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Geodetic Support for the Placement of Renewable Energy Facilities within the Territorial Planning System

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SUMMARY

The rapid development of renewable energy is intensifying competition for land resources, opportunities for grid connection, and public support for the implementation of new projects. Under these conditions, the selection of locations for solar and wind power plants becomes not only an engineering or energy-related task but, above all, an issue of rational spatial development of territories. This study proposes an approach to the preliminary selection of areas for the placement of renewable energy facilities based on the integration of geodetic methods and geoinformation technologies into the territorial planning system. The methodology involves the use of GNSS measurements, photogrammetry from unmanned aerial vehicles, digital terrain models, cadastral data, information on land-use restrictions, transport and energy infrastructure, as well as indicators of solar radiation and wind potential of the territory. All spatial data are converted into a unified format and integrated through multi-criteria analysis to create a suitability index for land parcels intended for the placement of energy facilities. Using the example of a hypothetical planning area, it is demonstrated that the use of modern geodetic materials significantly improves the accuracy of identifying the boundaries of suitable sites, reduces conflicts with agricultural production and protected natural areas, and enables a justified comparison of alternative options before the commencement of detailed design. The obtained results indicate that the energy potential of a territory is only one of the factors determining the feasibility of project implementation. Equally important are the terrain characteristics, accessibility of transport infrastructure, the possibility of connection to the power grid, the configuration of land parcels, and the presence of environmental protection restrictions. The proposed approach can be used by local authorities, design organizations, and investors to align the development of renewable energy with strategies for sustainable land use and contemporary requirements of spatial planning.

Keywords: Renewable energy; Geodesy; GIS; UAV photogrammetry; Territorial planning; Land suitability; Land use; Multi-criteria analysis.

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Introduction

The active development of renewable energy is significantly changing approaches to land resource use at both regional and local levels. According to the International Renewable Energy Agency (IRENA), by the end of 2025, nearly half of the world's installed generation capacity was based on renewable energy sources, with the main increase provided by solar and wind power plants. In this context, an important practical question arises: how to select areas for the placement of new energy facilities in a way that ensures a balance between energy efficiency, land legislation requirements, environmental safety, and the development needs of territorial communities.

Practice shows that an area with high solar or wind potential is far from always suitable for the implementation of an investment project. Obstacles may include complex engineering and geological conditions, significant fragmentation of land ownership, the presence of protected areas, flood risk, the high value of agricultural land, or the absence of opportunities for connection to the power grid. At the same time, areas with somewhat lower energy potential may prove to be considerably more attractive due to the availability of high-quality transport infrastructure, clearly defined land parcel boundaries, and minimal environmental and social risks (Akay, 2025; Bimenyimana et al., 2024; Eldamaty et al., 2023; Mustafa et al., 2025).

Today, geographic information systems, multi-criteria analysis methods, and analytic hierarchy processes are widely used for selecting areas for renewable energy facilities. However, most existing studies are based on generalized spatial data and insufficiently consider the capabilities of modern geodetic support and its integration with territorial planning tools. As a result, a gap emerges between analytical land suitability maps and actual management decisions that must be implemented through urban planning documentation, cadastral procedures, and land-use mechanisms. The aim of this study is to develop an approach for integrating geodetic data, geoinformation technologies, and territorial planning tools for the justified selection of areas for the placement of renewable energy facilities at the early stages of project preparation.

Method and Theory

The proposed approach to selecting areas for the placement of renewable energy facilities is based on the integration of geodetic methods, geoinformation analysis, and territorial planning tools. The methodology is implemented as a sequential multi-stage process that enables the transition from the collection of initial spatial data to the formulation of justified recommendations regarding land use (Figure 1).

The first stage involves establishing a reliable geodetic framework for the study. For this purpose, GNSS measurements, existing cadastral materials, and, where necessary, the results of aerial surveys using unmanned aerial vehicles are employed (Khainus et al., 2023). The application of photogrammetric methods makes it possible to obtain high-accuracy orthophotos and digital terrain models that reflect microrelief features, transport infrastructure, built-up elements, drainage systems, and the actual boundaries of land use.

Figure 1. Geodetic and GIS-oriented workflow for site selection of renewable energy facilities.

