PV is 271 kWh/day, and the capacity utilization of the solar PV is estimated as 18.8%. The solar PV generated power for 4370 hrs/yr, and the LCOE of the solar PV was estimated as 0.0352 $/kWh.

Similarly, a 60 kW Biomass generator was used for the EVCS design. The biomass generator operated for 6356 hrs/yr, and the capacity factor of the biomass generator is estimated as 44.3%, and the minimum energy produced from the biomass generator is estimated as 12 kW. The maximum electrical

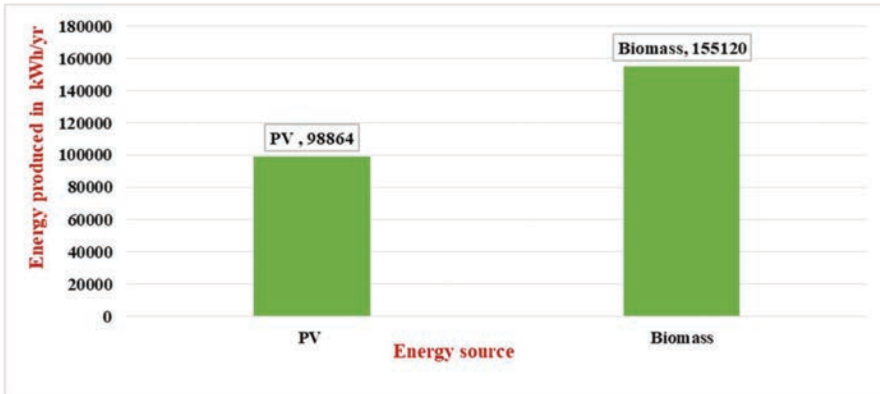

Figure 5 Solar PV and Biomass with battery storage.

output is estimated as 40 kW, and the average electrical output is estimated as 24.4 kW, and the amount of fuel consumed by biomass generators is estimates as 712 KG. The optimum number battery used for the designing of the EVCS for this case is 100; each battery is rated with 1 kWh, and the bus voltage is 12 V, and storage wear cost is estimated as 0.419 $/kWh., nominal capacity 100 kWh and usual nominal capacity is estimated as 60 kWh and lifetime throughput is 74238 kWh. The energy input to the battery is estimated as 8233 kWh/yr, and the energy output is estimated as 6640 kWh/yr, and the total losses in the battery per annum estimated as 1653 kWh/yr, annual throughout is 7424 kWh/yr, and the storage depletion estimated as 60 kWh/yr.

Case-2

The EVCS performance is analysed without battery storage, the amount of energy generated from the solar PV is estimated as 98864 kWh/yr, and the amount of energy generated from the biomass generator is 188143 kWh/yr as shown in Figure 6. When case-2 is compared with case-1 the amount biomass utilization increased, the amount of biomass increased due to the lack of energy storage system. The amount of biomass consumed without battery storage is estimated at 1032 KG. The number of hours of operation is increased from 6356 hrs/yr to 7601 hrs/yr and capacity utilization factor of biomass generator in this case estimated as 35.8% and the minimum energy output of the biomass generator estimated as 18.00 kW, maximum energy out recorded as 59.1 kW and the mean output of the generator estimated as 24.8 kW.

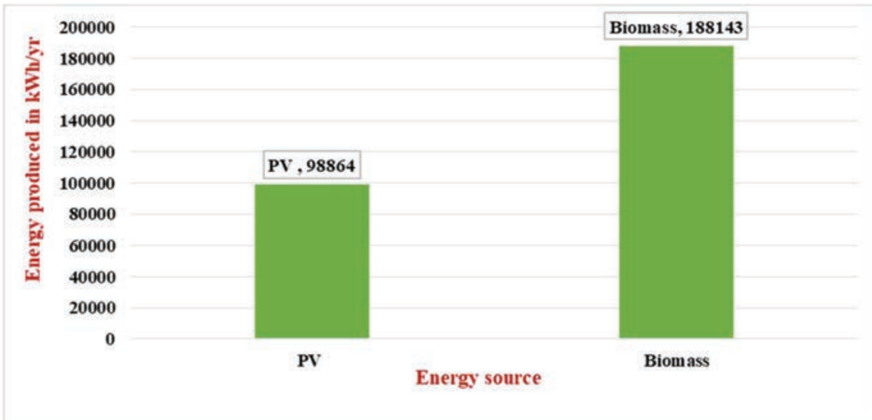

Figure 6 Solar PV and Biomass without battery storage.

Case-3

In case-3 when solar PV and diesel generator and battery storage is considered an energy source, the amount of energy produced from the solar PV is constant the same as that of case-1 and case-2, i.e. 98864 kWh/yr and the amount energy produced from diesel generator is estimated as 140541 kWh/yr. In this case, the solar PV penetration is estimated as 41.3%, and the energy produced from the diesel generator is estimated as 58.7%. The number of hours required to operate a diesel generator is estimated as 5154 hr/yr, the capacity factor is estimated as 26.7%, and the amount of energy fuel consumed is estimated at 59874 L.

For the modelling purpose, the 1 kWh lead-acid battery is considered, the optimum batteries required for this combination estimate at 259. The energy input to the battery is estimated as 31607 kWh/yr, and the energy output of the battery is estimated as 25418 kWh/yr, and the total losses in the battery are estimated as 6337 kWh/yr, storage depletion of the battery is estimated as 147 kWh/yr, and the annual throughput is 28418 kWh/yr as shown in Figure 7.

