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A diversified Machine Learning based Techno-financial Prediction of a Multi-Energy Hybrid System with the aid of HOMER Simulation Tool.

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Abstract: This research focuses on analyzing grid-dependent hybrid energy systems under various configurations to provide reliable power to an office building in Madurai, Tamil Nadu, India.Analyzing insights into a hybrid energy system design with rooftop solar panels, a diesel generator, battery packs, and a converter is the principal target of the investigation. To observe the optimal design, this research considered both technical and economic variables. In this study, cost of energy and renewable fraction data is collected for the considered commercial building resource components using the Homer tool. The regression model was compared with three evaluation matrices of the prediction models: ridge, polynomial, lasso, and decision tree to verify its performanceconcerning techno-economic factors. The findings of the study demonstrate that the decision tree regression model works better than the other three models, with lower mean square error and root mean square error values and significantly greater R-squared values as well.
Keywords—*Hybrid Energy system, On-grid system, Techno-economic analysis, Machine learning Techniques*

1. Introduction

A large percentage of commercial industries rely largely on coal and oil to give consistent and long-lasting power supplies in many parts of the world.[1] and also have inadequate resources to fulfill the growing global energy needs [2]. It will lead to more dependence on green energy (RES), like sunlight and wind electricity, which lessen the environmental impact of traditional resources [3]. Despite this, using fossil fuels exclusively has several drawbacks, such as their detrimental impacts on the atmosphere and climate, the possibility that fossil fuel sources will run out as a result of excessive use, which may have an impact on wellness and their detrimental impacts on the wellness of people[4] Because the reserves of coal and oil are running out and are becoming expensive to produce, green energies like sunlight and wind are becoming more commonly embraced as alternatives to the energy that is better for the surroundings.[5] Clean energy and independent electrical infrastructures have become attractive options for supplying electricity in several nations.[6] This reduces the usage of existing power supply such as coal and encourages the utilization of green energy sources[7]An established private corporation called Tata Power is making plans to build 10,000 solar-powered tiny electrical grids in India to supply power to five million families nationwide.[8] Intelligent meters can be utilized for establishing building power management, thereby making it possible to predict the usage profile for that particular building.[9] Hybrid Energy Systems operate independent systems, radio networks, satellite ground systems, and small towns.[10]

Furthermore, depending solely on one green source of power may not be practical given the risks and difficulties entailed. To prevent the sporadic nature of a single RES, the HRES enables the combination of multiple environmentally sustainable energy. [11] Diesel generators (DGs) are the go-to choose for autonomous grid use because of their affordable start-up prices. They possess a negative impact on the environment and come with high maintenance and operating costs. Because of this instability, wind and sunshine are unable to provide a steady source of electricity [12]. The present challenge for the technique is to integrate it into a normal network framework without bringing the framework to a breaking point. It also involves ensuring effective source consumption, or "modeling demand," and staying up according to the existing resource platforms' status.[13]. Many studies on hybrid electrical networks, which integrate several sources of environmentally friendly electricity with or without conventional ways to generate electricity, have been conducted throughout the past decade, especially for remote areas [14]. The research findings suggested a nonlinear programming technique to enhance an intelligent microgrid's efficacy by reducing carbon and running expenses while utilizing unconventional resources.[15]. employing sunlight from the sun, wind farms, and battery packs for powering residential buildings and determined that over 50% of the power was produced by green energies [16]. Assessed the grid-connected and autonomous grid HRES's technological, financial, and sensitivity assessments in Tamil Nadu, India. The results of their investigation indicated that the load-following grid-connected scheme would have a minimal net present cost of $7.66 million and an LCOE of $0.127 per kWh.[17]. Investigated the techno-financial evaluation of HRES with daylight and storage bank, wind, and the production of biogas for towns and villages in Vaddeswaram, Andhra Pradesh, India.[18]. Examined the cost-benefit assessment of an HRES with sunlight, battery pack, pump-hydro, distributed generation, and hydroelectric power for a community in Bihar, India.[19]. Examined the economic analysis for a grid-connected rural community in Chamarajanagar, Karnataka, India. According to their analysis, the autonomous infrastructure has a $0.214/kWh cost of energy.[20].

The main aim was to get the most affordable net price and power expense possible. Thus, the HRES functioned better than the DG mechanism alone. [21] Parallel services are supplied for dwellings as well as businesses depend on the estimated NPC and COE to encourage the most affordable sources of power (COE) [22]. In China, a thorough evaluation of the grid-tied rooftop solar panels framework and its power recovery system's technical and financial feasibility was done. The results of the review showed that, in comparison to infrastructure without battery backup, the addition of batteries increased total infrastructure costs while having no appreciable effect on lowering emissions [23]. An Ethiopian grid-tied green power framework's potential was looked into. The results showed that combining a green source of energy into the utility is a wise financial decision as it significantly lowers carbon dioxide emissions[24].