The need to use specifically geodetic data is explained by the fact that decisions regarding the placement of solar and wind power plants often depend on relatively minor spatial differences. A few meters of distance from residential development, the boundary of a protected zone, the configuration of a land parcel, or a change in slope gradient may be of decisive importance.

At the next stage, thematic spatial layers are prepared and standardized. All datasets are converted into a common coordinate system, uniform spatial resolution, and shared boundaries of the study area. This approach ensures the correctness of subsequent spatial calculations and enables the comprehensive analysis of heterogeneous information. To assess the suitability of territories for solar energy development, indicators such as total solar radiation, slope gradient and aspect, the degree of shading, and the distance to existing power grids and transport infrastructure are used. In the case of wind energy, the main criteria include wind speed, wind power density, terrain characteristics, the degree of landscape openness, as well as the accessibility of engineering and transport infrastructure.

Alongside factors that increase the attractiveness of an area for investment, restrictive factors are also taken into account. These include protected natural areas, water bodies, sanitary protection zones of settlements, sites with complex engineering and geological conditions, areas of historical and cultural heritage, and land parcels whose legal status precludes the placement of energy facilities.

After all spatial layers have been prepared, they are integrated using multi-criteria analysis methods. Each factor is assigned a weighting coefficient according to its influence on the final result. Weight values may be determined by expert judgment, through the analytic hierarchy process, or in accordance with regional territorial development policy priorities (Saraswat et al., 2021; Rediske et al., 2020). The preliminary selection criteria used in the proposed model are summarized in Table 1.

Table 1. Geodetic and planning criteria used in the proposed preliminary selection model

Layer / criterion	Geodetic or GIS data source	Planning role
Terrain slope and aspect	UAV photogrammetry, DEM/DSM, GNSS control	Identifies constructible surfaces and erosion-sensitive areas.
Parcel and land-use boundaries	Cadastral layer, orthophoto interpretation, field verification	Links suitability classes with ownership and zoning decisions.
Grid and road proximity	Topographic database, utility corridors, GNSS survey of access points	Reduces connection cost and construction disturbance.
Environmental and social buffers	Protected-area datasets, settlement layers, hydrography, planning restrictions	Defines exclusion zones and conflict-sensitive buffers.

The result of the calculations is the generation of an integrated suitability index for the placement of renewable energy facilities. At the same time, the resulting suitability maps should not be regarded as a final decision regarding the construction of a specific facility. Their primary purpose is to support management decision-making at the early stages of planning and to identify areas that require detailed engineering and geodetic surveys, environmental impact assessments, and consultations with stakeholders. Thus, the proposed methodology ensures the transition from preliminary regional analysis to detailed design at the level of individual land parcels and provides a basis for aligning the development of renewable energy with the principles of sustainable spatial development of territories.

Results

To validate the proposed approach, a hypothetical planning area was used, for which all spatial factors were integrated into a unified land suitability assessment system for renewable energy development.

After the normalization of input data and their integration through multi-criteria analysis, an integrated land suitability index with values ranging from 0 to 1 was generated. Based on the obtained results, the study area was divided into three categories: highly suitable areas, moderately suitable areas, and areas with significant constraints or unsuitable for the placement of energy infrastructure.

The schematic modeling results showed that the most promising sites are formed where high solar or wind potential is combined with gentle terrain slopes, the availability of transport access, and proximity to existing power grids. In contrast, areas subject to environmental protection restrictions, sanitary protection zones of settlements, or complex engineering and geological conditions are automatically assigned to the low-suitability category regardless of the level of their energy potential.