Case-4

In case-3 solar PV and the diesel generator are considered sources; storage is available in the EVCS. In this case, the storage is not available, EVCS has to be run by only two sources such as Solar PV and DG, the amount of energy produced from the solar PV is estimated as 98864 kWh/yr and the amount of energy produced from the diesel generator estimated as 188107 kWh/yr. In

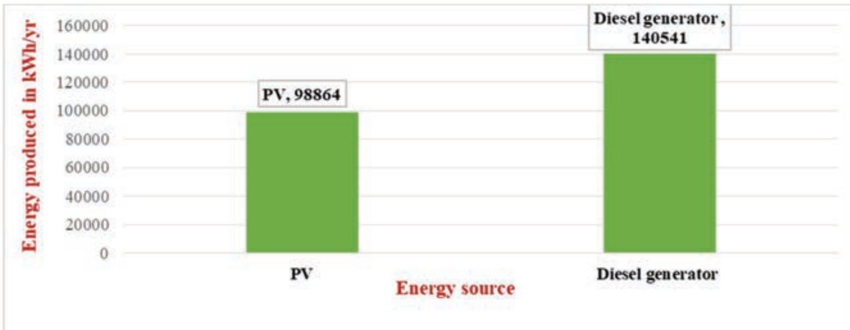

Figure 7 Solar PV and Diesel Generator with battery storage.

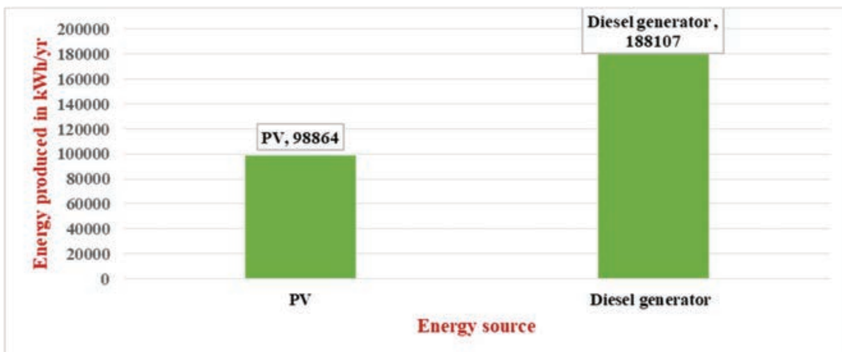

Figure 8 Solar PV and Diesel Generator without battery storage.

the total power generation, 34.45% produced from the solar PV and 65.54% of power produced from the DG, when case-3 compared with case the amount of power produced from the DG is increased due to the lack of storage in the EVCS.

NPC Variation for EVCS different architecture design

Figure 9 shows the variation of NPC for a different architecture, NPC is assessed for a different combination of energy sources, the NPC for diesel generator based system is very high, and it is not economically feasible for the design the NPC values assessed for the diesel-based system is 41,60,000 $ as shown in figure. PV-Biomass and battery storage architecture give optimum NPC values comparing that of other schemes.

Figure 10 indicates the initial project variation for Delhi metropolitan city. The initial cost is meagre in the DG-based system, but DG can be used to

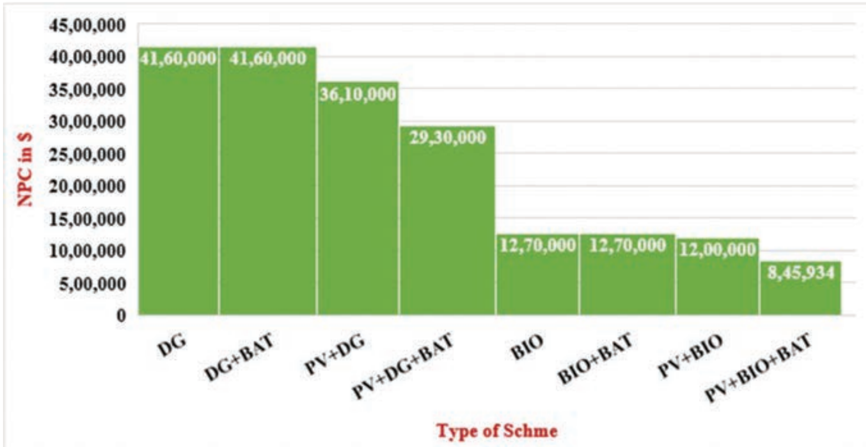

Figure 9 Variation of NPC for a different architecture.

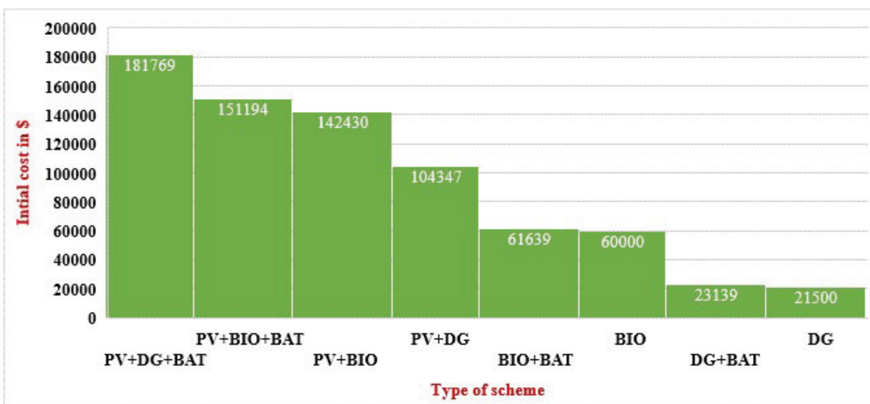

Figure 10 Initial project variation for Delhi metropolitan city.

improve the reliability of the power supply in the EVCS. The initial cost required for the PV-Biomass battery storage system is 151,194 $, and PV-DG and battery storage system is 181,769 $.

Figure 11 represents the LCOE variation for a different scheme, and it is observed that LCOE is less than 0.149 $/kWh for PV, Biomass and battery storage systems comparing to all other schemes.

