ANALYSIS OF SOLAR ENERGY SUITABILITY IN INDIA AND IOT-ENHANCED SOLAR TRACKING SYSTEMS (SUN TRACKER)

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Introduction

The increasing global demand for renewable energy has driven interest in optimizing solar energy deployment, particularly in regions with variable sunlight exposure. Solar energy presents a sustainable solution, but its efficacy heavily depends on precise site selection and efficient system monitoring. Many solar panel systems underperform due to suboptimal positioning or lack of real-time operational feedback. This project focuses on a dual approach: geospatial analysis for solar suitability mapping, and an IoT-driven monitoring system for performance tracking. Using sensors like LDRs and microcontrollers like ESP32, this project aims to bridge the gap between theoretical solar potential and actual output by providing both data-driven site analysis and live system monitoring. This holistic solution not only improves deployment strategies but also promotes intelligent maintenance and fault detection.

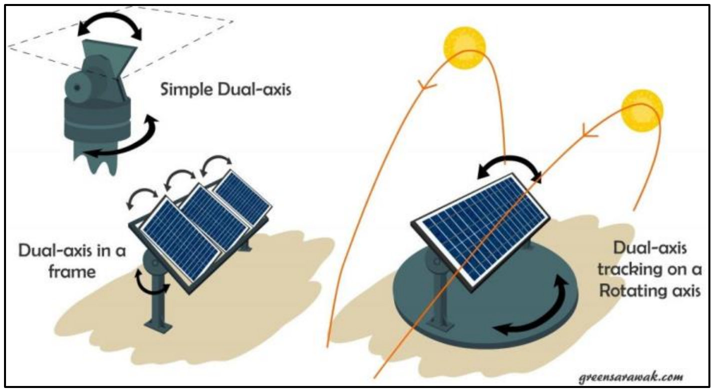

Figure 1 Sun Tracking For Solar panels

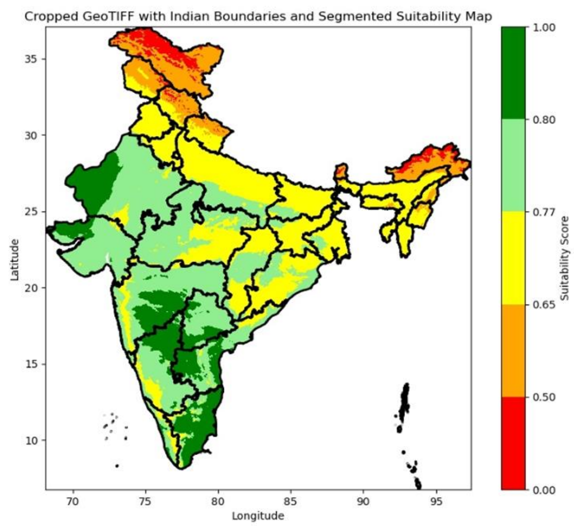

Figure 2 Cropped GeoTIFF with Indian Boundaries

Objectives:

1. To identify optimal locations for solar panel deployment using solar irradiation data.
2. To design a cost-effective and efficient sun tracking system using readily available components.
3. To implement real-time monitoring and control through an ESP32 microcontroller integrated with Bluetooth technology.
4. To maximize solar energy capture by continuously aligning the solar panel with the sun.

5. To utilize LDR sensors to provide accurate feedback for optimal panel orientation.
6. To create a user-friendly interface for monitoring system performance and making manual adjustments if necessary.
7. To enhance solar energy efficiency through intelligent data collection and visualization.
8. To demonstrate a working prototype that integrates mapping and monitoring.

Methodology:

The project is divided into two integrated components: mapping and monitoring. For the **mapping component**, publicly available GIS datasets such as solar irradiance maps, slope, aspect, and land cover data are analyzed using tools like QGIS. Suitable regions are identified through weighted overlay analysis and classified based on solar potential.

For the **monitoring system**, hardware including ESP32 microcontrollers, LDRs, and servo motors are used. LDR sensors are placed in multiple directions to measure sunlight intensity. Based on this input, servo motors dynamically adjust the solar panel's angle to achieve maximum light exposure. The system is powered via a small solar setup and transmits data wirelessly using the ESP32's Wi-Fi capabilities.

Data is visualized using a Bluetooth-based mobile interface or web dashboard that displays real-time readings such as light intensity, orientation status, and panel performance. Code is written in Arduino IDE, and the system is designed for low energy consumption.

