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AI Based Solar Energy Forecasting

Vivek Shingne[1], Animesh Tiwari[2], Vinay Yadav[3], Divyesh Surve[4], Dr. Anil Kale[5]

[1,2,3,4]*Student at Mahatma Gandhi Mission's College of Engineering And Technology, Navi Mumbai*
[5]*Associate Professor at Mahatma Gandhi Mission's College of Engineering And Technology, Navi Mumbai*

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Abstract – *Due to increase in demand for electricity and rising depletion of fossil fuels, there is a growing shift towards the renewable sources of energy. Out of which, solar energy is a crucial one. However, its dependency on weather conditions creates challenges in forecasting and efficient usage. Our aim is to build an intelligent system that provides accurate solar energy predictions based on location and helps the user to estimate energy generation, cost savings and environmental impact. In this paper, we propose a system titled "AI Based Solar Energy Forecasting" that will predict solar energy generation using weather-based parameters. The system utilizes a Linear Regression model trained on historical solar and weather data to provide reliable energy forecasts based on location. In addition to this it also offers option to input number of solar panels, panel area, efficiency and local electricity rate to estimate electrical energy output, cost savings and C02 emissions avoided.*

***Key Words*: Solar Energy, Renewable Energy Forecasting, Linear Regression, Machine Learning, CO_2 Emission Reduction.**

1.INTRODUCTION

The increase in the need for clean and sustainable energy is increasing day by day. In such conditions, the solar energy has come out as one of the proper solution to this. Solar energy is renewable, widely available and environmentally friendly. But the production of solar energy relies on the weather factors which makes it difficult to predict it accurately. So the inaccurate forecasts might lead to the energy loss and increased dependency on non-renewable energy. Accurate forecasting will help people plan their energy usages much better and also save money while also contributing to the environment due to reduced carbon footprint. In this project, we focus on building an AI Based Solar Energy Forecasting using machine learning techniques, particularly Linear Regression to predict solar energy based on the weather factors of a location. Also our system allows user to estimate their energy outputs, cost savings and environmental benefit through an easy to use web application.

2. Motivation

In the old one or we can say traditional solar energy generation systems, getting the predictions regarding the solar energy has always been difficult. Most of the conventional methods rely on static data or fixed assumption, who often fail to adapt to the sudden changes in the weather factors like for example, unexpected cloud cover , changes in temperature or dust in the atmosphere. This factors have a direct effect on the potential of the solar panels, which might lead to fluctuations in the energy generation that are very hard to predict with the old models.

Further many of these approaches were strongly dependent on manual feature selection and static formulas which made them less flexible when applied across different locations. This challenges gave rise to the need for more dynamic system providing consistent and reliable forecasts, regardless of location, time or year.

1. By taking these limitations into consideration, we thoroughly explored the machine learning techniques and developed a Linear Regression based model for solar energy prediction. Our approach removes the need for difficult manual computations by automatically learning meaningful patterns from the environmental data like temperature, cloud cover and solar irradiation.

2. Inspired by modern data driven methods we trained and fine-tuned our model using historical weather and solar generation datasets that allows it to adapt to the varying conditions and give more accurate predictions as compared to the standard rule based forecasting techniques.

3. When compared with the conventional solar forecasting systems, this framework achieves an effective balance between the prediction accuracy and computational simplicity which makes it highly suitable for both residential and small scale commercial use. In addition to that, our system not only provides forecasts but also gives insight into potential cost savings and environmental impact (through CO2 emissions reductions) which makes it a practical application in the field of smart energy management.

3. Literature Survey

As we previously discussed traditional solar energy forecasting methods/techniques strongly depend upon the statistical models and weather based simulations, which were focusing upon historical datasets of temperature, sunlight hours and other related factors. While these methods provide a reasonable accuracy in stable weather conditions but they often fail to adapt to sudden changes like temperatures shifts etc. These limitations create a reduction in their effectiveness in real world situations where weather is constantly unpredictable. And also the earlier systems depended on the manual features and static formula and they struggled when applied to different geographical locations resulting in the outdated predictions. To overcome this our project uses a real time weather data fetching using the API that keeps our model updated with the latest environmental factors.

4. Existing System

Solar energy forecasting systems are crucial for efficient planning and utilization of solar power across residential, commercial and industrial environments. There are different existing systems that predict solar energy production using different methods and technologies. Here's a quick recap:

Manual calculation methods: Traditionally, solar energy potential is calculated manually using mathematical models using the solar angles, historical weather data and geographical parameters. This methods are time-consuming.

Static PV simulation tools: Software tools like PVWatts make use of historical weather data and fixed assumptions to get solar power output. Even though this tools are useful they lack real time adaptability.

Weather-based forecast models: These systems depend on generalized weather forecasts from meteorological services to estimate solar generation.

