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AI-Based Rooftop Solar Energy Potential Mapping

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ABSTRACT: The rapid growth of urbanization and increasing energy demand have intensified the need for sustainable and renewable energy solutions. Rooftop solar energy presents a viable option; however, identifying suitable rooftops and estimating solar potential remains a complex task. Existing methods rely heavily on manual surveys, basic GIS tools, or limited automation, making the process time-consuming, costly, and less accessible to small-scale users. Additionally, analyzing multiple factors such as rooftop area, orientation, sunlight availability, and shadow effects requires technical expertise, creating challenges in effective decision-making.

This project introduces an AI-Based Rooftop Solar Energy Potential mapping system designed to automate rooftop detection and solar energy estimation using satellite imagery and geospatial data. The system integrates deep learning techniques, image segmentation models, and GIS-based analysis to provide accurate and context-aware insights. It evaluates key parameters influencing solar potential and generates structured outputs along with visual maps for easy interpretation. By incorporating an interactive interface for location selection and analysis, the system enhances usability and reduces manual effort. This solution improves efficiency in urban energy planning and supports the adoption of renewable energy, contributing to sustainable development and smarter resource utilization.

I. INTRODUCTION

The rapid expansion of urban areas and increasing energy consumption have significantly raised the demand for sustainable and renewable energy solutions. Rooftop solar energy has emerged as a promising alternative, offering the potential to generate clean electricity within urban environments. However, identifying suitable rooftops and analyzing their solar energy potential remains a challenging task. Data related to buildings, satellite imagery, and environmental conditions are often complex and require advanced tools for accurate interpretation. Manual assessment methods are time-consuming, costly, and not scalable for large urban regions.

With advancements in Artificial Intelligence, Deep Learning, and Geospatial Technologies, it is now possible to automate rooftop detection and solar potential analysis efficiently. The proposed AI-Based Rooftop Solar Energy Potential Mapping system leverages satellite imagery, Digital Surface Models (DSM), and image segmentation techniques to identify rooftops and evaluate their suitability for solar panel installation. By integrating GIS analysis, shadow detection, and solar estimation models, the system provides accurate and visual insights. This approach enables users such as urban planners and building owners to quickly assess solar potential and make informed decisions with minimal effort.

II. LITERATURE SURVEY

[1] City-Scale Rooftop Solar Potential Using Deep Learning (2021)

Researchers proposed a deep learning-based approach using Convolutional Neural Networks (CNNs) to detect rooftops from satellite imagery and estimate solar photovoltaic potential at a city scale. The study demonstrated improved accuracy and scalability compared to traditional methods.

Limitation: Requires high computational resources and large annotated datasets for effective training.

[2] Deep Learning Framework for Solar Potential Estimation (2024)

This research focused on integrating deep learning models with high-resolution satellite imagery to enhance rooftop detection and solar potential estimation. It considered multiple environmental factors to improve prediction accuracy.

Limitation: Limited real-time implementation and dependency on high-quality image datasets.

[3] Solar PV Estimation Using DSM and Satellite Images (2023)

Researchers utilized Digital Surface Models (DSM) along with satellite imagery to estimate rooftop solar potential, considering elevation and shadow effects. This approach improved accuracy in dense urban environments. Limitation: Requires availability of high-resolution DSM data, which may not be accessible for all regions.

[4] Voice-Enabled Intelligent Systems Using Speech Recognition (2022)

This study explored the use of Geographic Information Systems (GIS) and remote sensing techniques for rooftop solar potential mapping. It enabled spatial analysis and visualization of solar resources. Limitation: Lacks automation and relies heavily on manual processing and rule-based methods.

III. METHODOLOGY

3.1 Requirement Analysis

System analysis is the process of studying and understanding the project objectives, user requirements, and technical constraints to design an efficient and practical solution.

The proposed system — AI-Based Rooftop Solar Energy Potential Mapping — aims to assist urban planners, government authorities, and building owners by providing an automated platform to identify suitable rooftops and estimate solar energy potential. The system uses Artificial Intelligence, Deep Learning, and geospatial technologies to analyze satellite imagery and spatial data. It enables users to evaluate rooftop suitability based on area, orientation, and shadow effects, and obtain meaningful insights easily.

3.2 System Design

System design defines the architecture, components, data flow, and interactions between different modules of the system. The design aims to transform functional requirements into a structured framework that guides system development.

For this project, the system integrates image preprocessing, deep learning-based rooftop detection, and a user-friendly interface. It allows users to select locations, process satellite images, and receive insights through visual maps and reports. The design ensures smooth interaction between input data, processing modules, analysis, and output visualization components.

3.3 Development Tools and Technologies

The system's interface is implemented using Streamlit or web-based frameworks, which enable seamless interaction between users and backend processing modules. Python libraries such as NumPy and Pandas are used for data preprocessing and handling spatial datasets efficiently.