Homer Pro Software

Systems for hybrid renewable energy are designed using a programme called HOMER Pro (HRES).It can be utilized to simulate electrical network configurations that incorporate a variety of traditional and renewable energy types.This programme analyses hybrid renewable energy systems (HRESs) that can be either freestanding or grid-connected, as well as performing optimization and sensitivity evaluations on multiple scenarios in each case study. HOMER has been widely utilized in research to determine the least expensive arrangement of various green power supplies.

2. Novelty and Research Contribution

To provide electricity to a commercial building at POP-FARME Tech Pvt Ltd in Tamil Nadu, India, the research article looks at different combinations of on-grid hybrid renewable energy systems (HRES). It is clear from the prior discussion and the results of a recent study that most researchers have placed a strong emphasis on the techno-economic assessment of HRES. Previous study has shown that only a few investigations have examined the environmental assessment of HRES. Based on the writer's perspective and earlier review, it appears that machine learning techniques have not been frequently used for anticipating HRES performance. The following are the contributions of the current study:

1. Determined the best design with a thorough evaluation of the several configurations, taking into account technological, financial, and environmental factors.
2. Predicted the system's performance, ridge, lasso, decision tree, and Polynomial regression machine learning models were trained using information gathered by HOMER Pro tools.
3. The most effective structure of the system design for forecasting techno-economic indicators has also been revealed by the research

3. System Description

Study Location:

POP-FARME Tech Pvt. Ltd. is the site of the hybrid energy system (HES) investigation, and the location coordinates are 09º55 ¬13.30 N and 78º07.20.60 ʼ E. The company's operations run with maximal power usage of 10kVA during normal working hours, which are 9:00 AM during sunlight and 6:00 PM during dusk**.**

Daily Load Schedule

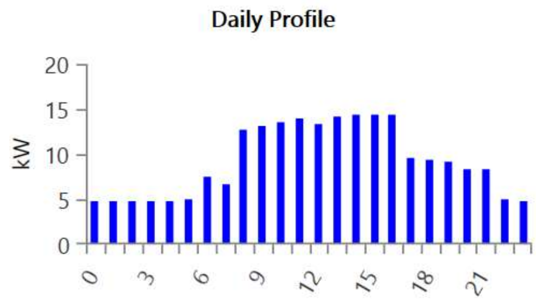

Fig.1 Daily Load Pattern

The POP-FARME Tech Pvt.Ltd test environment runs all year from 09:00 a.m. to 06:00 p.m. as an official building unit. This sequence of operation is visible in the daily profile, as Fig. 3 illustrates. which was acquired by use of the HOMER tool. Next, as shown in Fig. 4, a seasonality graph is created to show that total usage stays largely constant over the year.

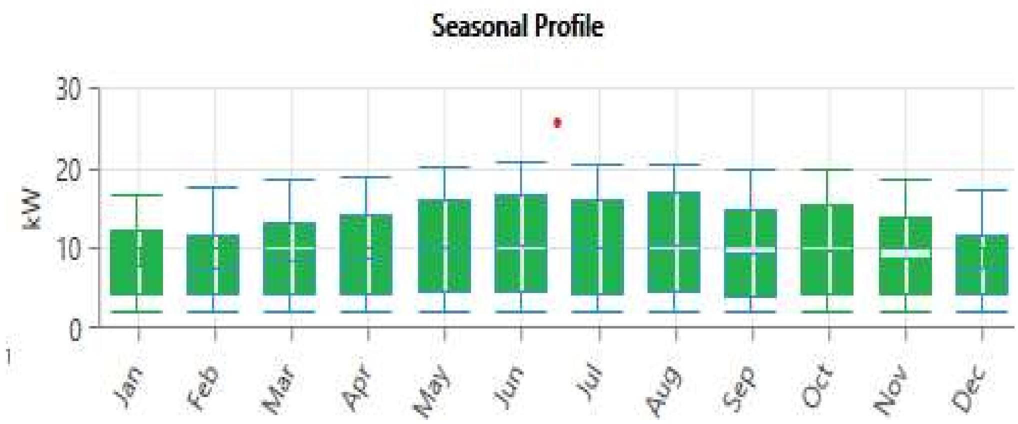

Fig.2.Seasonal Profile over the year

Resource Parameters for a study location

*G*HI data from NREL (National Renewable Energy Laboratory) is a vital asset for comprehending the annual fluctuations in the ambient temperature, radiation from the sun, and clearance index at a particular geographic region. The highest recorded irradiance, measuring 6.550 kWh/m2/day, occurred in March, whereas the lowest, at 4.882 kWh/m2/day, occurred in December.

