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The Future of Agri-PV in Central Asia: A GIS-Based Spatial Screening Framework

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Abstract

Central Asia combines extensive agricultural land, high solar resources and increasing pressure on land, water and energy systems, creating a relevant context for agrivoltaic (Agri-PV) deployment. This study develops a spatially explicit GIS-based multi-criteria framework for regional-scale screening of Agri-PV potential across Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan and Afghanistan. Five spatial criteria were considered: cropland occurrence, global horizontal irradiation, terrain slope, maximum air temperature and proximity to the electricity grid. Each criterion was transformed to a dimensionless 0–1 score using criterion-specific membership functions and combined through a multiplicative overlay. The resulting composite index represents technical and infrastructural screening potential on existing cropland rather than crop-specific agronomic suitability. Approximately 207,276 km^2 of cropland received a non-zero composite score under the baseline screening definition. The largest absolute areas occur in Qostanay, North Kazakhstan and Aqmola, whereas several regions in Uzbekistan and Turkmenistan exhibit higher median composite scores. A threshold-sensitivity analysis shows that administrative-region rankings remain highly stable for minimum composite scores of 0.1–0.3, with Spearman rank correlations of 0.998, 0.992 and 0.976 relative to the baseline ranking, respectively. PV resource quality within screened-in cropland is additionally characterized using specific electricity yield rather than an assumed installed-capacity potential. The framework is intended for regional strategic screening; crop-specific performance, irrigation requirements, hydrology and project-level feasibility are not explicitly modelled. Potential Water–Energy–Food nexus implications are therefore interpreted as hypotheses for subsequent assessment rather than as benefits directly quantified by the GIS model.

Keywords: Agrivoltaics; Agri-PV; Central Asia; GIS-based screening; multi-criteria assessment; photovoltaic yield; Water–Energy–Food nexus; agricultural land

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1. Introduction

1.1. Background and Context

Central Asia represents a strongly coupled Water–Energy–Food (WEF) system in which agricultural production is closely linked to irrigation and transboundary hydrology [1]. In Uzbekistan and Turkmenistan, agriculture accounts for a dominant share of freshwater withdrawals, while the Amu Darya and Syr Darya form the principal water sources for

major irrigated agricultural regions [2,3]. Long-term abstraction, conveyance losses and inefficient irrigation have contributed to declining downstream water availability and to the desiccation of the Aral Sea, with associated salinization, land degradation and ecological impacts [4] (c.f. Figure 1).

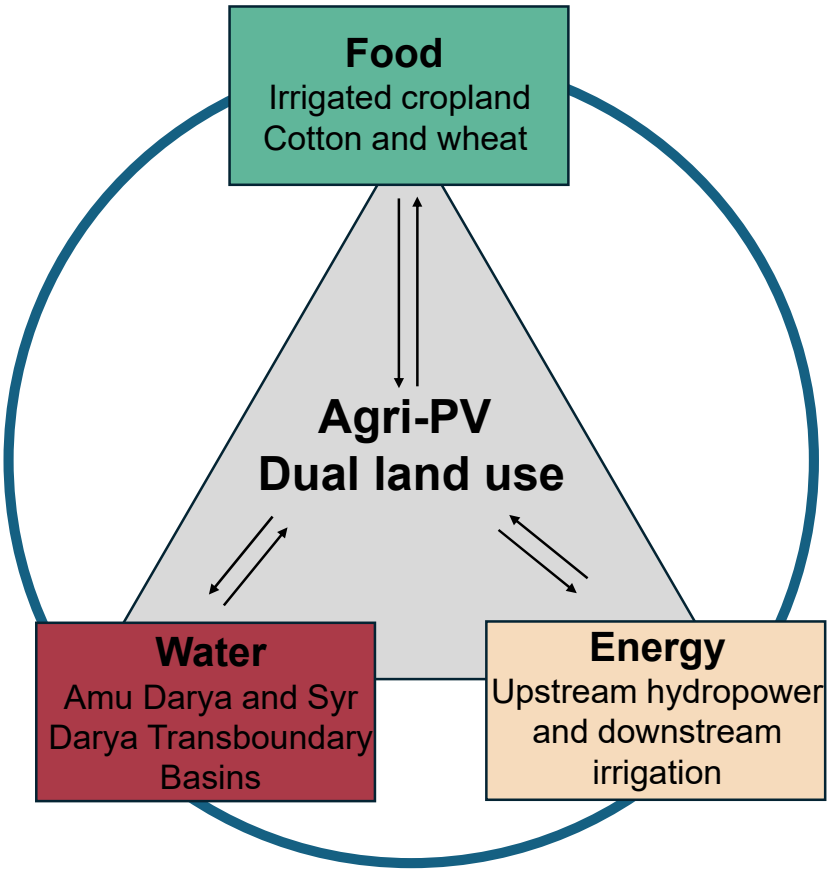


Figure 1. Conceptual Water–Energy–Food nexus in Central Asia.

Climate change is expected to intensify these pressures through rising temperatures, higher evapotranspiration and greater hydroclimatic variability [5–7]. At the same time, Central Asia possesses substantial solar resources, with GHI commonly reaching approximately 1500–2000 kWh/m/year in many parts of the region [8]. Expansion of ground-mounted PV can therefore support energy diversification, but it may also create land-use competition where solar development overlaps productive agricultural land.