If the complete charging station runs with a DG source with battery storage, the LCOE is 0.732 $/kWh, which is not economical for the customer. Similarly, the LCOE for PV-DG and battery storage systems is also very high,

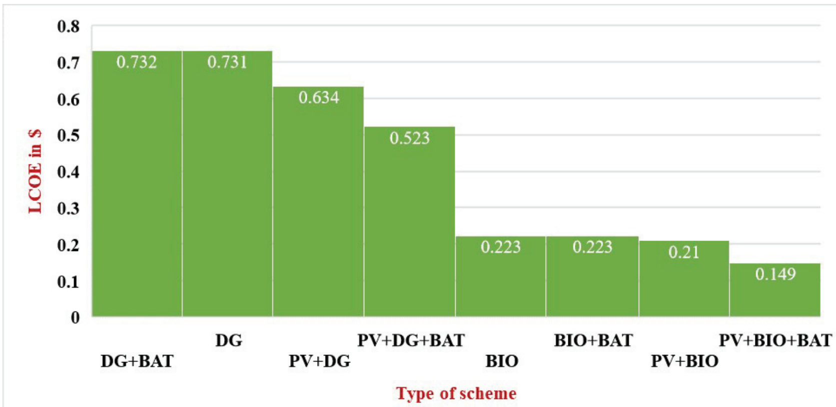

Figure 11 The LCOE variation for a different scheme.

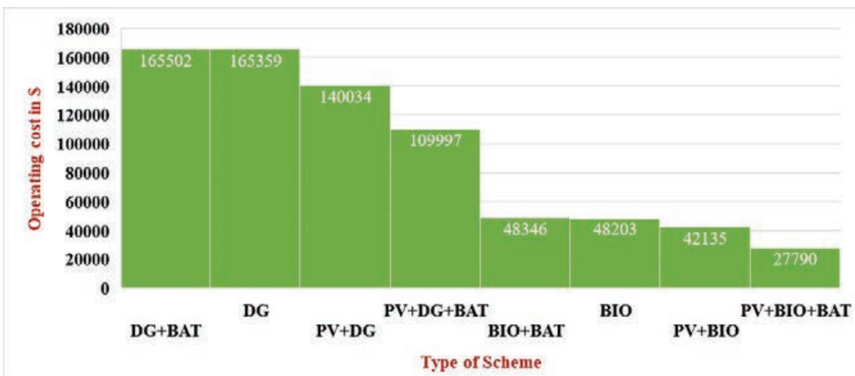

Figure 12 Operation cost variation of the different schemes.

0.523 $/kWh. For the economical operation of the EVCS, PV-biomass and battery storage gives better results.

Figure 12 represents the operation cost variation of the different schemes, and the operating cost varied from 165,502 $/Yr to 27790 $/yr. The operating cost for the PV -Biomass and battery storage is less than that of other scheme available. The operating DG and battery storage is a system very high comparing that of all other systems.

Table 1 variation indicates the variation different parameter depending on the type of scheme, sizing of the energy sources is also represented, and amount fuel consumed is also assessed. Comparing to all the scheme solar

Table 1 Indicates the variation of different parameter

PV in (kW)	Biomass in kW	Diesel Generator in kW	Battery in kWh	Converter in kW	Initial Cost ($)	Operating Cost ($/yr)	Total NPC ($)	LCOE ($/kWh)	Renewable Fraction (%)	Biomass in (tons)	Diesel (L)
60	40		100	30.6	151,194	27,790	845,934	0.149	100	712	
60	60			34.8	142,430	42,135	1.20 M	0.210	100	1032	
	60			—	60,000	48,203	1.27 M	0.223	100	1224	
	60		5	0.464	61,639	48,346	1.27 M	0.223	100	1224	
60		60	259	35.2	181,769	109,997	2.93 M	0.516	38.2		59,874
60		60		36.2	104,347	140,034	3.61 M	0.634	17.3		83,502
		60			21500	165,359	4.16 M	0.731	0		99,482
		60	5	0.464	23,139	165,502	4.16M	0.732	0		99,482

PV -biomass and battery storage system is more economical. The LCOE and NPC estimated for a solar PV biomass and battery storage system estimated as 0.149 $/kWh and 845,934 $. Solar PV- Biomass and battery storage system gives 100% renewable energy penetration to EVCS and amount biomass consumes is estimated as 712 tons per annum. The performance of the solar PV-Biomass without storage is also performed the fuel consumption of the biomass generator increased to 1032 tonnes fer annum and the LCOE and NPC estimated 0.210 $/kWh and 1.20 M$.

Similarly, when the EVCS is running with solar PV-DG and battery storage the LCOE and NPC of the estimated as 0.516 $/kWh and 2.93 M$, when it is compared with solar PV-Biomass and battery storage the LCOE and NPC cost is very high, and it is not economical for the design.

The amount renewable energy penetration is estimated as 38.2%, and this system is found to be not an environmentally friendly. The amount of diesel required to run the EVCS is assessed as 59874 L/yr.

Similarly, the performance of the same system assessed without battery storage, the amount of renewable energy penetration reduced to 17.3% and amount fuel required increased to 83,502 L/yr. The LCOE and NPC of the system is estimated as 0.613 $/kWh and 3.61 M$.