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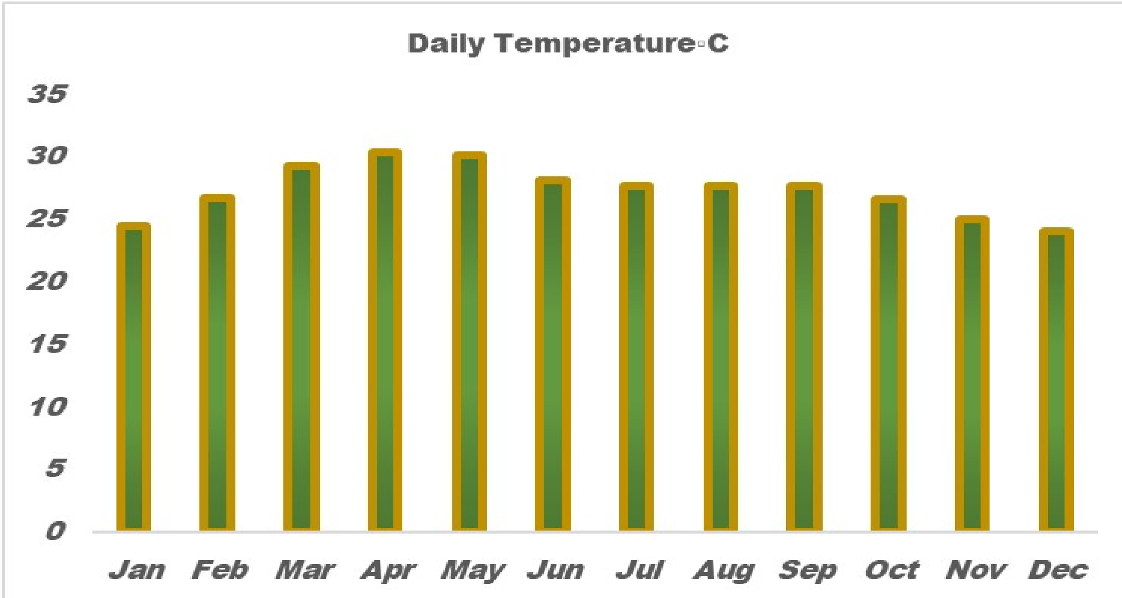