Agri-PV offers a dual-land-use option by combining agricultural activity and PV electricity production on the same land unit. Experimental studies show that PV-induced shading can modify near-surface microclimate and, for selected crops and system configurations, reduce evapotranspiration or irrigation requirements [9–13]. These responses are crop-, climate- and design-specific and cannot be inferred from land-use information alone.

Regional deployment consequently depends not only on solar resource but also on the spatial coincidence of agricultural land, terrain conditions and infrastructure access. GIS-based multi-criteria analysis provides a transparent means of integrating these heterogeneous spatial factors for strategic screening. The purpose of the present assessment is therefore not to determine crop-specific Agri-PV feasibility, but to identify agricultural areas where favourable technical and infrastructural conditions coincide and where more detailed agronomic and project-level assessment may subsequently be justified.

1.2. Agri-PV in the Central Asian Context

The relevance of Agri-PV in Central Asia arises from the convergence of high solar resource availability, extensive agricultural land and growing pressure on land and water resources [14]. In contrast to conventional ground-mounted PV, Agri-PV is designed to retain an agricultural function while introducing electricity generation. This dual use can be particularly relevant where renewable-energy expansion would otherwise compete with cropland. However, the technical possibility of co-location should not be equated with agronomic suitability, because crop response depends on shading tolerance, water demand, management practices and system geometry.

Potential hydrological benefits are especially relevant to the region's irrigation-dependent agricultural systems. Previous studies have reported reductions in evapotranspiration or crop water demand under selected Agri-PV configurations [11–13], but the magnitude and even direction of agronomic responses vary with crop, climate and design. The present study therefore treats WEF benefits as a motivation for spatial screening and as a topic for interpretation after the GIS analysis; it does not quantify irrigation savings, crop yield or hydrological impacts.

1.3. Current Status of Agri-PV Research and Deployment in Central Asia

GIS-based multi-criteria approaches have already been applied to Agri-PV screening at regional and national scales [15–19]. These studies demonstrate that the selected criteria and aggregation rules depend strongly on the planning context. Some assessments incorporate crop type, soil, regulation or economic criteria, whereas others focus primarily on technical feasibility. The novelty of the present study therefore does not lie in introducing a new optimization algorithm. The contribution is instead regional and comparative: a harmonized transnational screening framework is applied across Central Asia, where agricultural systems range from the extensive grain belt of northern Kazakhstan to highly irrigation-dependent agricultural corridors in Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan and northern Afghanistan. Applying the same criteria across national boundaries enables direct comparison of the spatial extent and relative quality of technically favourable cropland. The analysis intentionally distinguishes regional technical screening from crop-specific agronomic suitability. Crop type, shading tolerance, irrigation intensity, soil characteristics, salinity, agricultural productivity and farm management are not explicitly represented. The resulting index therefore identifies where cropland coincides with favourable solar, terrain, temperature and grid-access conditions; it does not demonstrate that a particular crop or farm is suitable for Agri-PV.

Relative to previous GIS-based Agri-PV studies, the present work contributes (i) a harmonized six-country screening at sub-national scale, (ii) an explicit non-compensatory multiplicative formulation, (iii) separate reporting of the extent of screened-in cropland and the quality of its composite score, (iv) characterization of specific PV yield within the retained cropland, and (v) a threshold-sensitivity analysis to evaluate the stability of regional priorities. The WEF nexus is used subsequently as an interpretative framework rather than as a quantitatively modelled outcome.

1.4. Research Objective

This study aims to develop and evaluate a harmonized GIS-based multi-criteria screening framework for identifying technically favourable cropland for potential Agri-PV deployment across Central Asia. Five spatial criteria representing agricultural land occurrence, solar resource, terrain, thermal exposure and electricity-grid accessibility are integrated through criterion-specific membership functions and a multiplicative aggregation rule. The resulting index is used to examine how the extent and relative qual-

ity of screened-in cropland vary among countries and first-level administrative regions. A threshold-sensitivity analysis evaluates the stability of regional priorities, while specific PV yield is used to characterize solar-electricity resource quality independently of assumed Agri-PV capacity density. The framework is intended for regional strategic screening and prioritization rather than crop-specific agronomic or project-level feasibility assessment.

2. Materials and Methods

2.1. Analytical Framework

The study applies a GIS-based fuzzy multi-criteria screening framework comprising three analytical stages. First, five spatial criteria representing cropland occurrence, solar resource, terrain, thermal conditions and electricity-grid accessibility were transformed to dimensionless scores between 0 and 1 using criterion-specific membership functions. Second, the five standardized layers were combined using a multiplicative aggregation rule to derive a composite technical screening index. Third, the resulting raster was aggregated to first-level administrative units to quantify the spatial extent and relative quality of technically favourable cropland. PV resource quality within retained areas was characterized using the Global Solar Atlas-specific PV electricity yield (PVOUT). The composite index is interpreted as a regional technical and infrastructural screening metric and not as a measure of crop-specific agronomic suitability.

2.2. Study Area

The study area comprises Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan and Kyrgyzstan together with Afghanistan. Afghanistan was included because its northern territory is hydrologically connected to the Amu Darya basin and because the analysis aims to represent the broader transboundary resource system; this inclusion does not imply that Afghanistan is conventionally classified together with the five post-Soviet Central Asian republics. The study extent encompasses the extensive grain belt of northern Kazakhstan, intensively irrigated valleys and oases in the southern republics, and the agriculturally used valleys of northern and central Afghanistan.