4.2 Bombay

Mumbai at 28°54.50 N, 77°.1926 E, India location is considered for the designing of the EVCS. Different cases analysed for the performance. When Solar PV and biomass sources are supplying and battery storage is available, the energy produced from the solar PV energy is estimated at 109906 kWh/yr, and energy produced from Biomass generator is estimated as 148878 kWh/yr. The energy produced from the solar PV is 38.9%, and the biomass contributes 61.6% of the total energy produced. The EVCS

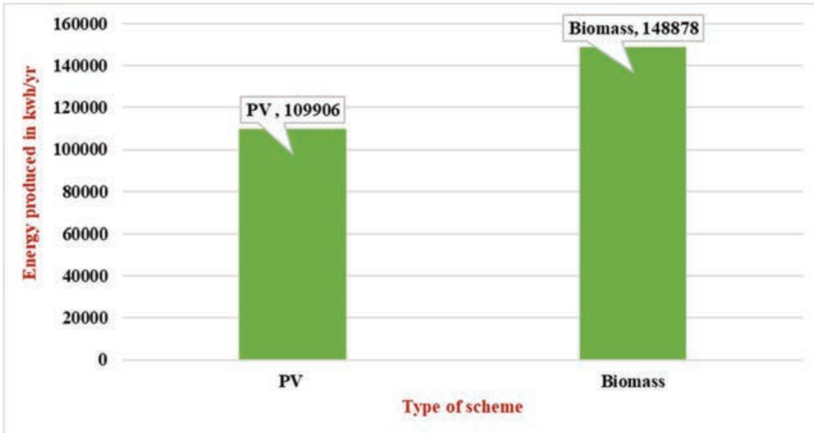

Figure 13 Solar PV and Biomass with battery storage.

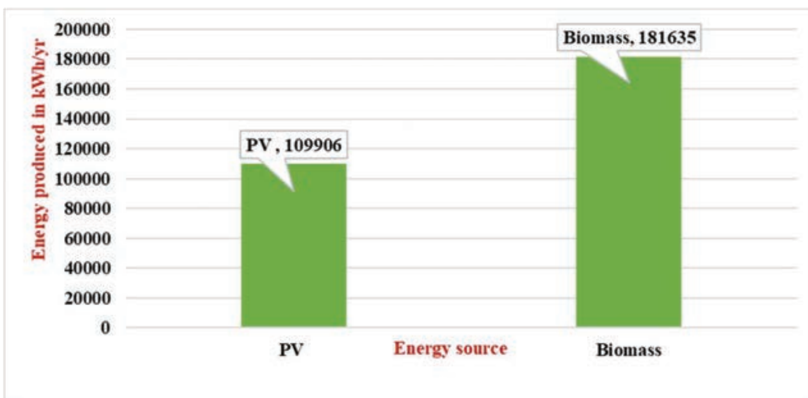

Figure 14 Solar PV and Biomass without battery storage.

load served estimated as 227,332 kW/yr, and the excess energy available is estimated as 22,258 kWh/yr. i.e., 8.37% of the total energy produced. Figure 13 represents the amount of energy produced from the different sources. Figures 14 to 19 illustrates the variation of techno-economic parameters for the Bombay location.

4.3 Bangalore

The energy produced by different sources and its techno-economic parameters are presented for the Bangalore location is shown in Figures 20 to 27.

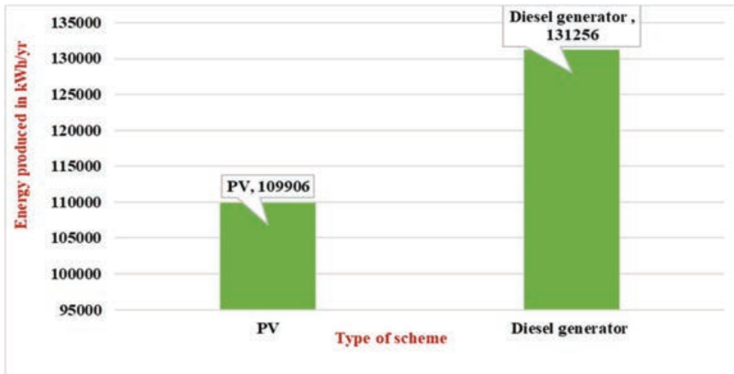

Figure 15 Solar PV and DG with battery storage.

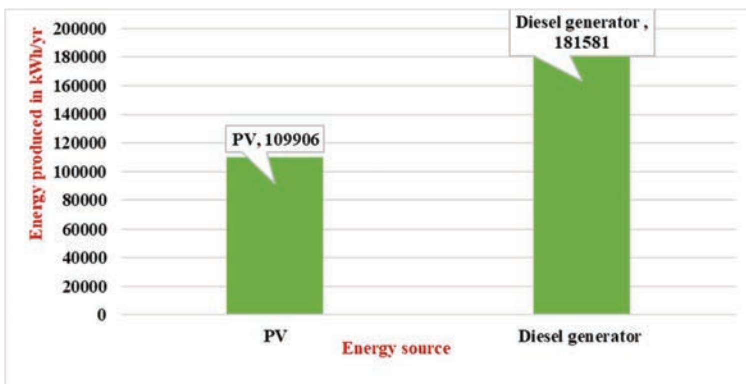

Figure 16 Solar PV battery without battery storage.

Figure 17 NPC variation with different schemes.

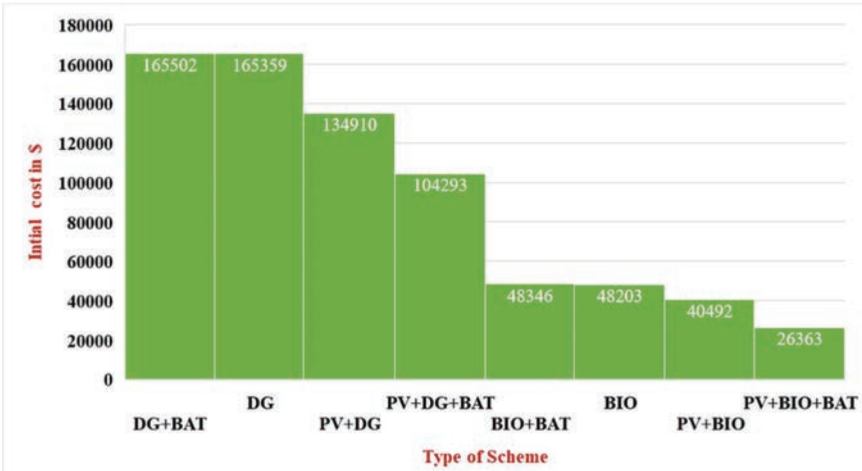

Figure 18 Initial cost variation with different scheme.