Fig.3. Daily temperature over the year

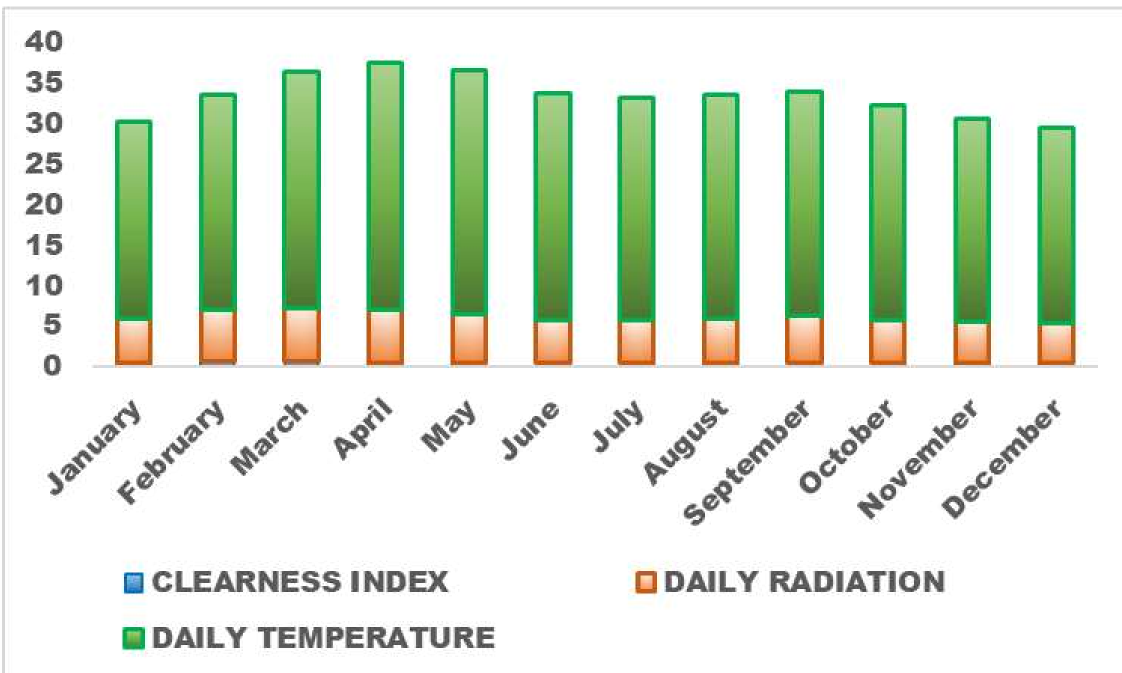

Fig.4.Clearness index and daily radiation over the year

3.4 HES Configuration Setup

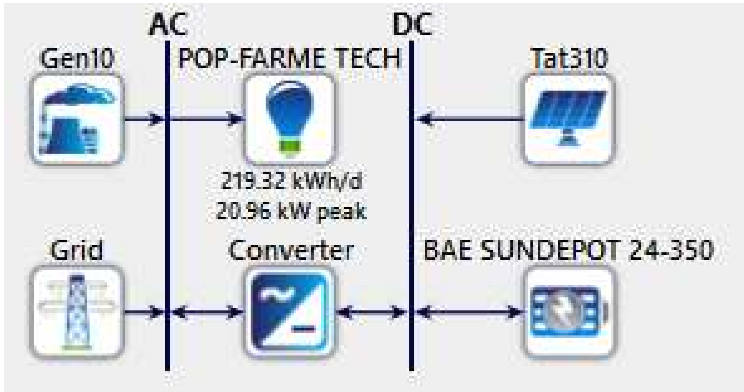

Fig.5.HES Configuration using the HOMER tool

The recommended hybrid energy system (HES) includes converters and loads in addition to photovoltaic (PV) panels, an electricity supply, a diesel generator, and battery packs as supply assets. The system design is techno-environmentally-economic feasibility improved by the use of the Homer software tool. A 10 kVA diesel generator, a 10 kVA utility supply, 3 kW rooftop green energy, and a 7200kWh battery made from lead acid are provided to supply electricity to POP-FARME Tech Pvt. Ltd.'s loads in the suggested configuration. The test system has a 2550-square-foot footprint. Although its solar energy usage has increased significantly, it only has 3kW solar panels, and its functioning depends primarily on power from the electricity grid

System Components

PV Generator

The rooftop photovoltaic system TATA 310 is placed at POP-FARME Tech Pvt.Ltd. It generates 18kW energy and has an optimum efficacy of 13%. Its flat roof panel has an operating temperature of 48.8¹C

Battery Pack

In the hybrid energy storage system, batteries are crucial and unavoidable because they store any excess power that is accessible. The energy storage component of the setup is a battery (BAE SUNDEPOT 24-350)7.85 kWh unit, which has a 95% roundtrip efficiency and can sustain maximal charging and discharging currents of 115A and 574A, respectively.

Converter

In order to connect the AC and DC networks for the required conversions, a common 2kW installed converter is used. It was discovered that this conversion and rectification had a 95% efficiency rate. There has a 15-year lifespan.

Diesel Generator (DG)

There is an installation of the generic 10kVA equipped DG unit. The expenses associated with managing and upholding diesel generators are mostly determined by the expenditure of diesel fuel. So, in the case of the sensitivity assessment, gasoline costs are taken into account.

4. Modelling of the system

The technique used for forecasting both the RF and LCOE of the HES has been trained using machine learning algorithms. The training outcomes of the RF forecasting algorithm using different regression models, like Ridge, Decision tree, Lasso, and Polynomial regression are displayed in Table 6. The evaluation metrics coefficient of determination (R2), root mean square error (RMSE), and mean square error (MSE), are generated to verify the correctness of the designs used for the regression evaluation.

Evaluation metrics for regression:

MSE, RMSE, $R^{2,}$ and so on are typically used by analysts to assess the effectiveness of the regression techniques [42].

MSE

The mean square error (MSE) can be defined as the following statistic used to assess the discrepancy between the expected and true values

$$\mathrm{MSE}=\frac{1}{S}\sum_{i=1}^{S}(f_i-\hat{f}_i)^2 \qquad (1)$$

RMSE

Root Mean Square Error (RMSE) is a widely utilized statistical measure.

$$\mathrm{RMSE}=\sqrt{\frac{1}{S}\sum_{i=1}^{S}(f_i-\hat{f}_i)^2} \qquad (2)$$

R^2

The most crucial metric for confirming the precision of the results anticipated by the regression approaches is the coefficient of determination (R^2).

$$R^2=1-\frac{\sum_{i=1}^{S}(f_i-\hat{f}_i)^2}{\sum_{i=1}^{S}(f_i-\bar{f}_i)^2} \qquad (3)$$

The regression technique with the greatest level of perfection is shown by an R2 = 1

Technical Factors

4. 2.1 Renewable Fraction

The portion of the electrical supply given to the load that came from green energy sources is known as the renewable percentage.

$$f_r = 1 - \frac{\mathcal{E}_{nonren}+ħ_{nonren}}{\mathcal{E}_{served}+ħ_{served}} \qquad (4)$$

Where, $\mathcal{E}_{nonren}$=non-renewable electrical production kWh/yr; $ħ_{nonren}$=non-renewable thermal production kWh/yr; $\mathcal{E}_{served}$=Total electrical load served kWh/yr ; $ħ_{served}$ = Total thermal load served kWh/yr

Economic Factors

4.3.1 COE-Cost of Energy

The COE is estimated as the fraction of annualized generating cost to the total electrical load served.

$$COE = \frac{C_{an,tot}-c_{boiler}H_{served}}{\mathcal{E}_{served}} \qquad (5)$$

Where, COE=Cost of Energy; $C_{an,\,tot}$=Net expenditure over the year; C_{boiler}=Boiler Marginal cost; H_{served}= Net load served from thermal; ε_{served}=Net load served from electrical.