2.3. Spatial Data and Screening Criteria

Five spatial criteria were used to characterize regional-scale technical and infrastructural conditions relevant to potential Agri-PV deployment (Table 1). Existing cropland was represented using ESA WorldCover, while GHI, terrain slope, maximum air temperature and grid proximity represented broad resource, construction and accessibility conditions. Each criterion was transformed to a dimensionless score from 0 (least favourable or excluded) to 1 (most favourable). The cropland layer acts as an agricultural-land mask and should not be interpreted as crop-specific agronomic suitability. Cropland was extracted from ESA WorldCover v200 [20]. Pixels classified as cropland (class 40) were assigned a value of 1 and all other land-cover classes a value of 0. This binary mask restricts the analysis to existing cropland but does not represent crop type, yield, shade tolerance, irrigation requirement or soil quality. Grid proximity was derived from the World Bank global electricity-infrastructure dataset [21]. Euclidean distance to the mapped grid was calculated and transformed using an inverse linear function, with a score of 1 at the grid and 0 at 3 km and beyond, following the baseline screening assumption adopted from comparable solar-siting work [22]. The 3 km threshold is treated as a screening assumption rather than a universal technical or economic limit; projects at greater distances may remain feasible depending on connection capacity, terrain and project scale. Terrain slope was derived from SRTM and transformed using an inverse linear function, with flat terrain assigned 1 and slopes at or above 8.53° (equivalent to 15%) assigned 0 [17].

Table 1. Spatial datasets and preprocessing used in the regional Agri-PV screening assessment.

Parameter	Resolution	Dataset	Source
Land-cover	10 m	ESA WorldCover 10 m 2021 v200	Google Earth Engine
Slope	90 m	Shuttle Radar Topographic Mission (SRTM)	Google Earth Engine
Average maximum annual air temperature (2014–2024)	11,132 m	ERA5-Land	Google Earth Engine
Distance to the electricity grid	1000 m	World Bank Map of Global Electricity 2026	World Bank data catalogue
Solar irradiation	1000 m	Global Horizontal Irradiation	SOLAR GIS

Maximum annual air temperature was obtained from ERA5-Land and represented as a relative thermal screening penalty above 25 °C following the formulation adopted by Fattoruso et al. [17]. GHI was obtained from SolarGIS; values below 500 kWh/m/year were assigned 0 and the score increased linearly to 1 at 2200 kWh/m/year. The temperature upper endpoint used in the normalization is a mathematical extrapolation of the adopted linear loss relationship and should not be interpreted as a physical PV operating limit.

2.4. Criterion Standardization and Membership Functions

For a pixel i, each criterion was transformed to a membership score between 0 and 1. The implemented functions were: cropland L = 1 for ESA WorldCover 2026 class 40 and 0 otherwise; grid distance $D = 1 - d/3000$ for $0 \leq d \leq 3000$ m and 0 for $d > 3000$ m; slope $S = 1 - s/8.53$ for $0 \leq s \leq 8.53°$ and 0 for steeper slopes; temperature T = 1 for $T < 25$ °C and $T = 1 - (T - 25)/(167 - 25)$ for $T \geq 25$ °C; and solar irradiation G = 0 for $G < 500$ kWh/m/year, $G = (G - 500)/(2200 - 500)$ for $500 \leq G < 2200$, and 1 at the upper bound. These equations reproduce the screening rules used to generate the composite raster.

2.5. Multiplicative Aggregation

The composite screening score for pixel i was calculated using Equation (1)

$$S_i = \mu_{L,i} \times \mu_{G,i} \times \mu_{S,i} \times \mu_{T,i} \times \mu_{D,i} \quad (1)$$

where

S_i = composite Agri-PV screening score for pixel i
$\mu_{L,i}$ = land-cover/cropland membership value
$\mu_{G,i}$ = global horizontal irradiation membership value
$\mu_{S,i}$ = slope membership value
$\mu_{T,i}$ = maximum air temperature membership value
$\mu_{D,i}$ = grid-distance membership value

The product operator implements a non-compensatory limiting-factor rule: a zero score for any criterion excludes the pixel, while favourable performance on another criterion cannot compensate for complete exclusion. The resulting value is therefore interpreted as a relative screening score rather than a probability of Agri-PV feasibility.

2.6. Administrative Aggregation and Specific PV Yield

The composite raster was aggregated to administrative units. Cell areas were calculated geodesically and summed for pixels with non-zero composite scores. For each administrative unit, the median composite score was used to characterize the relative

quality of screened-in cropland. Solar-electricity resource quality was characterized independently using the Global Solar Atlas PVOUT 2026 raster, expressed as annual specific electricity yield (kWh/kWp·year). PVOUT was summarized within screened-in cropland using regional medians. Absolute electricity-generation potential was not calculated because doing so would require explicit assumptions about Agri-PV capacity density, module arrangement, row spacing, ground coverage ratio and system losses.

2.7. Threshold-Sensitivity Analysis

The stability of regional prioritization was evaluated by progressively increasing the minimum composite score required to retain a pixel. Five thresholds were assessed: $S > 0$, $S > 0.1$, $S > 0.2$, $S > 0.3$ and $S > 0.4$. For each threshold, retained cropland area was recalculated for all 82 first-level administrative units. Ranking stability relative to the baseline $S > 0$ case was quantified using Spearman's rank correlation coefficient. This test evaluates whether the identification of priority regions depends strongly on accepting all non-zero composite scores or remains stable under increasingly stringent screening conditions.

