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AGRI-PV BEYOND CROPLAND: A NATIONAL-SCALE SPATIAL SCREENING FRAMEWORK FOR SEMI-ARID AFRICA

Summary

This study presents a national-scale GIS-based screening framework to assess the suitability of Agri-Photovoltaic (Agri-PV) systems in semi-arid Namibia, extending the concept beyond cropland to grazing-dominated landscapes. Key criteria include solar irradiation, slope, land cover compatibility, rainfall, temperature, and transmission availability, while protected areas are excluded. Results highlight central and north-central regions as highly suitable, with moderate potential in western and southern areas. The framework supports early-stage planning for decentralized and grid-compatible Agri-PV deployment in semi-arid African rangelands.

Keywords: Agri-Photovoltaics, Namibia, Semi-arid Africa, Spatial suitability, Decentralized energy, Rangeland energy systems

Field of application for the findings: Renewable energy planning and sustainable land-use management in semi-arid regions.

Addressed audience: Energy planners, policymakers, researchers in solar and sustainable development.

1. Introduction

The rapid expansion of solar photovoltaic (PV) systems is critical to the global energy transition, especially by given favorable circumstances such as reducing cost, matured and robust installation techniques, supportive policies as well as extreme climate change events. However, large-scale ground-mounted PV has intensified land-use competition, particularly where agriculture, biodiversity, and rural livelihoods depend on limited land resources. This highlights the need for land-efficient models. Agri-PV, which combines agricultural production and solar electricity generation on the same land, offers a promising solution for the duel land use. The existing research has largely focused on crop-based systems in Europe and Asia and mainly considered the integration of PV with cropland integration. While, in the majority part of Sub-Saharan Africa (SSA), agriculture is dominated by livestock-based, extensive grazing systems in semi-arid environments rather than intensive cropping / agriculture. This leads to the research question whether Agri-PV can be suitable / adapted to the rangeland contexts. Despite high solar potential, spatial planning studies on grazing-compatible Agri-PV in Africa remain limited and that is considered as the gap in the research. Namibia, a country located in SSA, represents a particularly relevant case due to its exceptional solar resources, low population density, vast semi-arid rangelands, and extensive livestock farming systems. With uneven rural electrification and growing demand for decentralized energy solutions, grazing-compatible Agri-PV could provide both electricity generation and climate-adaptive land use. However, systematic national-scale spatial assessments identifying suitable areas are lacking, and renewable energy planning is often constrained by limited data and institutional capacity. This study develops a national-scale, multi-criteria GIS-based screening framework to evaluate the spatial suitability of Agri-PV deployment in Namibia, explicitly extending the concept beyond cropland systems. Rather than providing site-specific optimization, the study establishes a strategic planning tool to highlight spatial opportunities and trade-offs. By repositioning Agri-PV within semi-arid rangelands, it contributes to sustainable solar deployment in African drylands and offers a transferable framework for similar regions.

2. Methodology

This study applies a national-scale multi-criteria spatial screening framework to assess the suitability of Agri-PV systems in Namibia, explicitly extending the concept beyond cropland toward grazing-dominated semi-arid landscapes. The methodology follows a weighted overlay approach, integrating technical, agro-environmental, and infrastructural criteria within a standardized 1–5 suitability scale.

Six spatial indicators were considered: (i) annual global horizontal irradiation (GHI), (ii) terrain slope, (iii) land cover compatibility, (iv) annual rainfall, (v) mean annual temperature, and (vi) transmission network availability. Protected areas were treated as exclusion zones and masked from the analysis. Solar irradiation represents the primary technical driver of photovoltaic performance, while slope influences construction feasibility and erosion risk. Land cover was classified according to agricultural compatibility, with grassland and cropland assigned the highest suitability due to their compatibility with grazing-based Agri-PV configurations. Rainfall and temperature were included to reflect agro-climatic conditions relevant to rangeland productivity and livestock heat stress. Transmission network density was incorporated as a planning-enabling factor, distinguishing regions with stronger grid-integration potential from more remote areas where decentralized Agri-PV systems may be more appropriate.