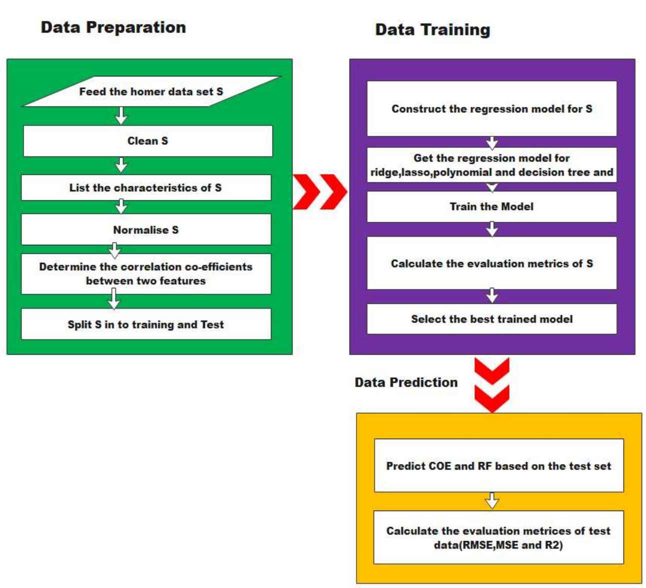

Fig.6. Illustration of data Processing

The data processing unit consists of three divisions such as preparation of data, train the data, and prediction the data. Initially, the primary data set was sorted out by removing any samples that had no values at all (missing values are indicated as 9, 999). Next, it was divided into training data and test data. Finally, it was normalized, examined using its statistics, and divided into data for verification and training. The next step involved building the various regression models like ridge, lasso, polynomial and decision tree, generating RFs and COE concurrently with the development of DT, identifying the key factors utilising the Gini coefficient, training the regression model using training data, and calculating assessment indicators like R2, mean MSE), and RMSE. The method of iterative optimisation was utilized to identify the optimal design.In the final phase, the test information was used to forecast RF and COE using f, and the outcomes were assessed using the three different measures.

5. Outcomes And Discussion

HOMER Simulation Outcome

The techno-enviro-economic outcomes of POP FARME Tech Pvt.Ltd, utilizing the HOMER-PRO software tool, are presented in Tables 1. Both the economics and technical aspects of the prediction process use the LCOE and RF, respectively, to estimate the photovoltaic array ratio and price. The various machine-learning techniques receive the input information from the Homer Pro findings**.**

Table 1 HES Performance Value from Homer Pro tool

Description	Proposed HES
Technical Parameter	**Optimum Outcome**
Solar PV	14
DG	8
Converter	7
Battery	1
Dispatch Strategy	LF
PV array	22,067
Grid purchases	805,116
Total production	897,226
PV capacity factor (%)	18
Renewable fraction (%)	1.10
Total consumption	884,852
Environmental Parameter	**Optimum Outcome**
Carbon dioxide	560,316
Carbon monoxide	350
Unburned hydrocarbons	14.2
Particulate Matter	1.40
Sulphurdioxide	2332
Nitrogenoxides	1107
Economic Parameter	**Optimum Outcome**
Initial cost (₹)	1,874,868
Operating cost (₹//yr)	5,118,935
Total NPC (₹)	68048563
COE (₹/kW)	4.95

Machine Learning Models

This section uses machine learning techniques to develop and analyze the HOMER outcome assessment. It uses a range of components as input factors, such as the size of the battery, converter size, DG size, and photovoltaic panel size. The analysis's primary findings are the system's LCOE and a number of technical and financial variables pertaining to Renewable Fraction (RF). Even this, before utilizing any machine learning technique, It is important to comprehend the features as well as the nature of the information that is provided. Data representation options can help identify the characteristics of the accessible data more easily. This technology is employed to estimate renewable fractions, and its artificial intelligence has been utilized for offering training on the price of electricity of the HRES. The trained results of the random forest algorithm's prediction of the renewable fraction are displayed in Table 2. Evaluation measures like as RMSE are used to validate the projected value's performance. R2 and MSE are computed.

A scatter and a Pearson correlation matrix were used in this investigation; they are presented in Fig. 7 and 8, as well. The data scattering and histogram in Fig. 7 are used to clarify the features of the information. The subsequent connection defines the Pearson product momentum coefficient. In Fig. 7, the Pearson correlation data are color-coded. Fig 8, a statistical indicator of the linear connection among the two parameters is the Pearson product momentum correlation. The values of the Pearson product momentum correlation, also known as the Pearson correlation coefficient, range from + 1 to - 1. A completely positive linear correlation is represented by a number of +1, an entirely negative linear correlation by a number of -1, and a nonlinear correlation by a number of 0.