Artificial Intelligence functionalities are powered by deep learning models and image segmentation techniques, enabling accurate rooftop detection and analysis. Geospatial tools like GeoPandas and Rasterio are used for spatial data processing, while visualization libraries such as Matplotlib and Plotly generate interactive outputs.

3.4 Implementation

The implementation phase involves translating the system design into a functional application by integrating all modules. It includes satellite image collection, preprocessing, rooftop detection, and solar potential estimation.

The system is implemented using a modular approach where users can select locations, process data, and receive results in real time. The AI module identifies rooftops and evaluates solar potential, while the visualization module presents the results in graphical and map formats. The overall system ensures a smooth workflow from data input to result generation.

3.5 Testing and Deployment

Software testing is an essential stage in the system development life cycle (SDLC) to ensure that the application functions correctly and produces reliable outputs. In this project, testing is performed to validate rooftop detection accuracy, solar estimation correctness, and system performance.

Testing focuses on validating input data, ensuring proper handling of satellite images, and verifying the accuracy of

generated outputs and visualizations. The user interface is tested for usability and responsiveness to ensure a smooth experience. The deployment phase involves making the system accessible through web or cloud platforms, allowing users to analyze locations and obtain solar insights efficiently. The deployment ensures scalability, reliability, and ease of access for real-world applications.

3.6 SYSTEM ARCHITECTURE

The system architecture defines the overall structure and workflow of the AI-Based Rooftop Solar Energy Potential Mapping System, illustrating how different components interact to process spatial data and generate accurate solar insights. It ensures a smooth flow of data from input to output while maintaining modularity, scalability, and efficiency. The architecture begins with the data acquisition layer, where users provide input in the form of location selection or satellite imagery obtained from geospatial sources. This input is then processed through specialized modules including image preprocessing for noise reduction, enhancement techniques for improving image quality, and spatial data handling tools that organize and structure the data into meaningful formats. The segmentation module converts processed imagery into rooftop regions, which are stored for further analysis and efficient retrieval.

Figure -1: Architecture of the System

The core of the system is the analysis engine, which follows a multi-stage workflow consisting of rooftop detection, feature extraction, solar potential estimation, and result generation. It intelligently processes satellite images, identifies rooftop structures using deep learning models, and evaluates key parameters such as area, orientation, and shadow impact. Supporting components such as the geospatial analysis module compute solar irradiation and energy potential, while the visualization module generates interactive maps and graphical outputs. The system also incorporates data storage for maintaining processed results and ensures smooth interaction between modules. Finally, the analyzed insights are delivered through an intuitive interface, enabling users to easily understand rooftop suitability and make informed decisions for solar energy adoption.

IV. EXISTING SYSTEM

The existing rooftop solar potential assessment process is largely manual and relies on traditional methods such as field surveys and basic GIS tools. Urban planners and analysts typically depend on predefined maps and limited spatial analysis techniques to evaluate rooftop suitability.

However, these methods are time-consuming, require technical expertise, and often fail to provide accurate and scalable results. They also lack the ability to efficiently process large volumes of satellite imagery and do not support automated analysis of factors such as shadow effects and rooftop orientation. As a result, solar potential estimation becomes inefficient, delayed, and less effective in identifying suitable locations for solar panel installation.

V. PROPOSED SYSTEM

The proposed system introduces an AI-powered Rooftop Solar Energy Potential Mapping solution that leverages deep learning and geospatial analysis techniques to provide accurate insights from satellite imagery. Unlike traditional assessment methods, this system supports large-scale data processing using high-resolution satellite images and spatial datasets, enabling comprehensive rooftop analysis.

The core of the system is an intelligent analysis engine that follows a structured workflow consisting of image preprocessing, rooftop detection, feature extraction, solar potential estimation, and result generation. It utilizes deep learning models and geospatial computations to identify rooftops and evaluate parameters such as area, orientation, and shadow impact. Users can interact with the system through a web-based interface by selecting locations and viewing results visually. The system provides detailed outputs such as solar potential maps, rooftop suitability analysis, and energy estimation, making it an efficient and user-friendly solution for sustainable energy planning and decision-making.

VI. RESULT

The implemented AI-Based Rooftop Solar Energy Potential Mapping system successfully analyzes satellite imagery and provides accurate insights on rooftop suitability and solar energy potential. The system effectively processes spatial data and identifies rooftops using deep learning techniques, delivering reliable results for various urban environments. It demonstrates consistent performance in detecting rooftop areas, evaluating orientation, and estimating solar energy generation potential.

The web-based interface enables real-time interaction, allowing users to select locations and instantly view solar potential results through visual maps and outputs. Sample use cases show that the system can efficiently identify suitable rooftops, estimate energy generation, and highlight areas with high solar potential. Overall, the results indicate that the system significantly improves the efficiency of solar assessment, reduces manual effort, and enhances decision-making for adopting renewable energy solutions.