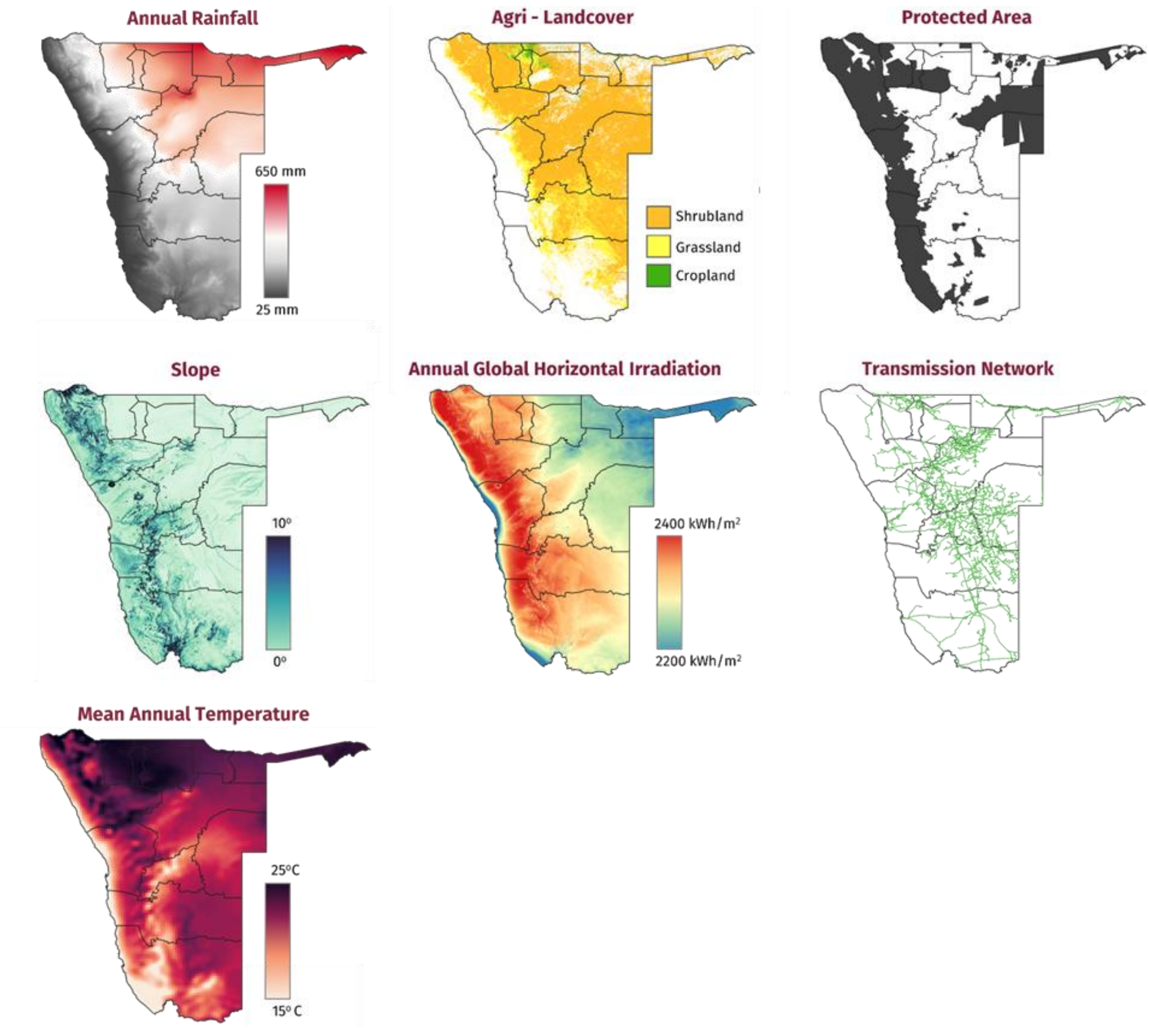

Fig. 1: Considered Criteria for the analysis in the presented study

Each criterion was reclassified into five suitability classes ranging from 1 (very low suitability) to 5 (very high suitability) based on literature-informed thresholds and Namibia-specific climatic and land-use conditions. A weighted linear combination was then applied to calculate the overall suitability index:

$$S = \sum w_i \cdot C_i$$

where C_i represents the standardized criterion score and w_i the assigned weight based on the literature review and similar existing study available on global scale.

For the preliminary results presented in this study, solar resource was assigned the highest weight (30%), followed by land cover compatibility (20%), slope (15%), transmission availability (15%), rainfall (10%), and temperature (10%). This weighting structure reflects the technical dominance of solar potential while maintaining the agro-environmental logic of grazing-compatible deployment. The resulting composite suitability index was classified into five final categories (1–5), representing very low to very high suitability. The analysis is intended as a strategic screening tool rather than site-level optimization. It identifies priority regions for decentralized and grid-compatible Agri-PV development while highlighting spatial trade-offs between solar potential, environmental conditions, and infrastructure availability.