3. Results

3.1. Spatial Patterns of the Five Screening Criteria

The five screening criteria exhibit distinct spatial patterns across the study area (Figure 2). Solar irradiation generally increases from north to south, whereas grid accessibility is concentrated along electricity-infrastructure corridors. Temperature penalties are stronger in the hottest lowland areas, while terrain suitability is highest across broad lowlands and declines sharply in the Tien Shan, Pamir and other mountainous regions. The cropland mask is concentrated in the northern Kazakh grain belt and in the irrigated valleys and oases of the southern republics. These contrasting patterns demonstrate that no single criterion determines the final screening outcome; favourable locations emerge where cropland coincides with acceptable resource, terrain and infrastructure conditions.

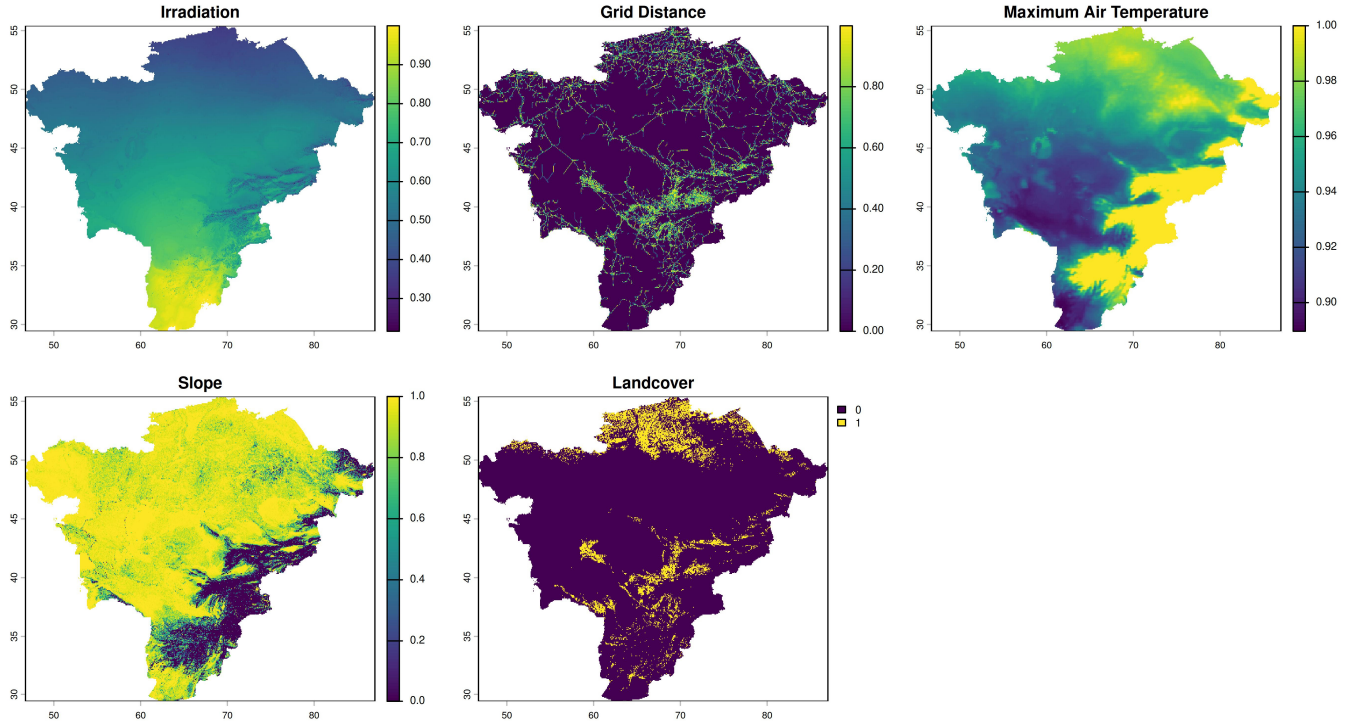


Figure 2. Spatial distribution of the five standardized criterion layers used in the regional Agri-PV screening assessment.

3.2. Composite Technical Screening Index

Multiplying the five standardized criterion layers yields the composite technical screening index shown in Figure 3. Non-zero scores are spatially clustered along major agricultural areas, including the Amu Darya and Syr Darya agricultural corridors, the Fergana Valley and the northern Kazakh grain belt. Large desert and high-relief areas are excluded primarily because they do not satisfy the cropland, terrain or grid-access conditions. The map should therefore be interpreted as a regional prioritization layer identifying where the five screening criteria coincide, not as evidence of crop-specific Agri-PV feasibility.

