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Rapid Assessment Framework for Evaluating Land Parcel Suitability in Solar Project

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ABSTRACT

Efficient land parcel evaluation is a critical step in the site origination process for solar energy projects. This paper presents a rapid assessment framework designed to streamline the evaluation of land parcels for their suitability in solar project development. The proposed method incorporates key parameters such as solar irradiance, soiling loss, soil type, hailstorm risk, interconnection connectivity, and the presence of wetlands. By leveraging a data- driven approach, the framework enables a fast yet comprehensive screening process, facilitating efficient identification of suitable land parcels for solar projects. Case studies demonstrate its effectiveness in identifying optimal sites while minimizing resource expenditure. This paper highlights the practical implications of the Rapid Assessment Framework method and its potential to enhance decision-making in renewable energy planning.

Index Terms—site origination, land parcel suitability, solar irradiance evaluation, environmental constraints, soiling loss impact, wetland mapping, interconnection connectivity

I. INTRODUCTION

The rapid expansion of renewable energy, particularly solar energy [1], has heightened the demand for efficient land evaluation processes in project development. Selecting suitable land parcels for solar installations is a critical step that significantly impacts the financial and operational success of projects [2]. However, this process is often fraught with challenges, including the need to consider diverse parameters such as solar irradiance, environmental constraints, terrain, soil characteristics, and proximity to grid infrastructure [3], all while adhering to tight project timelines.

Evaluating land parcels for solar projects can be time consuming and resource-intensive [4], requiring detailed anal yses that may not be practical during the early stages of project origination. This creates a need for a streamlined, data driven approach that allows for quick and reliable preliminary evaluations to support decision- making.

This paper introduces a rapid screening framework de signed to evaluate land parcel suitability for solar projects efficiently. By incorporating key parameters such as solar irradiance, soiling loss, soil type, hailstorm risk assessment, interconnection connectivity, and the presence of wetlands, this method provides a comprehensive overview of site potential. The Rapid Assessment Framework of Land Suitability enables project teams to prioritize high-potential sites and avoid parcels with significant constraints, thus optimizing the overall origination process. The subsequent sections detail the development and implementation of this framework, its application in various scenarios, and its practical implications for the solar energy industry. This work aims to advance the field of solar site selection by demonstrating a method that balances speed, accuracy, and comprehensiveness, contributing to more effective renewable energy planning.

II. METHODOLOGY

A. *Overview*

The proposed Rapid Assessment Framework employs a comprehensive multi-parameter analysis to systematically evaluate land parcel suitability for solar energy projects. The framework encompasses a structured approach to evaluating critical parameters essential for solar project feasibility as summarised in Table I.

TABLE I FRAMEWORK PARAMETERS

Parameter	*Description*
Solar Irradiance	Measures the sunlight energy available for solar power generation
Soiling Loss	Evaluates energy loss due to dust and snow accumulation on panels
Soil Type	Assesses the ground's suitability for solar infrastructure and installation
Interconnecti onConnectiv ity	Analyzes proximity and ease of connection to the power grid
Terrain	Examines land topography to ensure compatibility with solar project requirements
Presence of Wetlands	Identifies waterlogged or ecologically sensitive areas that may hinder development
Hailstorm Risk	Evaluates the likelihood of hail damage to solar panels and infrastructure

B. ***Parameters***

1) *Solar Irradiance:* Solar irradiance measures the amount of solar energy that reaches a specific location over time, influencing how much power a solar system can generate. It varies based on factors like geographic location, latitude, altitude, and time of year. Areas with high solar irradiance, such as those close to the equator, are ideal for solar power generation. By assessing this parameter, developers can identify regions with maximum sunlight exposure, which helps optimize the energy production potential of solar installations. In this framework, solar irradiance is evaluated by collecting readily available satellite data from trusted and bankable sources such as SolarAnywhere [5] and SolarGIS [6]. These sources measure Global Horizontal Irradiance (GHI) data using advanced satellite imagery, accounting for parameters like cloud cover, atmospheric aerosols, water vapor, and surface albedo to provide accurate and reliable solar resource assessments. By calculating kilowatt-hours per square meter per day, the methodology generates a precise quantitative metric that enables comparative evaluation of different land parcels, ultimately determining their potential for efficient solar energy generation.