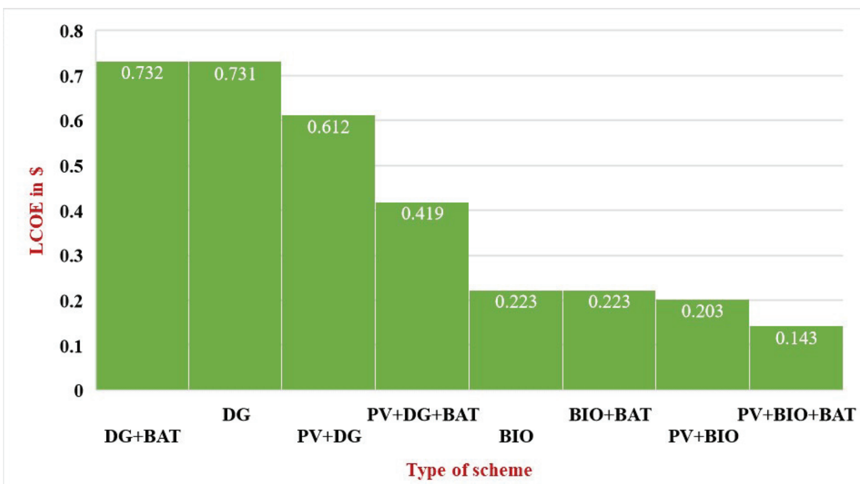

Figure 19 LCOE variation.

4.4 Chennai

The variation of energy produced and its techno-economic parameters are presented illustrated in Figures 28 to 35.

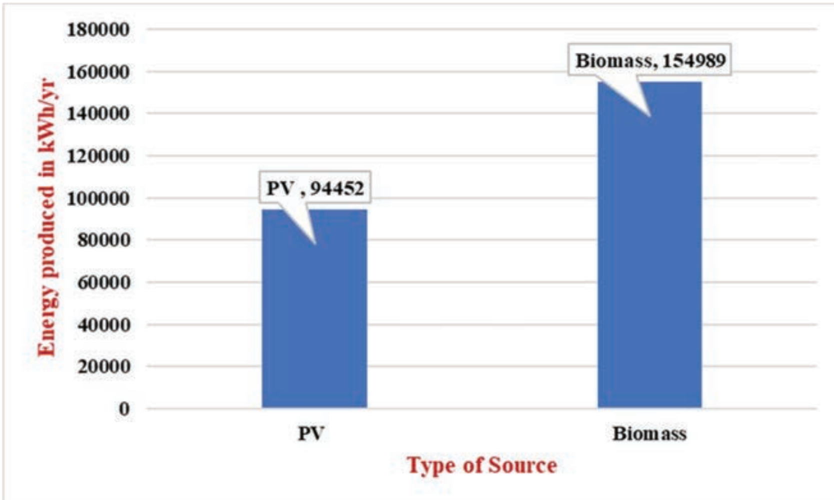

Figure 20 Energy produced when Biomass, PV and battery is active.

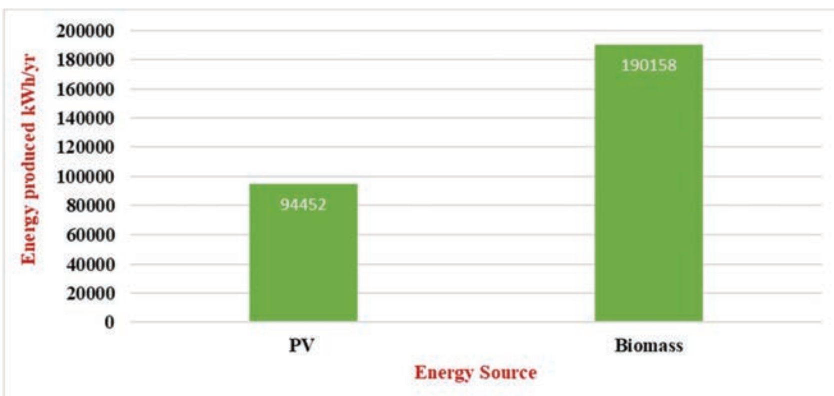

Figure 21 Solar PV and Biomass without battery.

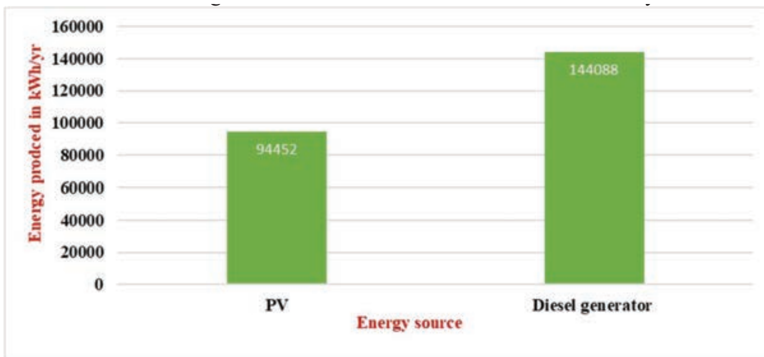

Figure 22 Solar PV, DG and Battery is active.