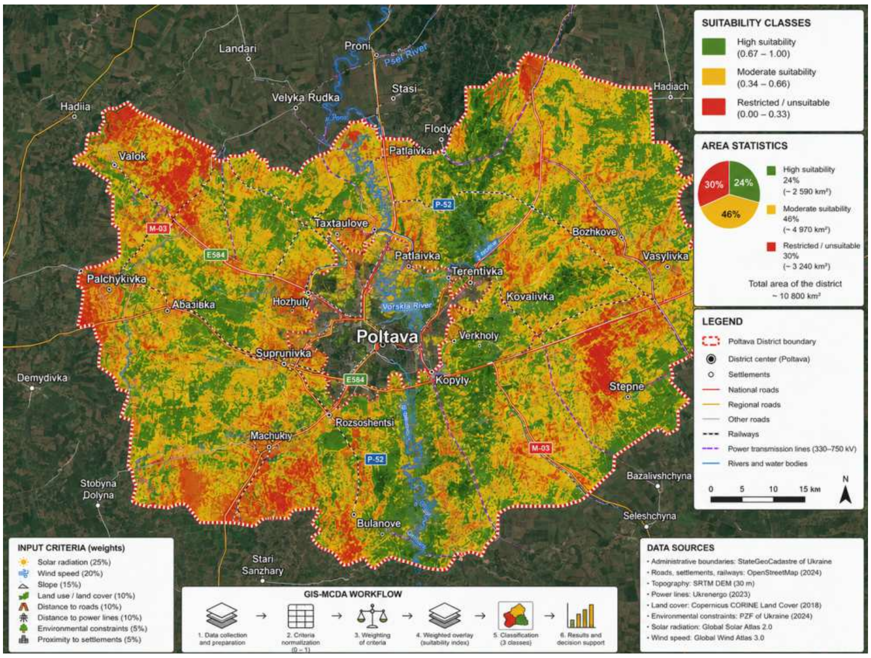

Figure 2. Conceptual suitability surface and class distribution for a planning unit

The obtained results showed that approximately 24% of the study area may be considered a priority for conducting detailed engineering and geodetic surveys and preparing feasibility studies for projects. Another 46% of the territory is characterized by a moderate level of suitability and requires additional analysis of trade-offs between economic, environmental, and social development factors. At the same time, approximately 30% of the area should be excluded from further consideration or classified as territories with a high level of constraints.

Although these values are illustrative in nature and are used to verify the logic of the proposed approach, they accurately reflect patterns identified in contemporary studies employing GIS-MCDA methods for site selection for renewable energy facilities. In particular, numerous studies indicate that areas with the highest levels of solar radiation or wind speed coincide only in isolated cases with areas where project implementation is the simplest from legal, environmental, and social perspectives (Akay, 2025; Mustafa et al., 2025).

The contribution of geodetic support becomes especially evident at the boundaries between suitability classes. The use of geodetic-accuracy orthophotos and digital terrain models makes it possible to determine whether a specific land parcel is genuinely suitable for development, whether acceptable surface slope thresholds are exceeded, and whether the potential site is fragmented by cadastral parcel boundaries or existing land-use structures. For solar energy projects, particularly in densely built-up areas or in the case of rooftop photovoltaic systems, additional importance is attached to the analysis of shading and the orientation of surfaces relative to solar radiation. In turn, for wind energy facilities, digital terrain models allow for a more accurate assessment of landscape openness, the influence of terrain features on wind flow velocity, and the possibilities for transport access to future facilities.

Thus, the proposed approach ensures a justified transition from regional-scale territorial screening to project decision-making at the level of individual land parcels. The practical value of the obtained results also lies in the possibility of their application during the preparation of territorial planning documents. Areas with high suitability scores may be considered priority zones for renewable energy development, areas of moderate suitability as reserve or conditionally promising zones, while territories with a high level of constraints should preferably remain under their existing land-use regime or require special justification for the possibility of their development.

Conclusions

The placement of renewable energy facilities should be considered not only as an engineering task but also as a territorial planning issue that requires the use of reliable spatial data and well-founded decisions regarding land resource use. The conducted study demonstrated that the integration of GNSS measurements, UAV photogrammetry, cadastral data, digital terrain models, and multi-criteria GIS analysis methods makes it possible to effectively identify priority areas for the development of solar and wind energy at the early stages of planning.

The obtained results confirm that a high energy potential of a territory alone is not a sufficient condition for project implementation. Decisive factors are often terrain characteristics, the accessibility of transport and energy infrastructure, land-use structure, and the presence of environmental constraints. The practical value of the proposed approach lies in the possibility of its application during the preparation of spatial planning documents for territorial communities and the designation of priority development zones for renewable energy. Further research should focus on validating the methodology using real municipal data and integrating it with economic and environmental models for project efficiency assessment.

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