3. Results

The overall Agri-PV suitability map is presented in Fig. 2. Central and north-central regions, including Khomas, Otjozondjupa, Oshana, and Oshikoto, demonstrate consistently high suitability. These areas combine strong solar irradiation, relatively flat terrain, grazing-compatible landscapes, and has comparatively developed transmission infrastructure. This convergence of favorable conditions indicates strong potential for grid-connected Agri-PV systems, where electricity generation can be integrated into the national transmission network while maintaining livestock-based land use. From a planning perspective, these regions represent priority zones for near-term implementation with lower infrastructure barriers and minimal land-use conflicts.

In contrast, western and southern regions such as Erongo, Kunene, and Karas present excellent solar resources but lower rainfall and limited transmission infrastructure. Although their suitability index is moderate, these regions present strong opportunities for decentralized Agri-PV applications. In sparsely populated rangeland environments, Agri-PV systems can function as localized energy solutions supporting rural electrification, solar water pumping, livestock management infrastructure, cold storage, or hybrid mini-grid configurations. In such contexts, the role of Agri-PV extends beyond electricity export to the grid and becomes a key component of distributed rural energy systems. Northern regions, including Kavango East, Kavango West, and Zambezi, show moderate-to-high suitability due to favorable rainfall conditions and grazing-compatible land cover. These regions may benefit from hybrid deployment models that combine decentralized energy supply with selective grid integration as transmission infrastructure expands. Beyond energy generation, the results highlight the broader potential of Agri-PV systems in grazing-dominated landscapes. This can create localized microclimatic effects, including partial shading, reduced soil temperature, and improved soil moisture retention. In semi-arid environments, these conditions may enhance rangeland productivity and reduce drought stress on grazing vegetation. In some locations, the modified microclimate could also support the drought-tolerant fodder crops / mixed agricultural ecosystem, potentially increasing land productivity without replacing livestock activities.

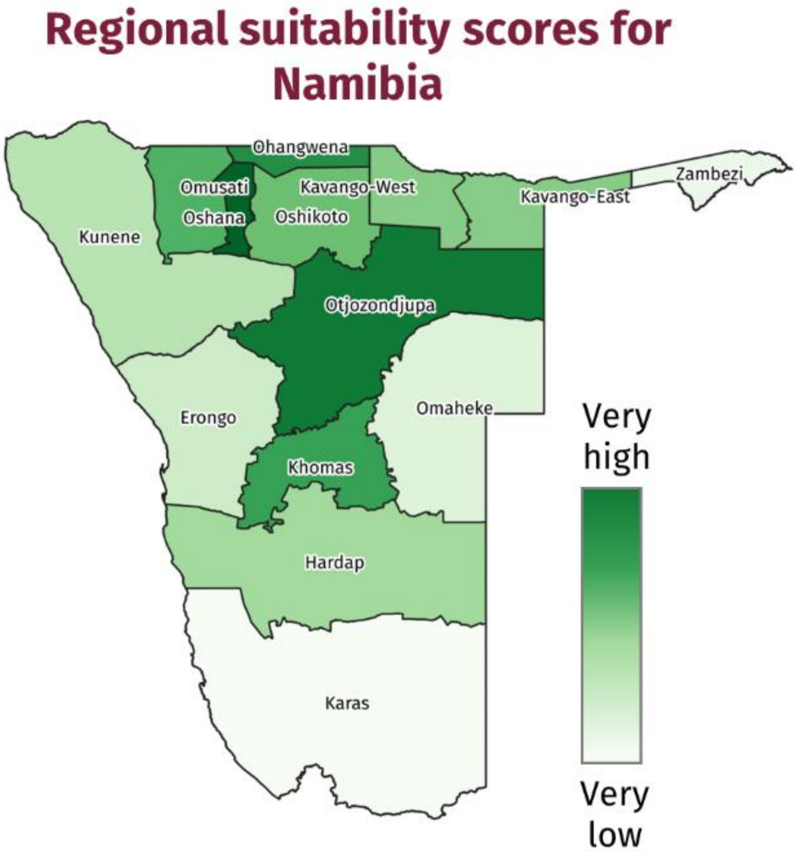

Fig. 2: Agri-PV Suitability Map for rangeland in Namibia (based on the preliminary results)

Overall, the analysis demonstrates that Namibia's Agri-PV opportunity space is not limited by cropland availability. Instead, extensive grazing systems provide a viable foundation for dual land use combining renewable energy production with rangeland management. The spatial differentiation between near-grid and remote regions provides a structured basis for aligning Agri-PV deployment with electrification priorities, infrastructure development strategies, and climate-resilient land-use planning. The proposed framework therefore offers a transferable planning approach for assessing grazing-compatible Agri-PV deployment in semi-arid regions across Sub-Saharan Africa.