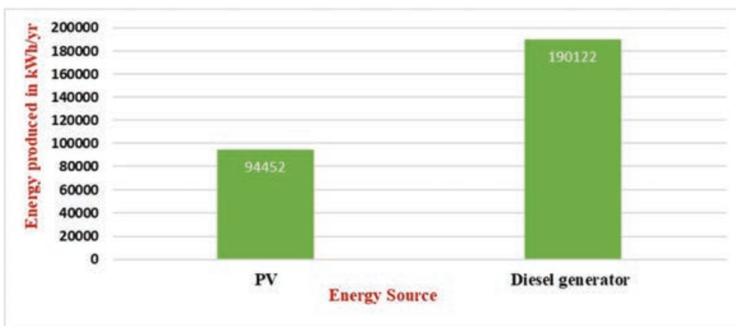

Figure 23 Solar PV, DG and without Battery.

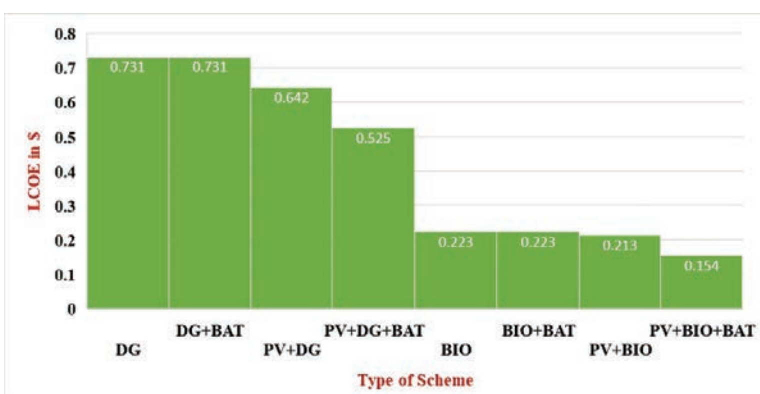

Figure 24 LCOE variation.

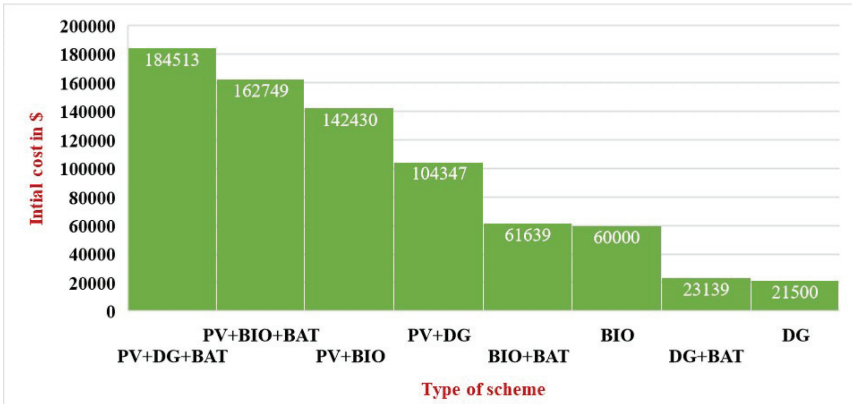

Figure 25 Initial cost variation.

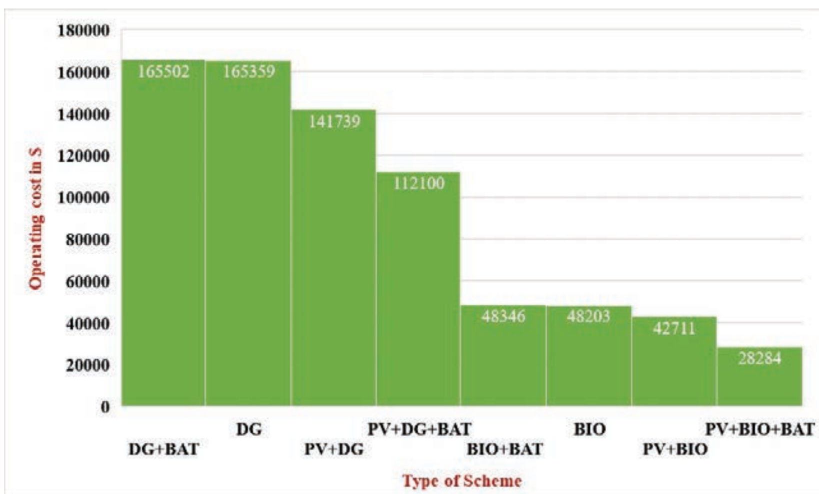

Figure 26 Operating cost variation.

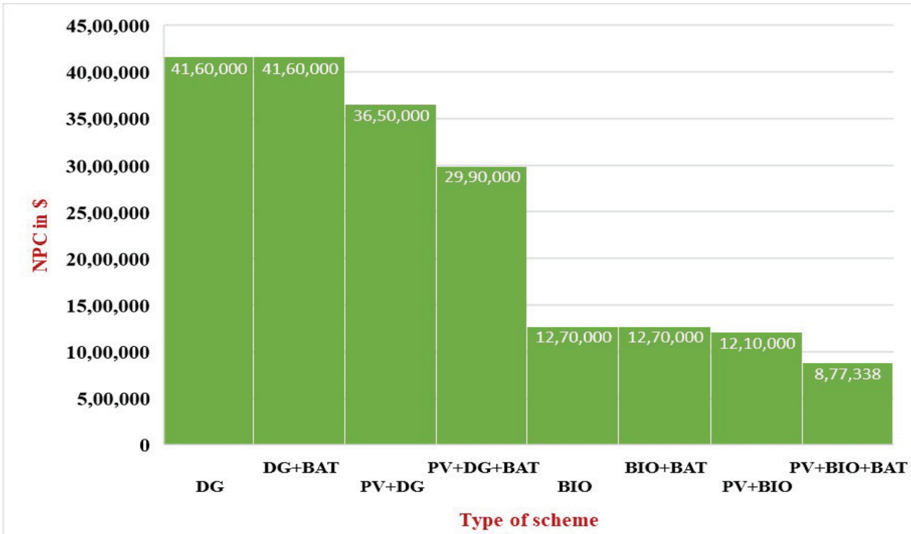

Figure 27 NPC variation.