IOT Based Solar Monitoring Systems: This make use of IOT sensors placed on solar panels for collecting real time data about panel performance and environmental conditions. But they are more focused about precise monitoring rather than precise future energy forecasting.

Satellite-image based models: This forecasting system uses satellite imagery to monitor cloud movements and solar irradiance. This system offers improved prediction capabilities.

AI and Machine Learning models: Now emerging systems are adopting AI and ML techniques to improve the accuracy of the prediction by learning patterns from historical and real time data. However most of these system are still under research and may not be accessible to the end users.

Overall while there are many existing system for solar energy forecasting many either lack real time adaptability or they might require complex infrastructure or may not provide user friendly outputs for everyday consumers.

5. Proposed System

The proposed system aims to a more advanced and an efficient solar energy forecasting solution by integrating artificial intelligence and real time environment data using API-based collection. The system will automatically fetch weather factors like temperature, cloud cover, solar irradiation and process this data using machine learning algorithms to generate accurate solar energy forecasts. This forecasts will help users calculate the solar energy potential for their specific location, taking into account the daily and seasonal variations. In addition to this the system will also be including a smart calculation section that will allow the end users to input the details such as number of solar panels, panel area, and efficiency and electricity costs. On the basis of this inputs, the system will calculate expected electrical output, cost savings and carbon emissions avoided. Further the platform will feature an interactive user friendly web interface with real time graphical visualization of the forecasted data that will help in enhancing the usability for the end users. Remote accessibility will enable users to monitor solar energy potential anytime thus helping in proper planning and decision making. The system is designed such that it will be scalable, adaptable and compliant with modern energy efficiency standards. Overall the proposed system aims to promote the sustainable energy usage by providing accurate real time solar forecasts and delivering insights regarding environmental benefits and energy savings to the users. Since the last decade, the solar energy forecasting techniques have largely relied on static models or difficult empirical formulas that depend heavily upon historical averages and generalized assumptions these conventional methods often fail to capture the dynamic nature of weather patterns and local environmental conditions, which might lead to inaccurate energy predictions and inefficient energy planning. Manual data collection and lack of real time adaptability further restrict the practical applications.

To overcome these limitations, we aimed our research on integrating machine learning models with real time weather data API's thus enabling dynamic and location specific forecasting. By using advance regression techniques and continuously updated environmental updates, our system significantly improves the accuracy of solar energy predictions. This approach empowers end users to make the data driven decisions, optimizing solar panel usage and maximizing the energy while maintaining a user friendly web interface for easy accessibility.

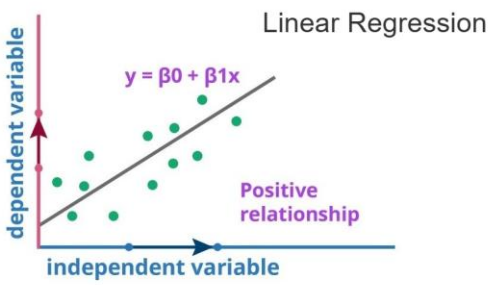

Fig 1: A typical Linear Regression model

Since Linear Regression is a supervised machine learning algorithm that basically maps the linear relationships between independent and dependent variables. It predicts the value of the dependent variable by getting the best fit straight line through the data points, which is given by the equation **: Y=mx+c.** This approach has been used for forecasting like sales forecasting (by businesses), weather prediction(by meteorology departments), stock market analysis(by financial analysts) etc. The goal of this approach is to reduce the prediction errors by adjusting the coefficient (m) and intercept(c) during training.

The Linear Regression approach goes with four steps as follows:

1) Data Collection: Collect the input data and the output.

2) Training: This phase helps identify the relationship between the variables.

3) Prediction: Using derived equation , it predicts outputs for new inputs.

4) Accuracy : The accuracy is tested using evaluation metrics like MSE(Mean Squared Error) and R^2score.

We selected Linear Regression as the core algorithm of our project due to its simplicity, efficiency and strong ability to model the relationship that present between the weather factors and solar energy output. Since the solar energy generation is directly affected by the various continuous numerical factors like sunlight hours, cloud cover, humidity, solar irradiation etc so Linear Regression suits this project idea.

It allows us to understand and quantify how every weather factor impact the solar energy production. Moreover Linear Regression models are computationally lightweight, enabling fast real time which is required for providing quick feedback to users. As a baseline algorithm it gives us a reliable starting point for forecasting, and its results can be easily interpreted which makes it user friendly for both technical and non-technical audiences. Also it allows for the system to be accessible, scalable and easy to maintain that can be later improved by integrating more complex models.