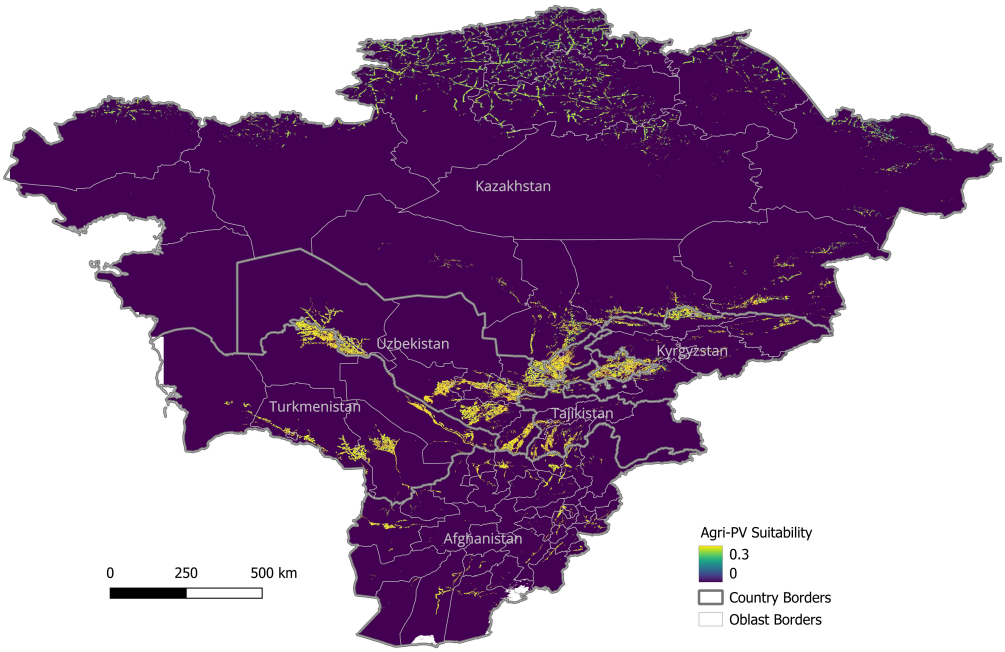


Figure 3. Composite technical screening index for potential Agri-PV deployment in Central Asia.

Country-level maps (Figure 4) reveal contrasting spatial configurations. Uzbekistan, Turkmenistan, Tajikistan and Kyrgyzstan contain relatively compact clusters associated with established agricultural valleys and oases, whereas Kazakhstan's screened-in cropland is distributed more broadly across the northern grain belt. Afghanistan displays a fragmented valley-following pattern. These differences indicate that the absolute extent of screened-in cropland and the spatial concentration of high composite scores represent distinct planning dimensions.

