SELECTING LOCATION FOR SOLAR POWER PLANTS USING GIS TECHNOLOGIES: EXAMPLE OF SKIRSNEMUNĖ ELDERSHIP

Ruta Puziene
Vilnius Gediminas Technical University, Lithuania
ruta.puziene@vilniustech.lt

Abstract. The development of renewable energy requires careful selection of territories to ensure efficient use of solar energy and minimal environmental impact. This study presents a methodological approach to selecting solar power plant locations using geographic information systems (GIS) technologies. The analysis integrates several essential criteria: terrain features, slope angles and their geographic orientation, technical requirements for installing solar power plants, and shading effects from adjacent structures. Additionally, the land productivity score is included as a selection criterion for solar power parks. GIS technologies enable multi-layered analysis, providing opportunities to identify optimal locations that maximize solar radiation absorption while ensuring proper infrastructure integration. Spatial analysis results indicate that despite the high average soil productivity in the Skirsnemunė eldership, 53.62% of its available territory is classified as highly suitable for solar park development. When land productivity scores are assigned an advisory weight in the site selection model – mirroring current national regulatory practices – this indicator fails to function as a decisive limiting factor against technical suitability parameters. Consequently, solar infrastructure expansion leads to direct loss of limited, high-productivity agricultural land.

Keywords: solar power parks, GIS modelling, land productivity scores.

Introduction

Global research over the past decade consistently demonstrates that GIS-integrated multi-criteria decision analysis (MCDA) is one of the most effective methods for selecting suitable locations for solar power plant construction [1]. Land suitability assessment relies on numerous criteria – including slope, solar radiation, land cover, terrain characteristics, infrastructure accessibility, and environmental constraints – based on methodologies widely applied in international studies [1-5].

One of the most significant recent investigations, conducted in Iran's Kermanshah Province, showed that GIS-MCDA methods enable the classification of territories by suitability levels, with slope emerging as the most influential factor for solar farm site selection. Zandi and Lotfata (2025) emphasized the importance of criteria normalization, permitting objective comparison of datasets measured in different units [1].

Studies from India confirm that the integration of AHP and WLC methods enables reliable and objective land suitability evaluation. Halder et al. (2022), applying a GIS-AHP modelling framework in the Kolkata region, identified five suitability categories and demonstrated how urbanization, water bodies, and natural boundaries constrain the expansion of solar energy infrastructure [2]. Bimenyimana et al. (2025) demonstrated that the WLC method is capable of identifying large-scale suitability zones in geographically diverse regions, with solar radiation ranging from 3.31 to 6.73 $kWh \cdot m^{-2}$ per day and up to 84% of land classified as moderately or highly suitable [6]. These results confirm that integrated multi-criteria analysis can accurately identify development priority zones and may be successfully applied in Lithuanian territories as well.

Additional studies, such as those by Hansoti et al. (2025), examined the applicability of the AHP method for practical planning, highlighting the same key characteristics considered in this research: terrain quality, slope values, distance to power lines and road infrastructure, and environmental restrictions [7].

The literature further stresses the necessity of eliminating unsuitable areas prior to performing final suitability modelling. UAE CSP studies demonstrated that restricted territories – protected areas, water bodies, and buffer zones – must be removed and excluded from aggregated spatial models [8].

Furthermore, scholars broadly discuss the versatility of GIS-MCDA approaches and their applicability in both urban and agricultural environments. Kocabaldir and Yücel (2020), analysing site suitability in Turkey, showed that the method can effectively identify priority photovoltaic development zones even in regions where land use is strongly shaped by agricultural activities [9].

Although many authors examine spatial modelling capabilities for solar plant site selection, relatively few studies consider soil productivity as a decisive factor. High-productivity soils represent valuable, limited natural resources, yet in many countries, renewable energy legislation does not regulate their protection. In Lithuania, the regulatory framework is mostly advisory, and municipalities or elderships may bypass such recommendations in practice. Thus, soil productivity is not prioritized when selecting sites for solar farms.

In Lithuanian elderships, soil productivity values range from 0 to 58.2. Unclassified cells lacking data were excluded from the national soil productivity analysis. The most fertile soils are concentrated in central Lithuania, while the least productive soils are located in eastern and western regions (Fig. 1 a). The average soil productivity score for Lithuania is 39.79 [10].