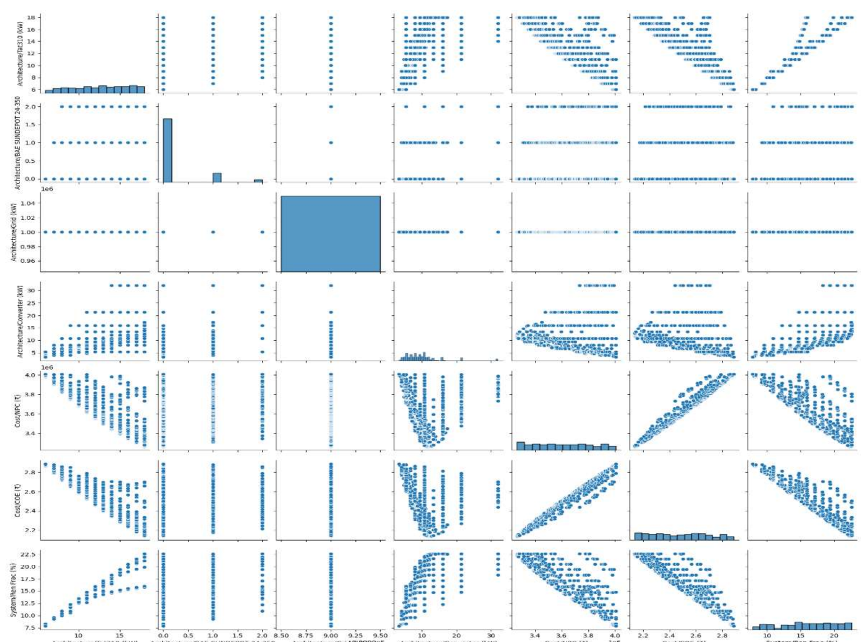

Fig.7 Scatter Matrix Plot

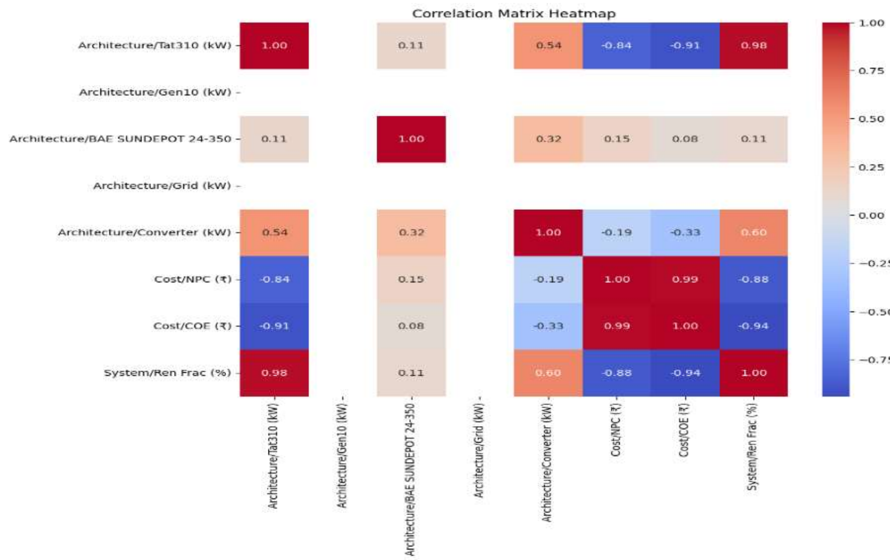

Fig.8.Pearsion Correlation Matrix

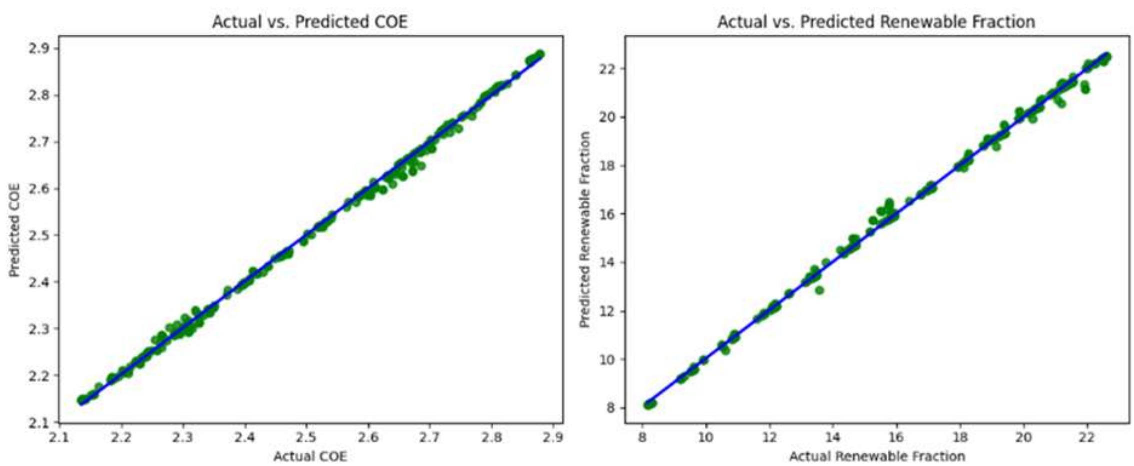

Fig.9. Predicted RF and COE versus the actual RF and COE for using ridge model

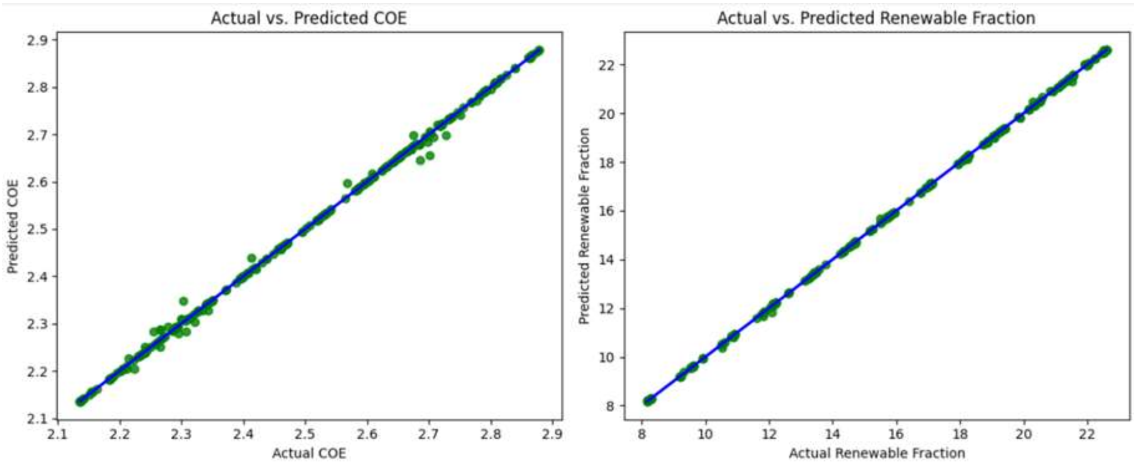