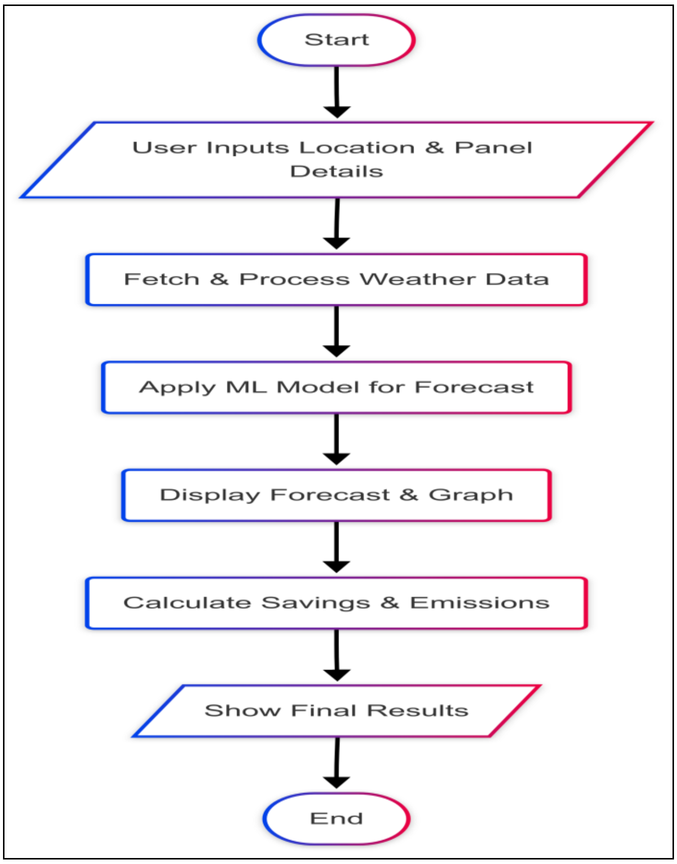

Fig 2: Solar Forecasting System

The system fetches real time and historical weather data using an API. The parameters include temperature, cloud cover, humidity, wind speed, solar irradiation etc. Then the Linear Regression model is trained using historical weather data using historical weather data combined with actual solar energy output. The model learns the relationship between the input features(weather factors) and output solar energy generation in kWh. Whenever a user enters their location (take a city name example: Surat) our system automatically fetches the updated weather conditions using API. Then the trained model (Linear Regression) uses this inputs to predict expected solar energy output for the location. The predicted solar output feeds into our calculation module. Based on the user inputs (number of panels, panel area, efficiency, electricity cost) the system further calculates a) an estimate of electrical energy consumption b) the potential cost savings c) the carbon emissions avoided. The final output is visualized using interactive charts and tables on our web application. Users can see daily predictions, helping them take better energy planning decisions.

As the system collects more data over time, the Linear Regression model can be retrained periodically over time to improve accuracy.

6. Methodology

The following steps describe the methodology that was used for the model development and evaluation.

a) Data Collection and Pre-Processing: First we obtained historical weather data containing features such as solar radiation, UV index, temperature, wind speed and more. Data cleaning was done to select target values and then features and target variables were carefully selected that focused on strong correlation to solar energy output.

b) Correlation Analysis: To understand the influence of different factors on solar energy generation, we conducted a correlation analysis. The results returned that solar radiation and uv index had highest correlation with solar energy.

Feature	Correlation Coefficient
Solar Radiation	0.9998
UV Index	0.9442
Visibility	0.5216
Temp Max	0.4499
Temperature	0.3718
Feels Like	0.2906
Feels Like Max	0.2771
Feels Like Min	0.2624
Sea Level Pressure	0.2044
Temp Min	0.1939
Severe Risk	0.172
Wind Direction	0.1623
Moon Phase	0.0063
Wind Speed	-0.0496
Dew Point	-0.0766
Wind Gust	-0.0985
Humidity	-0.2964
Precipitation Probability	-0.4027
Cloud Cover	-0.4031
Precipitation	-0.5214
Precipitation Cover	-0.545

Fig 3: Correlation Analysis

c) Model Selection And Training: We experimented with three algorithms (Linear Regression, Random Forest, Gradient Boosting). We split the dataset into 80:20 with a random state of 42. We trained and evaluated the performance of these models using metrics like MAE, R^2score and RMSE.

Model	MAE	RMSE	R^2score
Linear Regression	0.085	0.105	0.995
Random Forest	0.097	0.131	0.999
Gradient Boosting	0.099	0.123	0.997

Fig 4: Model Performance Analysis

d) Model Selection

After proper analysis, Linear Regression turned out to be the best performing model with:

MAE: 0.085

RMSE: 0.105

R^2score: 0.999

Given strong linear correlation among features and target variable, Linear Regression provided the most efficient and interpretable solution.