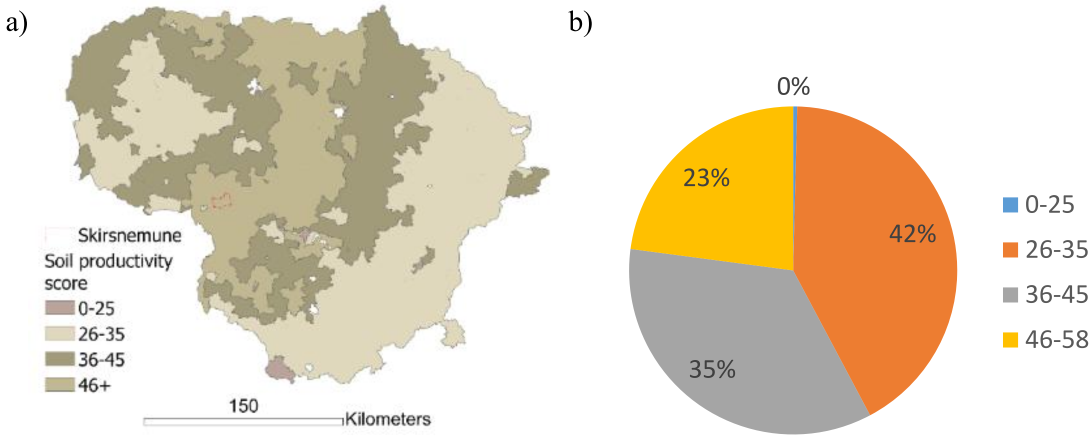

Fig. 1. **Distribution of soil productivity classes in the territory of the Republic of Lithuania:** a – geographical location; b – proportional distribution of land areas by soil productivity classes

Low-productivity soils account for the largest share of national land resources – 42 %, whereas high-productivity soils constitute only 23 % (Fig. 1 b). Considering that fertile soils are relatively scarce, their preservation for agricultural use is of particular importance.

The current legal requirement for the protection of these soils in Lithuania is essentially advisory. This creates a regulatory conflict due to the absence of explicit restrictions, leaving interpretation entirely to practical implementation. A political attempt was made to introduce a fixed restriction threshold (e.g., ≤ 35 points), but it was rejected. The scientific novelty of this study lies in explicitly treating the soil productivity score as a quantitative suitability criterion and investigating its impact on the installation of solar power parks under current Lithuanian legal frameworks.

This study aims to identify areas suitable for solar park development and to determine the potential loss of agriculturally valuable lands resulting from the installation of solar power plants.

Materials and methods

Study Area. The study was conducted in the Skirsnemunė eldership, located in central Lithuania and characterized by highly productive soils, with productivity values ranging from 11.4 to 76.1 points (Fig. 2). The average soil productivity score in the area is 52.1, which exceeds the national average of 39.79. This region represents one of the most fertile parts of the Republic of Lithuania.

The southern boundary of the eldership is defined by the Nemuna River. The terrain is highly favourable for agricultural activities, with elevation gradually increasing from 11.9 m in the south to 65.2 m in the northeastern part of the eldership (Fig. 2b). Forest land dominates the northeastern portion, where agricultural activities are not conducted. Overall, natural conditions in the eldership are highly favourable for agriculture. Consequently, 72% of its territory is classified as agricultural land, 20% as forest land, and 3% as built-up areas (Fig. 2c). Land use is therefore strongly oriented toward agriculture. These characteristics served as the basis for selecting this eldership as the study area.