Multiple iterations of the hardware model are tested to validate functionality under varying light conditions. Testing includes controlled indoor setups and limited outdoor deployments.

Results & Conclusions:

Testing revealed that the dynamic panel adjustment system increased average light capture by approximately 22% compared to static setups. The real-time data logging and monitoring interface allowed quick identification of performance drops due to shading or misalignment. The solar suitability map produced via GIS tools correctly identified optimal rooftop zones on the college campus, matching practical installation insights. Integration of both modules demonstrated the advantage of combining analytical planning with smart monitoring. The IoT framework functioned efficiently, offering reliable connectivity and low-latency updates. Overall, the system improved both planning precision and operational efficiency, marking a step forward in intelligent solar energy management.

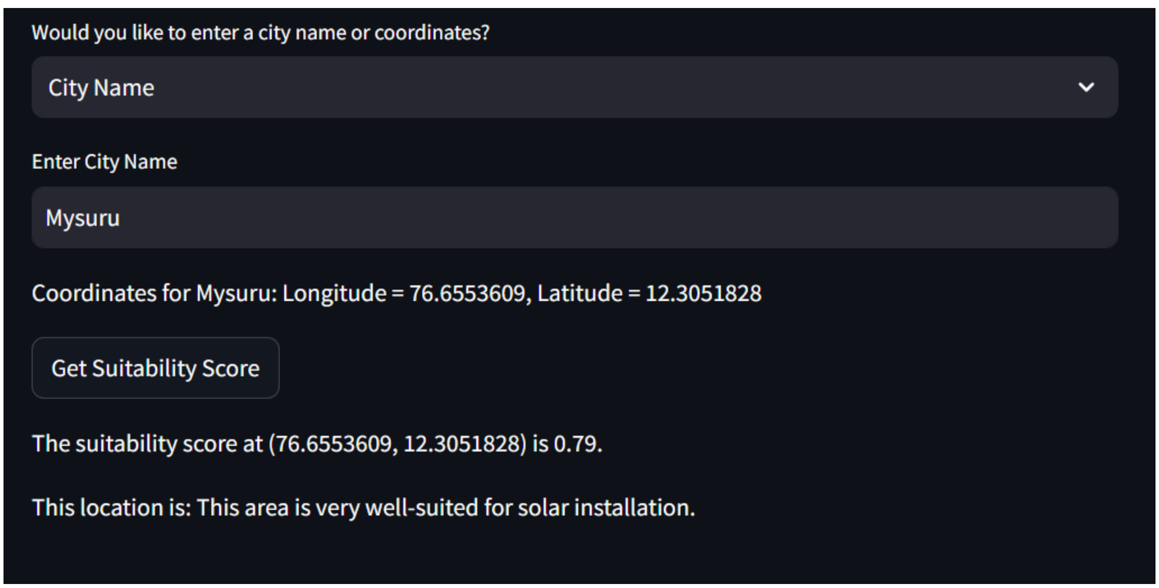

Figure 3 Web-Based Suitability Assessment Tool

Project Outcome & Industry Relevance:

This project offers an end-to-end framework for solar energy deployment that can serve both institutional and commercial sectors. By combining GIS-based site planning and IoT-based real-time monitoring, the system improves decision-making and operational sustainability. Potential industry applications include smart city infrastructure, residential solar services, and industrial-scale solar farms. The ability to dynamically optimize energy capture and detect inefficiencies offers both economic and environmental benefits. The project also showcases scalable, low-cost design ideal for developing regions or budget-conscious implementations.

Working Model:

Working Model – A functional prototype has been developed using ESP32, LDR sensors, and servos. It operates under real-world conditions to monitor light intensity and panel position in real time. GIS analysis was also performed for solar mapping, making the project both study and hardware-based.