Fig.10. Predicted RF and COE versus the actual RF and COE for using polynomial model

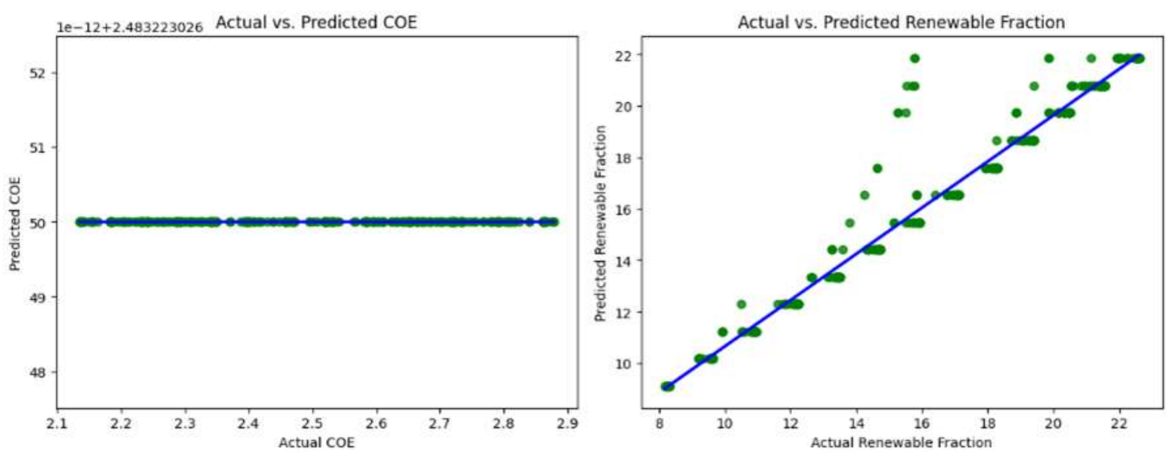

Fig.11. Predicted RF and COE versus the actual RF and COE for using lasso model

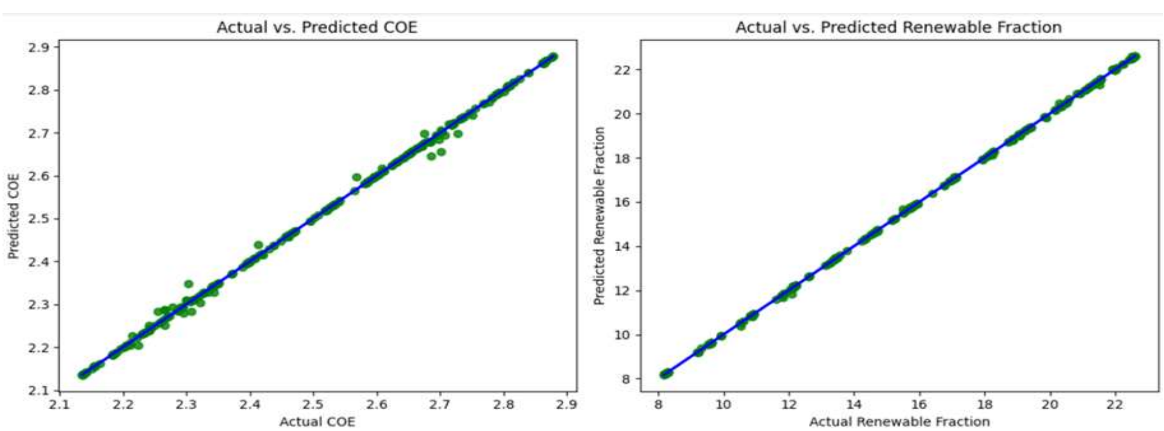

Fig.12. Predicted RF and COE versus the actual RF and COE for using decision tree model