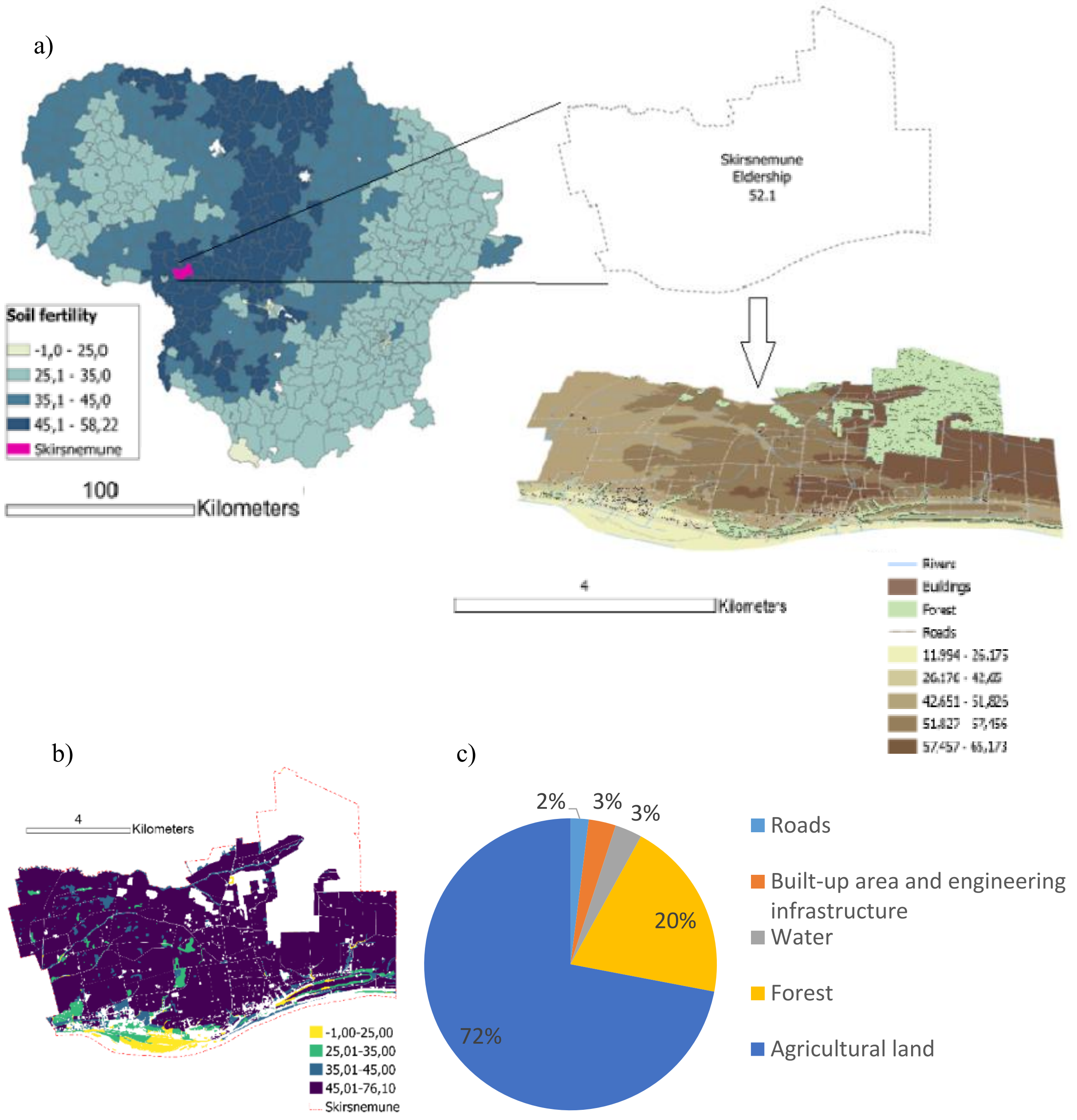

Fig. 2. **Skirsnemunė eldership**: a – geographical location and characteristics; b – soil productivity scores; c – land-use distribution (percentages)

Data Sources. The analysis was based on Lithuanian spatial datasets obtained from www.geoportal.lt: LiDAR Point Cloud. Digital spatial laser scanning data (2009-2010) of the land surface of the Republic of Lithuania (SEŽP_0,5LT). Point density: approximately 1 point·m^{-2}; vertical accuracy: ± 0.15 m; horizontal accuracy: ± 0.30 m; Georeferenced Cadastre Database (dynamic), 2026-01-31. Includes spatial objects related to water bodies, land cover, transport networks, engineering infrastructure, geodetic benchmarks, elevation data, etc.; Forest Cadastre Data, 2023-05-02; Lithuanian Hillforts Dataset, 2015-10-14; Register of Cultural Heritage, 2025; EU-significant Natural Habitats Dataset, 2015-02-18; Flood-prone Areas Based on LiDAR-derived Topography, 2014-12-29; State Cadastre of Protected Areas, 2026-02-17; Soil Spatial Data Set, 2026-01-01.