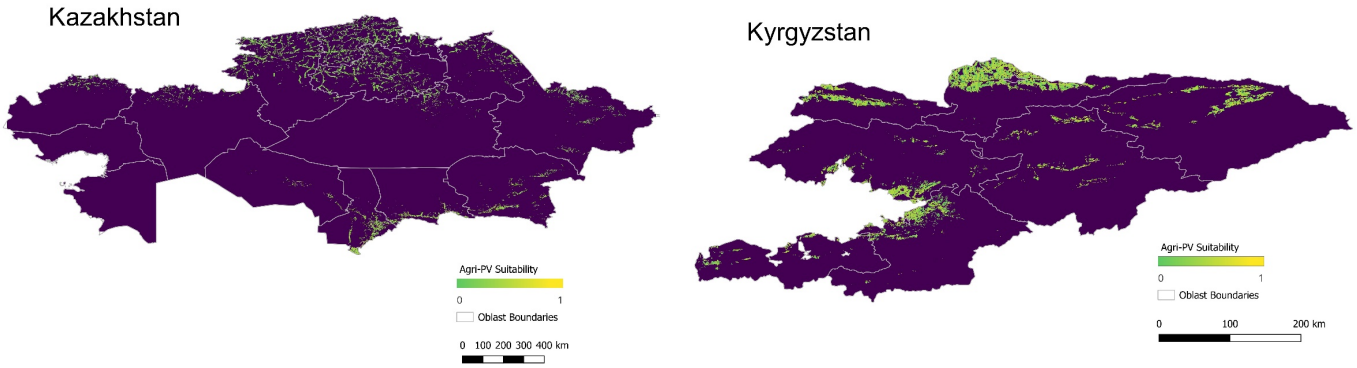


Figure 4. *Cont.*

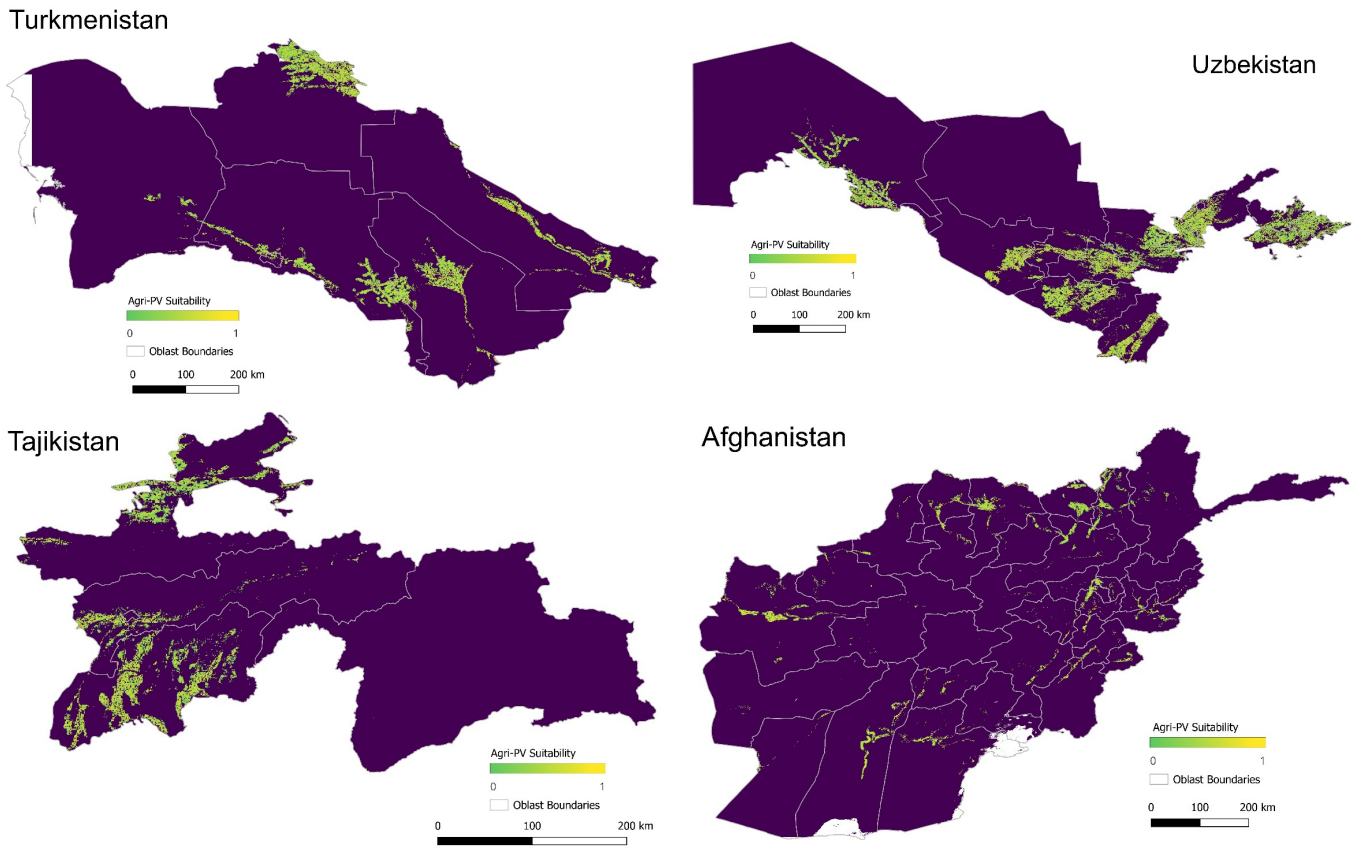


Figure 4. Composite technical screening index shown separately for each of the six study countries.

3.3. Spatial Extent of Technically Favourable Cropland

Under the baseline definition, in which all pixels with a composite score above zero are retained, approximately 207,276 km^2 of cropland passes the regional technical screening criteria. Kazakhstan accounts for the largest share at approximately 96,443 km^2, followed by Uzbekistan (51,745 km^2), Turkmenistan (24,467 km^2), Afghanistan (14,174 km^2), Kyrgyzstan (11,812 km^2) and Tajikistan (8634 km^2). At first-level administrative scale, Qostanay (18,080 km^2), North Kazakhstan (17,892 km^2) and Aqmola (17,718 km^2) contain the largest retained areas, followed by South Kazakhstan (8926 km^2), Qashqadaryo (7682 km^2) and Daoguz (7472 km^2). These values represent cropland retained by the technical screening model and should not be interpreted as land demonstrated to be agronomically suitable or legally available for Agri-PV development.

3.4. Regional Quality of the Composite Screening Index

The extent of screened-in cropland does not by itself describe the quality of the retained locations. Median composite scores therefore provide a complementary measure of how consistently favourable the five criteria are within each administrative unit. Kazakhstan contains the largest total screened-in area but several of its northern regions have comparatively modest median scores, whereas regions in Uzbekistan and Turkmenistan generally exhibit higher median values (c.f. Figure 5). This distinction separates deployment scale, represented by retained area, from the relative quality of the combined screening conditions.

Figure 6 summarizes the distribution of administrative-unit median composite scores by country. Kazakhstan exhibits the lowest country-level median of regional scores, while Uzbekistan, Turkmenistan and Afghanistan contain a larger share of high-scoring administrative units. This reinforces the distinction between extensive land availability and consistently favourable screening conditions.