AI-Based Rooftop Solar Energy Potential Mapping

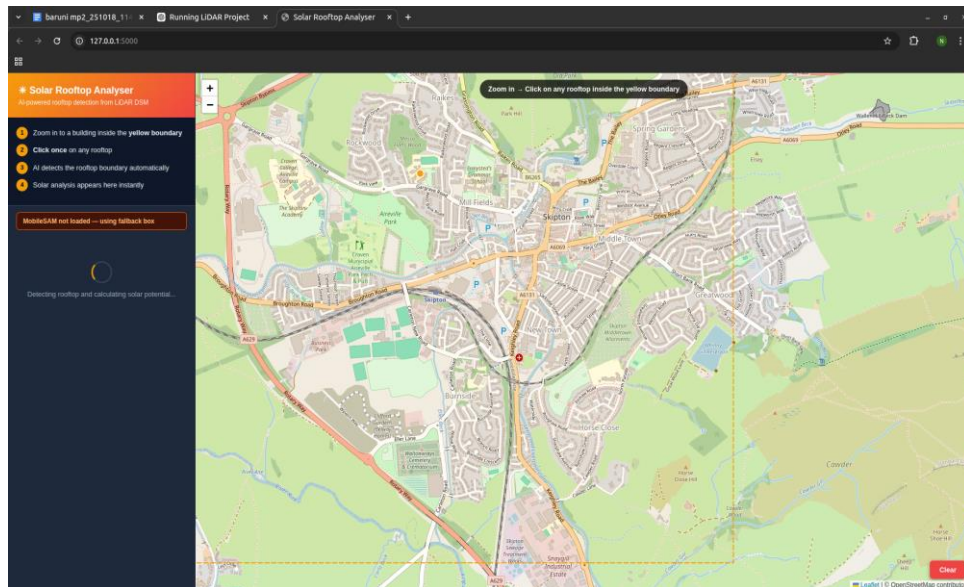


Figure -1: inputs

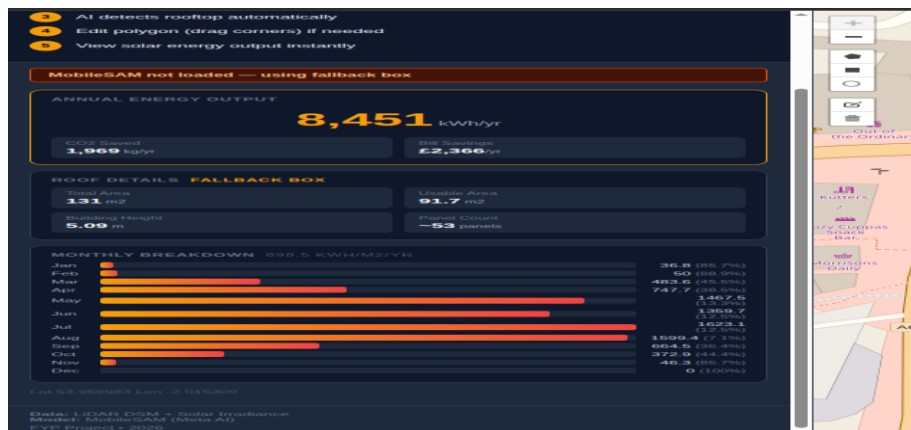


Figure -2: outputs

VII. FUTURE ENHANCEMENT

The current system provides accurate insights into rooftop solar potential through automated analysis and AI-driven techniques, but several enhancements can further improve its capabilities and usability. Future improvements include integrating real-time satellite data and environmental datasets such as weather conditions and solar irradiation levels to enable dynamic and more precise energy estimation. Incorporating advanced visualization techniques and interactive GIS dashboards can help users better understand spatial patterns and solar potential distribution across different regions. The system can also be enhanced using advanced deep learning models for improved rooftop detection accuracy and predictive analysis of energy generation over time.

Additionally, expanding support for larger geographic areas and higher-resolution datasets will make the system more scalable and effective for real-world applications. Deploying the application on cloud platforms and developing a mobile-based interface can improve accessibility for users across different devices. Enhancing features such as automated report generation and integration with smart city infrastructure can further extend its usability. These improvements aim to transform the system into a comprehensive AI-powered solution for sustainable energy planning and efficient solar resource utilization.

VIII. CONCLUSION

The project aimed to address the growing need for efficient assessment of rooftop solar energy potential by introducing an intelligent and automated solution. Traditional methods for evaluating solar suitability are often manual, time-consuming, and require technical expertise, making it difficult to analyze large urban areas effectively. In contrast, the proposed system provides a smart, user-friendly platform that enables automated rooftop detection and real-time solar potential analysis using satellite imagery and geospatial data.

Through the integration of technologies such as image processing, deep learning, and geospatial analysis, the system effectively delivers accurate insights into rooftop suitability, solar energy estimation, and spatial distribution patterns. The web-based interface enhances usability, allowing users such as urban planners, authorities, and building owners to interact with the system effortlessly and make informed decisions for adopting renewable energy solutions.

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