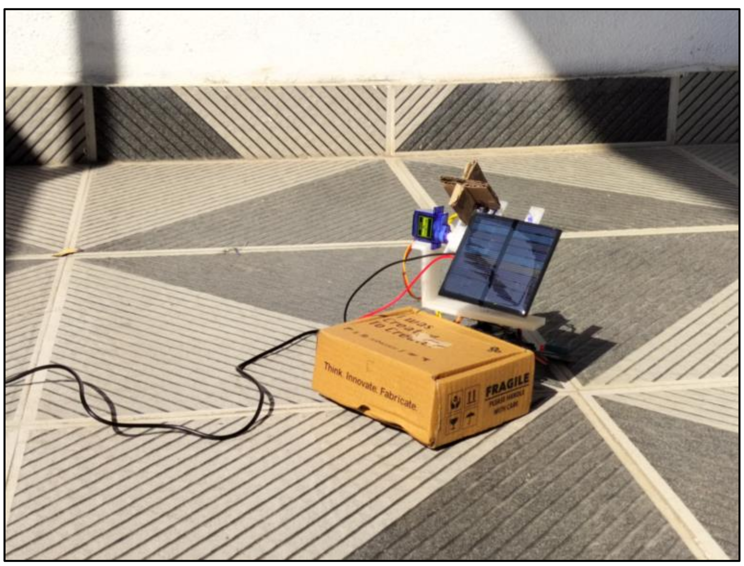

Figure 4 Sun Tracker

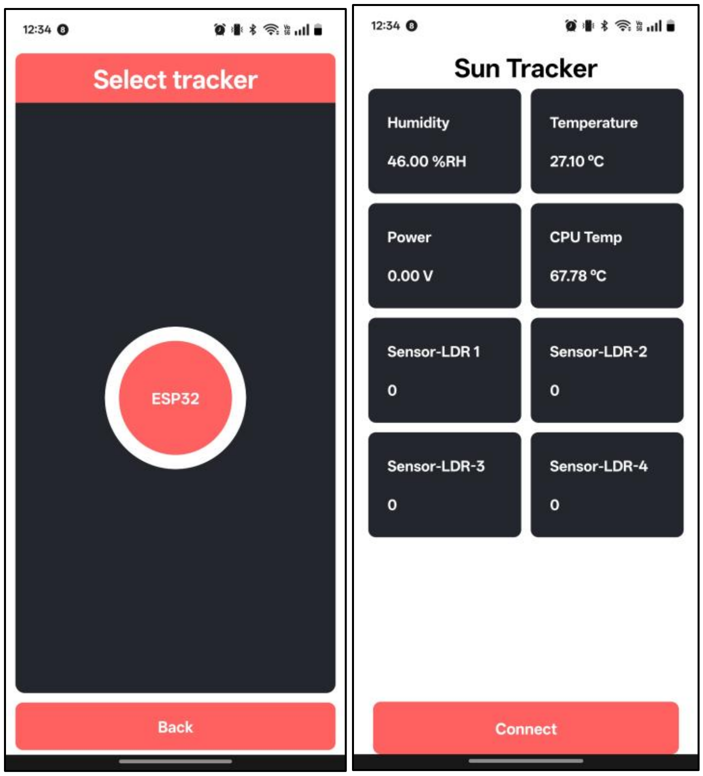

Figure 5 Sun Tracker Monitoring Mobile App

Project Outcomes and Learnings

1. Practical experience was gained in designing embedded systems and integrating sensor technologies.
2. The project provided hands-on learning in calibrating and implementing servo motor controls based on analog sensor data.
3. Skills in designing a user interface for remote monitoring via Bluetooth were developed.
4. An iterative design approach led to improvements in both the hardware configuration and software algorithms.
5. The limitations of static solar panels were effectively addressed through the dynamic tracking solution.

Future Scope:

Future improvements may include implementing ML models to predict sunlight availability using historical weather data. Expansion of the monitoring module can involve temperature and voltage sensors for full system diagnostics. Cloud-based dashboards and mobile app integration can enhance user accessibility. For large-scale applications, the model can be adapted to control entire solar farms with automatic fault reporting. Additional layers in the GIS analysis like proximity to grid connections or legal constraints could refine mapping accuracy. Integration with government solar missions and incentives could help in real-world deployment and partnerships. The project can also evolve to include predictive maintenance alerts and automation using edge AI.

Future enhancements may include:

1. Developing an IoT-enabled remote monitoring dashboard using Wi-Fi for real-time data analytics and system management.
2. Integrating AI-based adjustments to further optimize the panel's alignment under varying environmental conditions.
3. Expanding the system to incorporate additional sensors for temperature, humidity, and power output monitoring.
4. Utilizing alternative or composite materials for improved durability and weather resistance in outdoor deployments.
5. Exploring modular designs that can accommodate multiple panels and integrate with broader smart grid systems.
6. Investigating dual-axis tracking mechanisms with higher precision and faster response times.