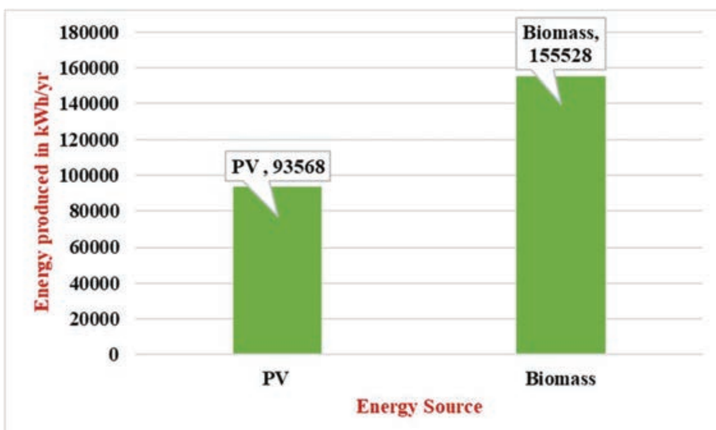

Figure 28 Energy produced by PV, Biomass with battery.

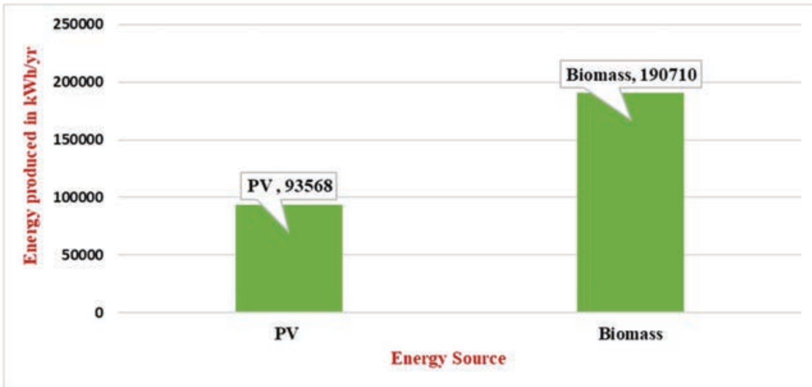

Figure 29 Energy produced by solar PV, biomass without battery.

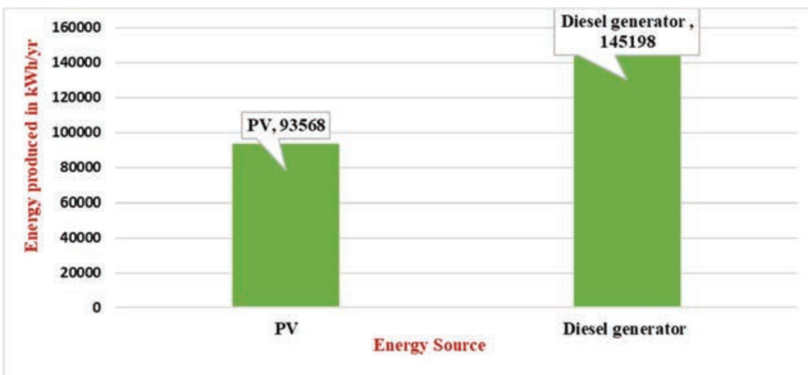

Figure 30 Energy produced by Solar PV, DG with battery.

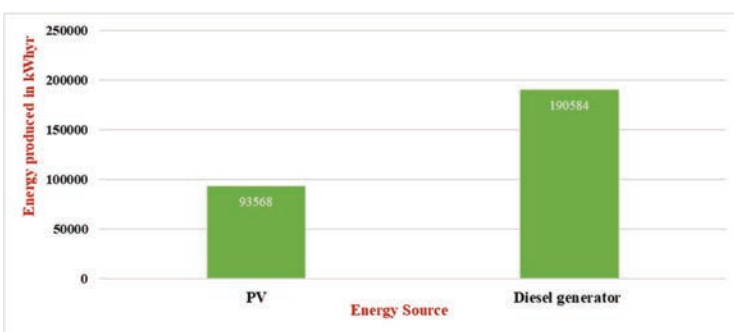

Figure 31 Energy produced by Solar PV, DG without battery.

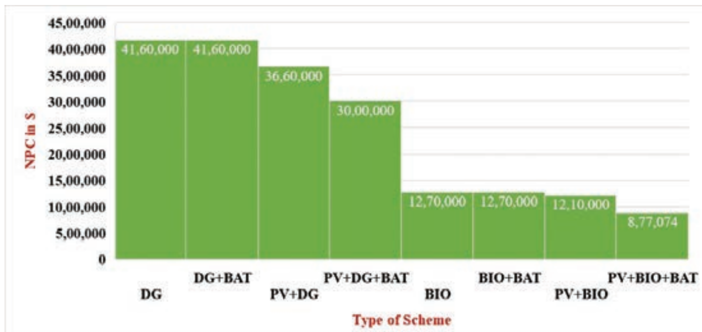

Figure 32 NPC variation.

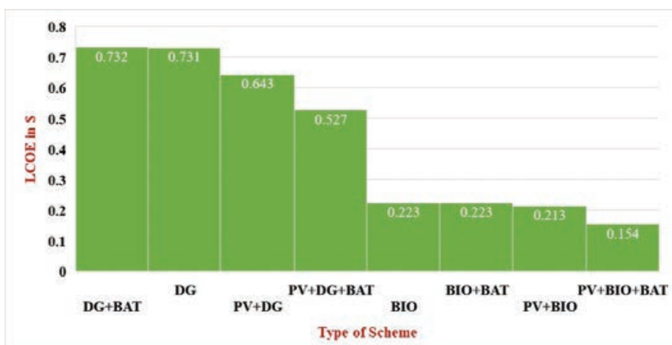

Figure 33 LCOE variation.