All datasets were imported into ArcGIS Pro and clipped to the boundaries of the Skirsnemunė eldership.

Data Processing. A Digital Elevation Model (DEM) was generated from LiDAR data in ArcGIS Pro. Slope and aspect models were derived from the DEM. Using the Area Solar Radiation tool, annual solar radiation ($kWh \cdot m^{-2}$) was calculated.

Soil productivity classification – soil productivity scores were categorized into four classes: -1 – no data, 0-25 – very low productivity, 26-35 – low productivity, 36-45 – medium productivity, 46-58 – high productivity.

All vector datasets were converted to raster format (Polygon to Raster) and reclassified (Reclassify) into five evaluation classes (1-5). Identification of Exclusion Zones.

Vector layers representing areas where solar power plants cannot be installed were processed as exclusion zones. These included: forests with a 75 m buffer (to account for shading), rivers and water bodies, flood-prone territories, protected areas, cultural heritage protection zones, EU-significant habitats, residential areas, individual buildings, and farmsteads.

These layers were converted to rasters with two values: NoData – unsuitable for solar development; 5 – suitable for further analysis. This ensured that prohibited areas were excluded from subsequent suitability modelling.

Criteria Standardization. For land-suitability evaluation, raster models (Slope, Solar Radiation, Soil Productivity, Euclidean distance rasters, and other positive or restrictive factors) were reclassified into five standardized categories: 1 – very low suitability, 2 – low suitability, 3 – moderate suitability, 4 – suitable, 5 – very suitable.

Multi-Criteria Decision Analysis (MCDA). Final suitability modelling was performed using the Raster Calculator, applying a Weighted Linear Combination (WLC). The criteria and their assigned weights were as follows: Environmental impact: 0.55, Infrastructure: 0.20, Environmental risk: 0.05, Soil productivity: 0.20. The sum of the weights equals 1.

Infrastructure accessibility (distance to roads and power lines) was included as a positive factor. Constraint layers were assigned NoData, eliminating unsuitable territories automatically. The final suitability raster was computed using Equation (1):

$$FS = SpR \cdot 0.25 + SoR \cdot 0.30 + DtR \cdot 0.10 + DtP \cdot 0.10 + SlR \cdot 0.20 + FdR \cdot 0.05 \quad (1)$$

where FS – final suitability;
SpR – slope reclass;
SoR – solar reclass;
DtR – distance to roads;
DtP – distance to powerlines;
SlR – soil reclass;
FdR – flood reclass.

Here, ConstraintLayers represent rasters with removed areas unsuitable for solar development (NoData). Normalization of Results. The resulting continuous suitability raster was reclassified into four categories: 2 – low suitability, 3 – moderate suitability, 4 – suitable, 5 – very suitable.

Identification of Suitable Areas. In the final step, territories suitable for solar park installation were identified, excluding protected areas, cultural heritage protection zones, hydrological constraints, forests, and built-up areas. The resulting suitability zones were visualized using thematic maps.

Results and discussion

The first step of the analysis involved determining the proportion of land in the Skirsnemunė eldership according to soil productivity scores (Fig. 3, blue bars). The proportion of land with soil productivity values below or equal to the national average, and the proportion above the national average, were calculated. (Fig. 3, orange line).

The results show that Skirsnemunė eldership is characterized by highly productive soils: only 9.4% of the land area falls below or equals the national average productivity score.

Subsequently, a multi-criteria GIS analysis was performed (Fig. 4a).

The results indicate that a substantial portion of the eldership exhibits high or moderate suitability for solar power installation, despite being one of the most fertile regions of Lithuania. This outcome is explained by favourable physical conditions: low terrain slope, uniformly high solar radiation levels, and dense road and power line networks.