2) *Soiling Loss:* Soiling loss occurs when dust, snow, or debris accumulate on solar panels, reducing their ability to absorb sunlight and thereby diminishing power generation. This is especially prevalent in dry or arid climates where dust levels are high along with cold regions that experience snowfall during winters. The severity of soiling loss depends on local environmental factors and weather patterns. It is essential to consider this parameter during the analysis phase, as it impacts the long-term efficiency of solar panels and may require regular cleaning and maintenance to mitigate the loss.

In this research framework, soiling loss is evaluated through quantitative assessments of dust and snow accumulation calculated by Kimber model and Townsend model respectively. The Kimber model analyzes dust soiling by using empirical data to estimate soiling losses on solar panels, accounting for factors such as local environmental conditions, dust deposition rates, and the frequency of natural precipitation or manual cleaning events [3]. The Townsend model calculates snow soiling by considering the accumulation and shedding of snow on solar panels, factoring in variables such as snowfall events, panel tilt angles, ambient temperature, and wind conditions to estimate energy losses due to snow coverage [4]. The methodology utilizes empirical models to convert environmental parameters into specific percentage-based efficiency losses, allowing for precise prediction of solar panel performance degradation and supporting maintenance strategies to reduce energy yield losses caused by soiling.

3) *Soil Type:* The type of soil at a potential solar development site plays a critical role in the construction process. Different soil types, such as sandy, with bedrock, or clay rich soils, affect the ease of installation, the stability of the structure, and the overall durability of the solar farm. Some soils may require additional groundwork or reinforcement to support the weight of solar panels and equipment. Soil type also influences water drainage, erosion risks, and long term maintenance needs, all of which must be considered for successful solar development. The methodology employs a concise analysis that involves soil classification and characterizing parameters such as soil composition to identify structural obstacles like bedrock. Soil data for regions across the United States can be accessed from the United States Department of Agriculture (USDA) website [5] and analyzed as needed. In project origination by providing immediate insights into land challenging cases, it is better for developers to understand earlier parcel suitability and potential environmental restrictions. that higher cost racking will need to be bought for drilling into bedrock.

4) *Interconnection Connectivity:* This parameter assesses the availability and proximity of the site to electrical infrastructure that can integrate the generated solar power into the grid. A good interconnection site ensures that energy produced from the solar farm can be efficiently transmitted to the grid. This includes evaluating transmission lines, substations, and overall grid capacity, which can impact both installation cost and long term viability. The framework analyzes interconnection data from various sources, such as utility providers, regional trans mission organizations (RTOs), and independent system operators (ISOs). These organizations maintain detailed databases of grid infrastructure, including the location and capacity of transmission lines, substations, and points of interconnection. By integrating this data, the framework assesses the feasibility of connecting the solar farm to the grid, by calculating the distance to the closest grid infrastructure and identifying any potential bottlenecks.

5) *Terrain:* Terrain refers to the physical characteristics of the land, such as its slope, elevation, and surface features. Steep or uneven terrain can make construction more difficult and expensive due to the need for land leveling, specialized equipment, or reinforced foundations. Flat or gently sloping land is typically preferred for solar installations because it reduces costs and allows for more efficient placement of solar panels. Terrain analysis is vital to determine whether the site is suitable for solar development and how the terrain could impact installation and energy generation efficiency. The framework quantifies terrain suitability by generating slope percentage maps, identifying areas with excessive elevation changes or challenging geographical features that could com plicate solar panel mounting. This process utilizes software that employs a digital elevation model (DEM) to analyze slope topography, represented as a grid of elevation points enabling the calculation of slope at any specific location within a site. Input data for this software can be sourced from providers such as the United States Geological Survey (USGS) [6].