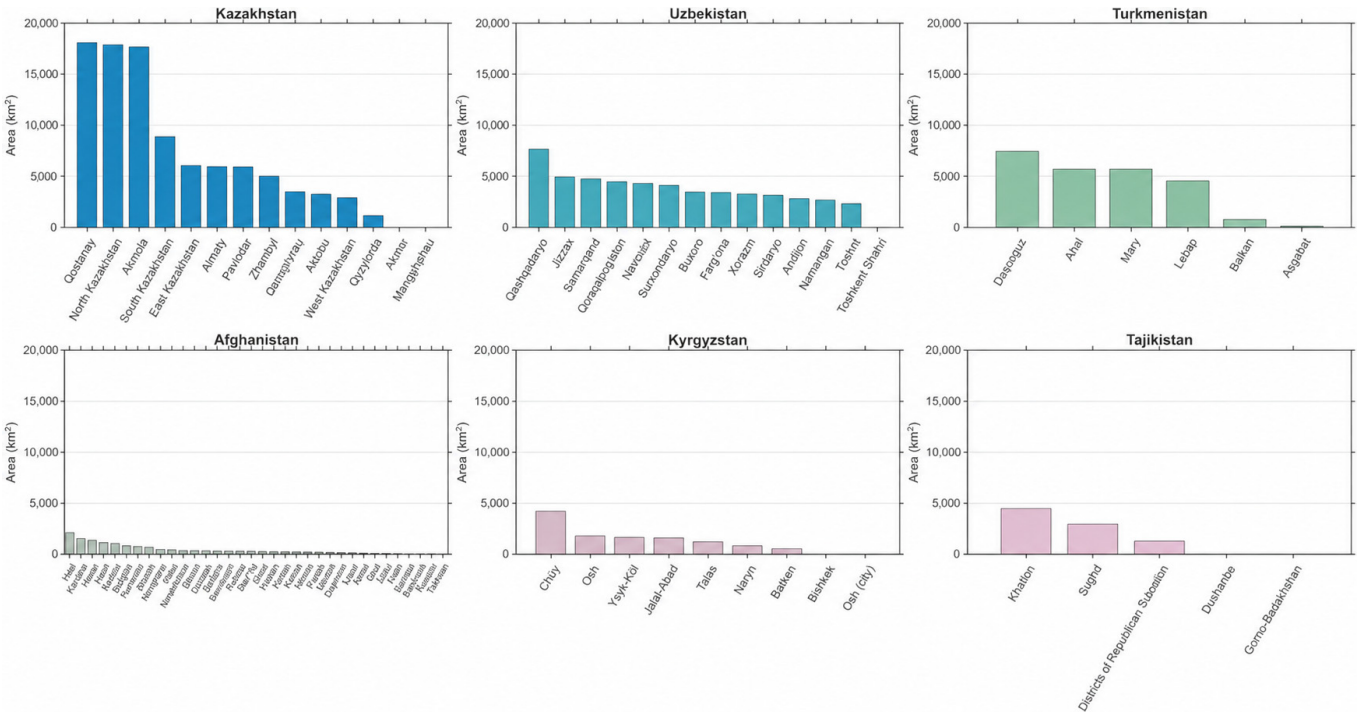


Figure 5. Spatial extent of cropland retained by the baseline technical Agri-PV screening framework at first-level administrative scale.

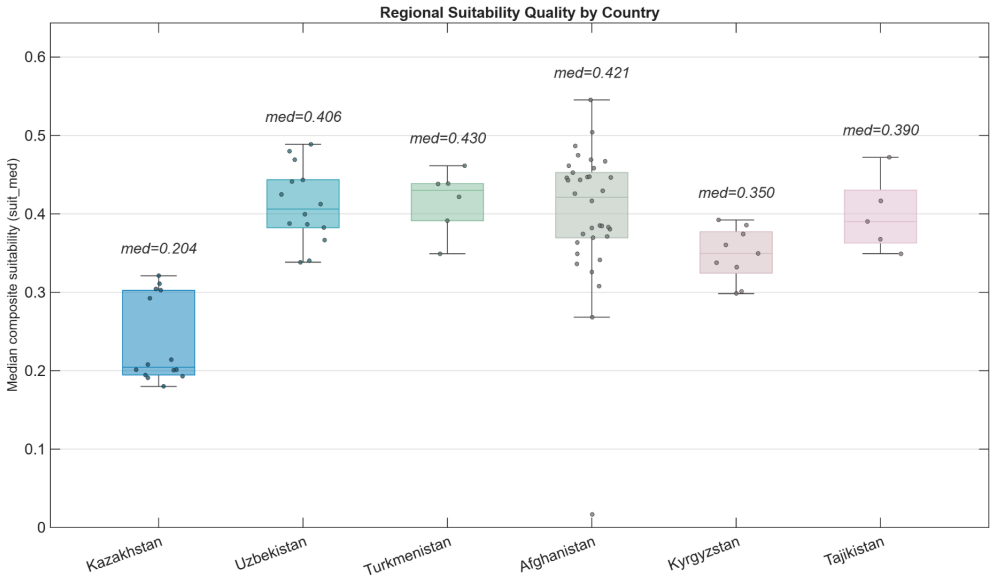


Figure 6. Distribution of first-level administrative-unit median composite screening scores by country.

3.5. Specific PV Yield Within Screened-In Cropland

The Global Solar Atlas PVOUT layer was used to characterize specific PV electricity yield within screened-in cropland rather than to estimate absolute regional electricity generation. Median specific yields are lowest in several northern Kazakh regions, including North Kazakhstan (approximately 1175 kWh/kWp·year), Qostanay (1217 kWh/kWp·year) and Aqmola (1232 kWh/kWp·year). In contrast, the highest regional medians occur in Afghanistan, including Ghazni (1976 kWh/kWp·year), Paktika (1945 kWh/kWp·year) and Ghor (1941 kWh/kWp·year). The result demonstrates that regions with the largest retained cropland areas are not necessarily those with the highest solar-electricity yield per unit of installed PV capacity. Absolute generation potential is not reported because it would

depend on Agri-PV design and capacity-density assumptions that are not specified at regional scale (Figure 7).

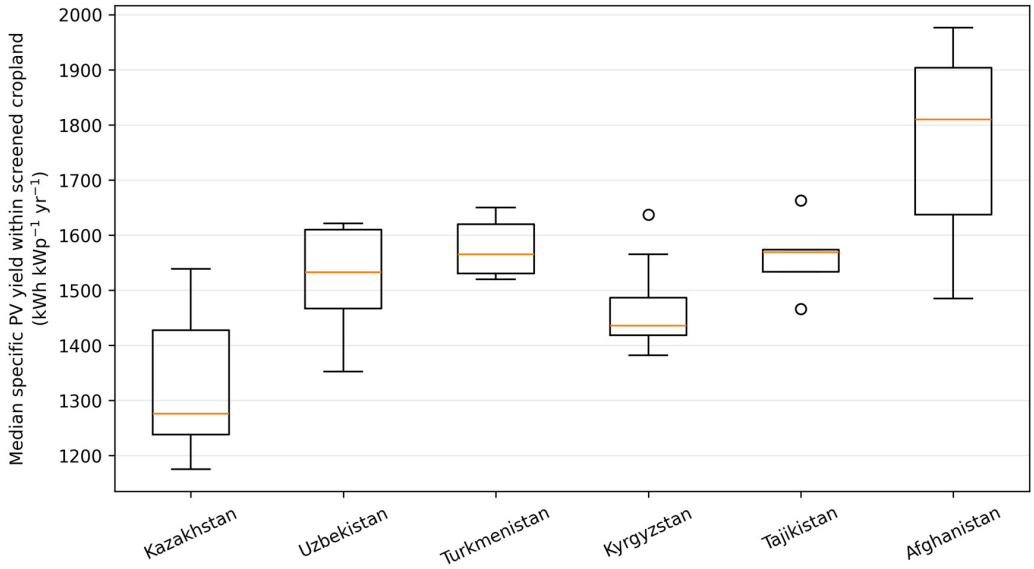


Figure 7. Distribution of administrative-region median specific PV yield within screened-in cropland by country.