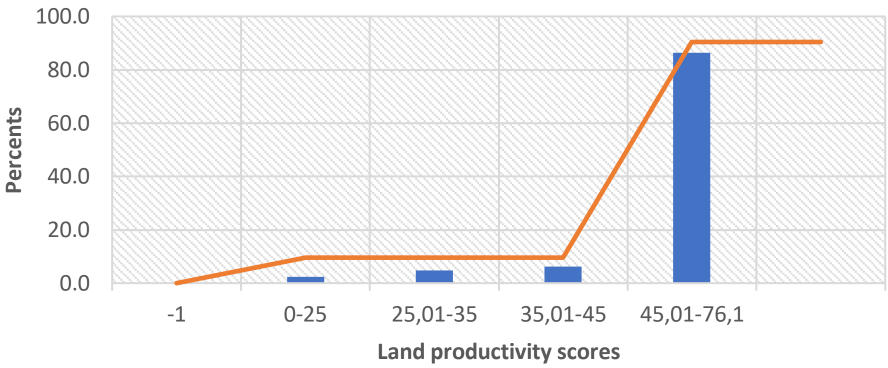

Fig. 3. **Land area distribution by soil productivity score**

The values of the final suitability model (RasterC_10) range from 1.55 to 4.93. Their spatial distribution reveals a distinct south–north gradient: the southern areas, located closer to roads and power infrastructure, show the highest suitability, while the northern part exhibits lower suitability due to forest cover, protected areas, and fragmented terrain (Fig. 4b).

After applying the exclusion mask (RasterC_1_su_kauke), unsuitable territories were fully removed from the dataset, ensuring that only locations where construction is physically and legally feasible were evaluated. The continuous suitability surface was then reclassified into three final categories. Zonal Statistics results (Fig. 4c) show the following: Highly suitable (Class 3) – 3595744 pixels (53.62%), Moderately suitable (Class 2) – 3095484 pixels (46.18%), Low suitability (Class 1) – 11107 pixels (0.17%). Thus, more than half of the entire eldership – excluding constrained zones – is highly suitable for solar park development.

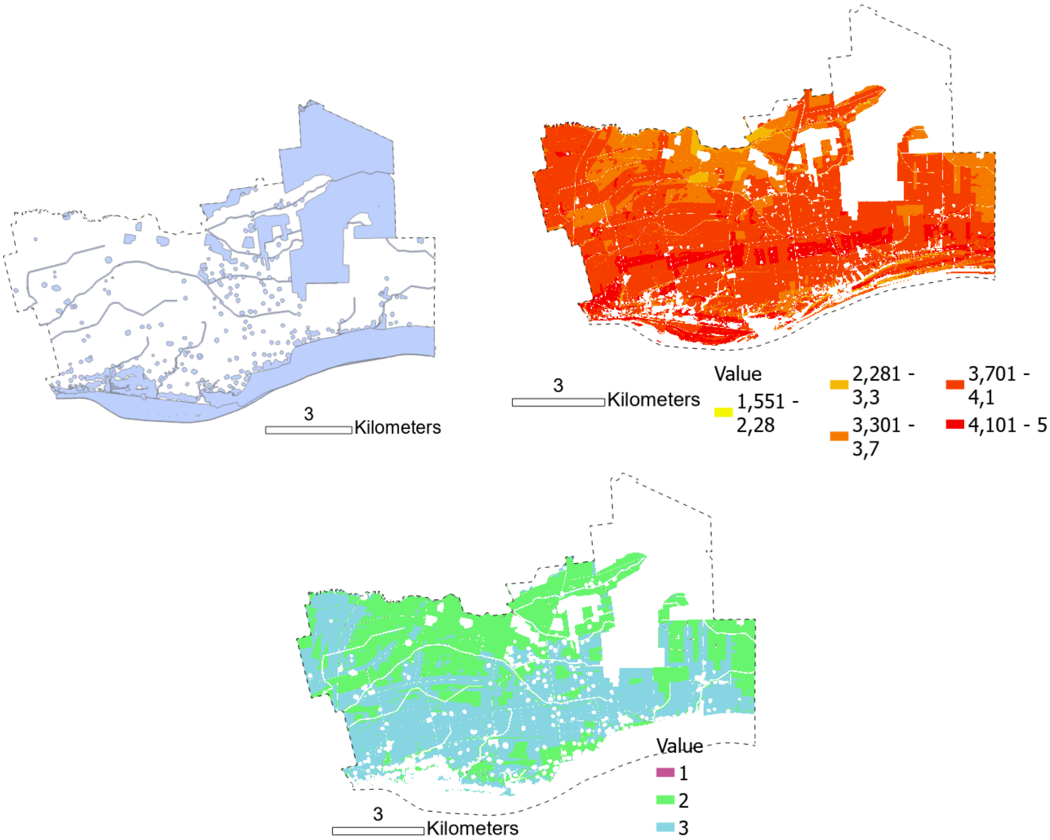

Fig. 4. **Modelling results:** a – exclusion and restricted zones for solar installation; b – land suitability for solar power plants; c – Zonal Statistics results