7. Result

We built an interactive web application using Flask, fully integrated with the trained model. The web application allows users to:

- Enter location (city name) for forecasting.
- Optionally provide panel-specific details (number of panels, area, efficiency, and cost).
- View detailed outputs including solar energy forecast, expected electrical output, cost savings, and carbon emission reduction.

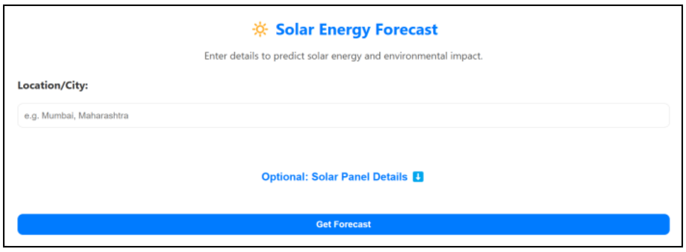

Fig 7.1: User Interface I

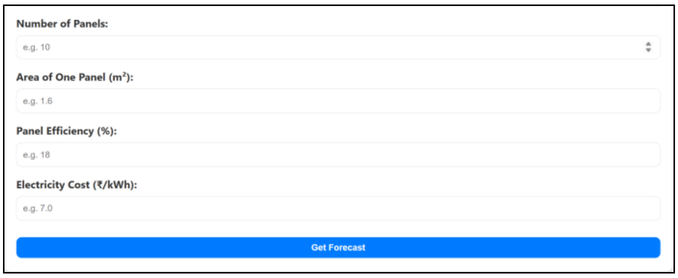

Fig 7.2: User Interface II

The user can enter the inputs to receive personalized solar energy recommendations.

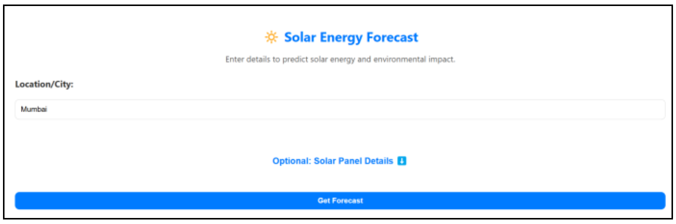

Fig 7.3: Input Section I

Fig 7.4: Input Section II

Date	Solar Energy (MJ/m²)
09-04-2025	25.62
10-04-2025	25.15
11-04-2025	25.43
12-04-2025	25.52
13-04-2025	25.54
14-04-2025	28.23
15-04-2025	25.14
16-04-2025	24.73
17-04-2025	24.48
18-04-2025	24.47
19-04-2025	19.53
20-04-2025	24.65
21-04-2025	24.72
22-04-2025	24.63
23-04-2025	25.03

Fig 7.5: Solar energy output

Date	Solar Energy (MJ/m²)	Energy (kWh)	Savings (₹)	CO_2 Avoided (kg)
09-04-2025	25.62	20.5	143.5	18.86
10-04-2025	25.15	20.12	140.84	18.51
11-04-2025	25.43	20.35	142.43	18.72
12-04-2025	25.52	20.42	142.94	18.79
13-04-2025	25.54	20.43	143.0	18.79
14-04-2025	28.23	22.58	158.07	20.77
15-04-2025	25.14	20.11	140.76	18.5
16-04-2025	24.73	19.78	138.47	18.2
17-04-2025	24.48	19.58	137.09	18.02
18-04-2025	24.47	19.58	137.03	18.01
19-04-2025	19.53	15.62	109.37	14.37
20-04-2025	24.65	19.72	138.01	18.14
21-04-2025	24.72	19.77	138.42	18.19
22-04-2025	24.63	19.7	137.91	18.12
23-04-2025	25.03	20.02	140.15	18.42

Fig 7.6: Energy, savings and CO2 avoided.

8. Conclusion

The AI Based Solar Energy Forecasting effectively shows the integration of machine learning with user-friendly web application to predict/forecast solar energy generation with high accuracy. After exploring and testing multiple algorithm

Linear Regression was found to be most appropriate.

The project focuses on technical performance but also keeping usability in mind. Using the web app, user can enter inputs and get clear and proper insights about solar energy generation, cost savings and carbon emission reductions. This makes it easy for households and small energy to consider solar energy adoptions. Also the modular design of this system ensures scalability and future enhancements, making it a solid foundation for a real world deployment. Overall, this project successfully aligns with academic objectives, showing academic objectives, relevance to social cause, practical implementation.

9. Future Scope

a) Geo-Location Auto Detection: Implement the automatic location fetching to improve the user experience and reduce manual input errors.

b) Push Notifications and Alerts: Allows the users to subscribe for regular updates on solar energy potential through email or SMS.

c) Mobile App: Build a platform independent mobile app to increase access and making it more convenient to use.

d) Energy Storage Recommendations: Provide battery storage on basis of extra energy.

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