6) *Presence of Wetlands:* Wetlands are protected areas due to their environmental importance. If a solar development site includes wetlands, there may be legal and regulatory restrictions on construction and land use. Since solar panel installation is categorically prohibited on wetland areas due to environmental regulations and ecological preservation man dates, these zones are immediately subtracted from the gross land parcel area, effectively reducing the developable solar footprint. These areas can also complicate infrastructure development due to water-related challenges such as flooding or soil instability. Identifying wetlands early in the planning process ensures compliance with environmental regulations and minimizes the risk of project delays.

By integrating geospatial data from federal and state wet land mapping databases, such as the U.S. Fish and Wildlife Service’s National Wetlands Inventory (NWI) [7], the frame-work rapidly identifies jurisdictional wetland zones within potential project sites, to calculate the precise percentage of wetland coverage. It enables project developers to quickly understand the net developable acreage, assess potential site constraints. This rapid assessment prevents costly late-stage discoveries of wetland-related limitations, supporting efficient

7) *Hailstorm Risk:* Hailstorms pose a significant risk to solar panels, as they can cause physical damage to panel surfaces, leading to cracks or breakage. The frequency and severity of hailstorms depend on geographic location and climate. Areas that experience frequent or severe hail events may require specialized panel designs or protective measures, such as stronger frames or hail-resistant glass, to ensure long-term durability and minimize repair costs. Assessing the historical data on hailstorms for a site helps in understanding the level of risk and allows for proper design adjustments.

The methodology assesses hail risk using detailed indices that account for factors like annual hail occurrence rates, maximum hailstone sizes, and regional historical damage patterns. By incorporating data from the National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center [8], the approach facilitates the rapid assessment of site specific hailstorm exposure, directly influencing solar panel design, module selection, and risk mitigation strategies. This comprehensive evaluation helps project developers quickly identify environmental risks that could affect the long-term performance and durability of solar projects, aiding informed decision-making during the initial land parcel assessment phase.

C. ***Analysis Framework***

The proposed framework integrates multiple parameters into a cohesive system for evaluating the suitability of land parcels for solar projects. This section outlines the weighting and prioritization of parameters.

Each parameter is assigned a weight based on its relative importance to the success of a solar project. The weights are determined through an iterative process that considers industry standards, expert input, and project-specific priorities, and may differ case by case. For example:

- High-Priority Parameters: Solar irradiance and interconnection connectivity, as they directly impact energy production and cost.
- Moderate-Priority Parameters: Soiling loss and soil type, which affect maintenance and construction challenges. • Low- Priority Parameters: Presence of wetlands and hail storm risk, as these are more site-specific constraints. In the case of multiple project analysis, a weighted scoring system is used to rank land parcels. Each parcel receives a composite score calculated by summing the products of parameter weights and their respective performance metrics. This allows for an objective comparison of sites based on their overall suitability.

Additionally, this framework can also be applied to analyze individual projects in the pipeline, allowing developers to evaluate each parameter in detail for a specific site. By doing so, they can

A. ***Case Study 1: High-Potential Parcel Identification***

- Scenario: A parcel located in a region with high solar irradiance and close proximity to grid infrastructure was proposed for development.
- Analysis Focus: Evaluating solar irradiance, proximity to grid infrastructure, soiling loss, and soil type.
- Outcome: The site was deemed highly favorable due to minimal soiling loss and suitable soil type, allowing the project to proceed with minimal adjustments and saving significant time in site selection.

B. ***Case Study 2: Avoiding Risk-Prone Sites***

- Scenario: A parcel located in a hailstorm-prone area with significant wetland coverage was analyzed.
- Analysis Focus: Assessing environmental and operational challenges, including weather risks and wetland presence. • Outcome: Despite high irradiance, the site was flagged as high-risk due to operational challenges, enabling the team to prioritize alternative sites and avoid potential delays and costs.

C. ***Case Study 3: Quick Comparison of Multiple Parcels***

- Scenario: Ten parcels needed evaluation under tight deadlines to identify high-potential candidates.
- Analysis Focus: Ranking parcels using a suitability scoring system based on weighted parameters.
- Outcome: Three top candidates were identified, significantly narrowing the focus for detailed feasibility studies and enabling the team to meet project deadlines efficiently.