The results highlight an important regional development issue that intersects with the need to preserve high-productivity soils for agricultural purposes: highly fertile soils are not automatically unsuitable for solar energy development. Although soil productivity was included as a factor in the analysis, it acted more as an advisory-level criterion and did not determine suitability outcomes. Technical parameters – solar radiation, slope, proximity to roads and power lines – had a significantly greater influence on the final suitability classification. Consequently, even highly fertile lands fall into high-suitability categories for solar park installation.

The study results obtained in Skirsnemunė eldership, which indicate the dominance of technical parameters over soil productivity criteria, align with the findings of other researchers. Kocabaldir and Yücel (2020) analyzed the Çanakkale province in Turkey, presenting a fundamentally different, strict spatial planning method that integrates legal regulations and arable land preservation. In their model, high- and medium-productivity agricultural lands were treated not as weighted criteria but as absolute restrictive factors, eliminating these territories from the analysis entirely. Consequently, 95% of the province's territory was deemed entirely unsuitable for solar energy development. Comparing the Skirsnemunė and Çanakkale case studies reveals that integrating high-productivity soils into spatial planning models merely with advisory-level weights is distinctly insufficient for their effective protection. These areas must either be eliminated entirely, or their weights must be shifted from advisory to highly restrictive categories. It is evident that the Lithuanian legal framework regulating this sector requires structural revision to enforce stricter regulations. In national renewable energy planning, high-productivity agricultural land must be legally reclassified to enforce agricultural preservation. This legal transformation is necessary to prevent solar infrastructure expansion in areas characterized by the most fertile soils, regardless of their technical viability.

In Latvia, the protection of high-productivity land is not inherently treated as an exclusionary criterion for solar park installations. However, a regulated planning principle is established: municipalities must protect high-quality agricultural land by restricting land subdivision and modifications in land use. Degraded territories must be prioritized for infrastructure development.

In Estonia, the non-agricultural use of high-productivity soils is strictly safeguarded by spatial planning, construction procedure enforcement, and mandatory Environmental Impact Assessments.

From an agricultural perspective, fertile lands are valuable and finite natural resources. From an energy planning perspective, these exact territories are technically optimal due to ideal physical and infrastructural parameters. High-suitability territories generally coincide with flat terrain, excellent connectivity to roads and power grids, and favourable solar radiation levels. The study results confirm that Skirsnemunė eldership possesses substantial technical potential for solar energy development. Simultaneously, this potential directly conflicts with the preservation of fertile agricultural land. Given that high-productivity soils are statistically scarce in Lithuania, the enactment of explicit legal regulations to protect such territories during renewable energy planning must be enforced. This research establishes a baseline for future studies to model alternative development scenarios, specifically incorporating strict exclusionary thresholds for soils exceeding the national average productivity score.

Conclusions

1. In the Republic of Lithuania, medium- and high-productivity soils account for 57.4% of the total land area, where economic activity is strictly oriented toward agricultural production. Skirsnemunė eldership serves as a stark representative case: only approximately 9% of its land area falls at or below the national average soil productivity level.
2. Because current Lithuanian legislation provides only advisory guidelines regarding restrictions on installing solar energy infrastructure on highly productive soils, soil productivity was incorporated into the analytical model solely as a weighted recommendation rather than a definitive constraint. Consequently, despite the prevalence of highly fertile soils in Skirsnemunė eldership, the spatial analysis demonstrated that the vast majority of its evaluated land area is designated as highly suitable (53.62%) or moderately suitable (46.18%) for solar park development. Due to the lack of direct statutory regulations for the preservation of high-productivity soils, the land productivity score is not legally executed as an exclusionary criterion for construction. The existing advisory regulatory framework is functionally ineffective in preventing the conversion of valuable agricultural land into energy infrastructure sites.

Author contributions

The author is solely responsible for the content of this article. Text was translated and edited using the AI tool Copilot AI, all ideas, interpretations, and final editorial decisions reflect the author's original work and judgment.

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