The evaluation results for the HES are displayed in Figs. 9,10,11 and 12, which examine the predicted and actual renewable percentages using four separate training regression algorithms. The analysis demonstrates that there is a good correlation between the data that was generated by HOMER Pro analyses and most machine-learning techniques used for predicting the renewable fraction, it is evident from analysing the RF method that the decision tree regression technique exhibits the highest accuracy of the four models under discussion, obtaining an amazing R2 value of 0.99 and displaying the least values of MSE and RMSE.

The evaluation results for the HES, which employs four distinct regression frameworks for training and evaluates the measured and expected levelized cost of energy, are displayed in Figs 9,10, 11 and 12. The analysis reveals a good correlation between the data generated by HOMER Pro analysis and most machine-learning methods used for LCOE predictions. The decision tree training procedure, specifically, shows the highest accuracy among the four algorithms examined, especially when analyzing the LCOE technique. It achieves an amazing r2 value of 0.90 and has the least rmse and mse values. Therefore, the decision tree regression model is the recommended option for figuring out the system's LCOE.

Table 2 Evaluation of four distinct model performance

Model	Ridge	Polynomial	Lasso	Decision Tree
RMSE	0.103	0.070	0.694	0.02196
MSE	0.01055	0.005	0.482	0.000482
R^2	0.9987	0.99962	0.474	0.9996

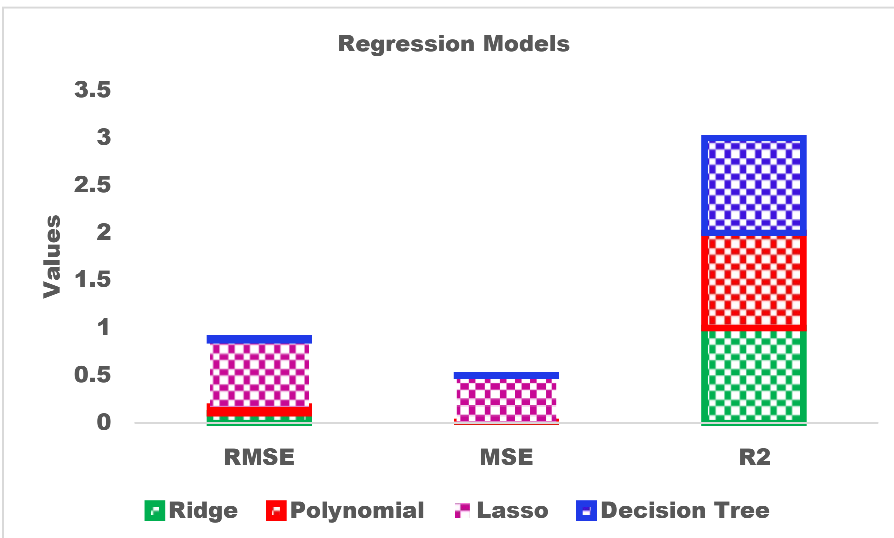

Fig.13. Comparative outcomes for four different regression models

Table 2 and Fig.13 show the comparative results of four different models, which verify that decision tree outperforms than other one, with a higher value of R^2(0.996), lower values of MSE (.0004) and RMSE (0 .02196)

6. Conclusion

The POP-FARME Tech Pvt. Ltd. in Madurai, Tamil Nadu, India, an office complex needs reliable electricity with existing HES. This research looks into different on-grid HES setups to supply it.This investigation optimizes the setup of the hybrid energy structure, which consists of solar energy, battery packs, a diesel generator, and a converter, using HOMER Pro software. For the business establishment, technical and financial assessments are all included in this optimization. Furthermore, four different machine learning models—the ridge. polynomial. lasso and decision tree algorithms were used to predict the system's outcomes using input taken from the HOMER Pro simulation tool.The study demonstrates the extent to which machine learning methods perform in predicting the properties and actions of intricate energy networks.The study's main conclusions are summarised here.

When it comes to the levelized cost of electricity and renewable fraction models, it is evident that, among the four models considered,Compared to other models under consideration, the decision tree regression model performs better.The decision treeregression model demonstrates superior performance, boasting the lowest RMSE of 0.02196 and MSEvalue of 0.000482, along with highest R^2 value of 0.996.

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