D. ***Case Study 4: Evaluating a Site in a Challenging Terrain***

- Scenario: A hilly region with variable soil types is proposed for development.
- Analysis Focus: Combining topographical and soil data to determine grading and foundation challenges. • Outcome: The parcel is flagged as low-priority due to high construction costs.

E. Case Study 5: Determining Connectivity Suitability • Scenario: A parcel with excellent solar irradiance is far from existing power lines.

- Analysis Focus: Calculating interconnection costs and proximity to transmission infrastructure.
- Outcome: The parcel is deprioritized due to excessive grid connection costs.

IV. DISCUSSION

gain a comprehensive understanding of the potential challenges associated with the project and make informed, expert decisions about its feasibility and next steps.

III. CASE STUDIES

The application of the proposed framework demonstrates its ability to streamline land parcel evaluation for solar projects effectively. The results are categorized into case studies and quantitative metrics, highlighting the framework's practical benefits and measurable performance improvements.

1) *Streamlined Evaluation Process:* The framework provides a systematic approach to evaluating land parcels, enabling rapid assessments while maintaining a comprehensive review of all critical parameters. This streamlined process helps project teams save time during the site origination phase.
2) *Informed Decision-Making:* By analyzing multiple parameters such as solar irradiance, soil type, environmental constraints, and grid connectivity, the framework offers a holistic view of each parcel's suitability. This supports developers in making well-informed decisions early in the project lifecycle.
3) *Risk Mitigation:* The framework helps identify potential challenges, such as environmental risks or high infrastructure costs, at an early stage. This proactive approach minimizes the likelihood of costly delays or project failures later in the development process.
4) *Resource Optimization:* Focusing on high-potential sites ensures that resources, including time and funding, are di rected toward the most promising opportunities. This targeted approach improves efficiency and overall project viability.
5) *Scalability and Flexibility:* The framework is adaptable for evaluating individual parcels or multiple sites simultaneously, making it suitable for projects of varying scales. Its flexibility supports both quick screenings and detailed analyses as needed.

The results showcase the versatility and efficiency of the framework, underscoring its value as a decision-support tool in solar energy project development. Its application not only streamlines the evaluation process but also ensures informed and strategic decision-making.

B. Limitations of the Current Implementation

While the framework offers significant advantages, certain limitations must be acknowledged. The accuracy of the analysis is heavily reliant on the availability and quality of input data. In regions where data such as soil composition or grid connectivity is sparse or outdated, the framework's effectiveness may be reduced. Additionally, the current implementation does not account for dynamic factors such as evolving land-use policies or real-time market fluctuations, which could influence project viability. Future iterations could incorporate predictive analytics or real-time data feeds to address these limitations.

C. Implications for the Solar Industry

The framework holds substantial potential to transform early- stage decision-making in the solar industry. By enabling rapid and informed evaluations, it accelerates the project

origination process, fostering faster deployment of renewable energy projects. This approach aligns with the industry's increasing focus on scalability and efficiency, especially in markets aiming to meet aggressive renewable energy targets. The framework's adaptability makes it scalable across diverse geographies and project sizes, from small-scale installations to utility-scale solar farms. Its integration with automation tools further enhances its potential, paving the way for its widespread adoption in solar energy planning and development.

CONCLUSION

This paper introduces a comprehensive framework for evaluating land parcels in solar energy development, addressing critical parameters such as solar irradiance, soil type, environmental constraints, and grid connectivity. The results demonstrate the framework's ability to streamline the site selection process, enhance decision-making, and mitigate risks at the early stages of project origination. The framework's benefits lie in its flexibility, scalability, and adaptability to varying project requirements, making it a valuable tool for both small and large-scale solar initiatives. While certain limitations, such as dependency on data quality and dynamic factors, exist, these can be addressed through future enhancements such as real-time data integration and predictive analytics. As the solar industry continues to expand to meet global renewable energy goals, this framework provides a practical solution to accelerate project development and ensure informed, strategic site selection. Its adoption has the potential to significantly contribute to the efficiency and success of solar energy projects worldwide.

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