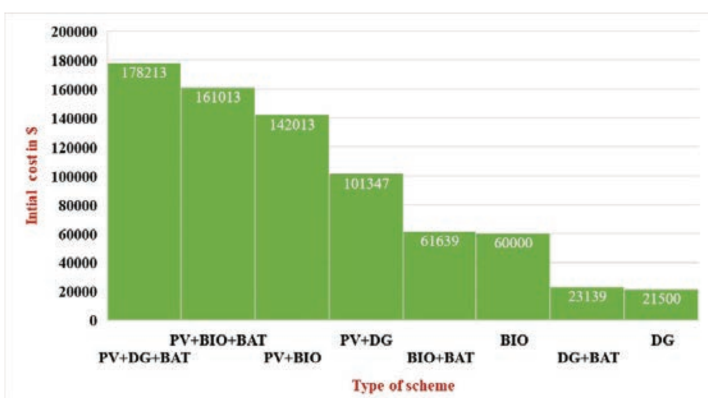

Figure 34 Initial cost variation.

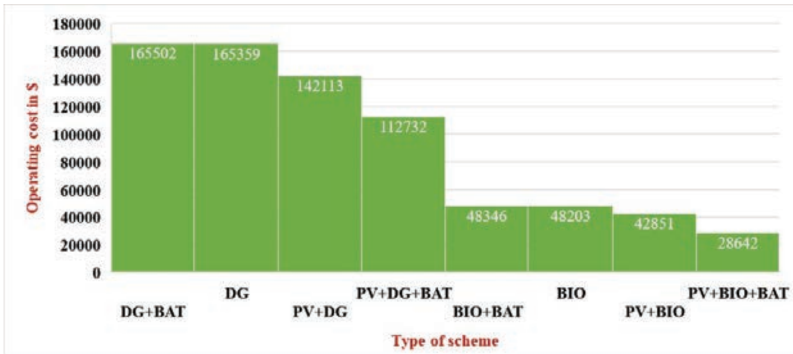

Figure 35 Operating cost variation.

5 Conclusions

In this work feasibility study of a hybrid energy based electric vehicle charging station designed for different metropolitan cities in India. The prosed EVCS is simulated in HOMER simulator and techno-economic performance of the EVCS is assessed in details. Different schemes are analysed to select the best scheme for the actual charging station implementation. Several case studies are assessed in terms of energy production, with and without battery and Economic parameters such as LCOE, Initial cost, operation cost and NPC is analysed for different EVCS.

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Biographies

Venkatesh Boddapati received his B.Tech (Electrical and Electronics Engineering) from Acharya Nagarjuna University, Guntur, Andhra Pradesh, and M.Tech (Power Electronics) from B.M.S College of Engineering, Bangalore, and Karnataka, India in the year 2009 and 2011, respectively. He received Ph.D. from department of EEE, NIT, Tiruchirappalli, Tamil Nadu, India under AICTE-QIP scheme, sponsored by Govt. Of India and B.M.S College of Engineering, Bangalore. Currently he is an Assistant Professor in the Department of Electrical and Electronics Engineering, B.M.S College of Engineering, Bangalore. His areas of interest include Renewable Energy, Micro-grids, Electric vehicles and designing of hybrid energy based Electric vehicle charging stations. He has published and presented more than 20 research papers, and authored one book and two book chapters. He is also a consultant for power quality improvement projects, large scale solar PV power plants design project, Microgrids design projects and Electric vehicles design projects. He is also a recognised reviewer, guest editor and conference chair for several reputed journals and conferences.

A. Rakesh Kumar completed his Bachelors in Engineering with a honors in Electrical and Electronics Engineering from Anna University, Chennai, India in 2011 and Masters in Engineering in Power Electronics and Drives from Anna University, Chennai, India in 2013. He worked as Assistant Professor with the Department of EEE, Rajalakshmi Engineering College, Chennai, India from 2013 to 2015. He then went on to join for a full time PhD with the School of Electrical Engineering (SELECT), Vellore Institute of Technology (VIT) from 2015 to 2019. He was also serving as Teaching cum Research Assistant from 2015 to 2019 with the same. Currently, he is a Post-Doctoral Fellow with the Nano and Micro grid lab, Department of EEE, National Institute of Technology, Tiruchirappalli, India.

D. B. Prakash received M.E. and Ph.D. degrees in Electrical Engineering (Power and Energy Systems) from UVCE and B.M.S. College of Engineering, Bengaluru, Karnataka, India. Presently he is working as Assistant Professor in Department of Electrical and Electronics Engineering, B.M.S. College of Engineering, Bengaluru. He has more than 8 years of experience in teaching. His research interests include AI techniques to Power System, Power System Operation and Control, Renewable Energy and DG placement. He has contributed significantly through several articles in renowned journals and conferences in the area of power systems, which have been cited widely. He is also an active reviewer for several reputed journals and conferences.

S. Arul Daniel completed his B.E. degree programme from the Government College of Technology, Coimbatore, in 1988 and M.E. degree in Power Systems from the Regional Engineering College, Tiruchirappalli in 1991. He pursued his PhD degree in Electrical Engineering at the Regional Engineering College, Tiruchirappalli between 1999 and 2003 & obtained the degree in 2003 from the Bharathidasan University. He is currently a **Professor (Higher Administrative Grade)** in the Department of Electrical and Electronics Engineering at NIT Tiruchirappalli. He has also served as the Head of the Department and Dean (Academic). His research interests include distributed generators, microgrids, and power electronic interfaces for renewable energy systems.