3.6. Sensitivity of Regional Priorities

The spatial prioritization remains highly stable under moderate increases in the minimum composite screening score. Retained cropland area decreases from 207,276 km^2 for the baseline $S > 0$ case to 177,923 km^2, 144,374 km^2, 105,460 km^2 and 63,764 km^2 for thresholds of 0.1, 0.2, 0.3 and 0.4, respectively. Despite this progressive reduction, administrative-region rankings remain strongly correlated with the baseline for thresholds up to 0.3. Spearman rank correlations are 0.998 for $S > 0.1$, 0.992 for $S > 0.2$ and 0.976 for $S > 0.3$. At $S > 0.4$, the correlation decreases to 0.759, indicating a more substantial shift toward regions with consistently high composite scores. Under the stricter thresholds, compact high-scoring regions in Uzbekistan and Turkmenistan gain relative importance compared with the extensive northern Kazakh cropland belt (c.f. Figure 8).

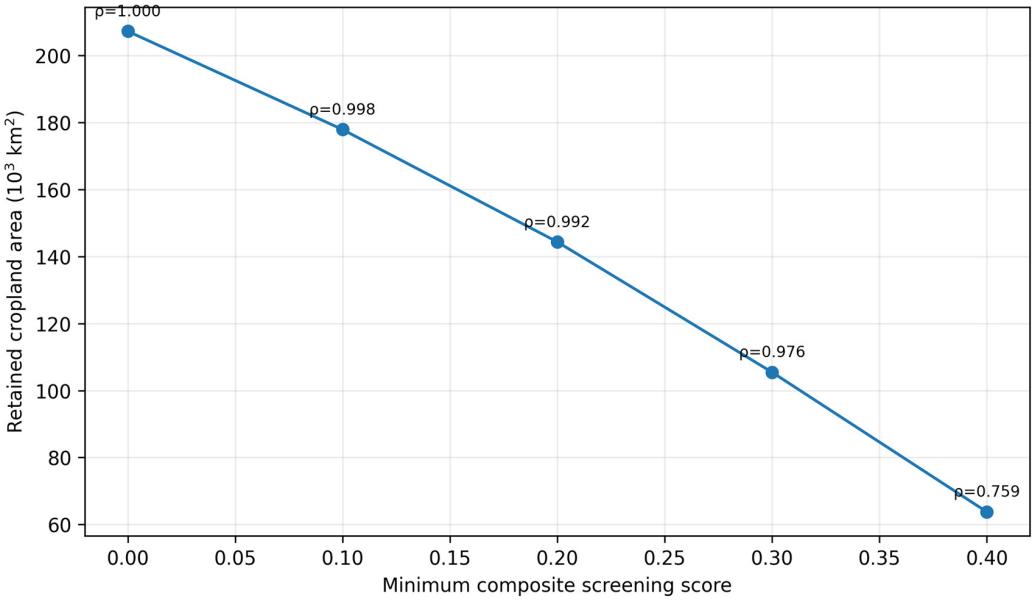


Figure 8. Sensitivity of retained cropland area to the minimum composite screening score.

4. Discussion

The results provide a regional screening perspective rather than a site-selection result. Their main value lies in showing how the extent of cropland, the quality of the combined technical conditions and the specific PV resource vary independently across Central Asia. Northern Kazakhstan dominates in retained area, while several regions farther south achieve higher composite scores and specific PV yields. This differentiation is relevant for prioritizing where more detailed agronomic, grid and economic assessments should be undertaken.

4.1. Regional Interpretation and Comparison with Previous GIS Studies

The contrast between northern Kazakhstan and the southern republics illustrates why regional Agri-PV planning should not rely on solar irradiation alone. Large cropland extent can compensate for moderate solar-resource quality when the objective is to identify broad deployment opportunities, whereas smaller agricultural regions may offer more consistently favourable combinations of solar resource, grid access and terrain. Previous GIS-based Agri-PV studies in Italy, Flanders, India and Germany similarly demonstrate that suitability rankings depend on the interaction of technical, agricultural, regulatory and infrastructure criteria rather than on irradiance alone [15–19]. The present study extends this spatial-screening perspective across a transnational Central Asian domain using one harmonized criterion set.

The threshold-sensitivity analysis adds an important qualification. Rankings remain almost unchanged under moderate screening thresholds, indicating that the identification of the principal regional clusters is not an artefact of accepting all non-zero pixels. At the strictest threshold, however, the ranking shifts toward regions with consistently higher composite scores. This shows that strategic conclusions depend on whether planners prioritize the total extent of potentially usable cropland or a smaller subset with stronger combined conditions.

4.2. Potential Relevance to the Water–Energy–Food Nexus

The spatial screening results can be interpreted in the context of Central Asia's WEF nexus, but the distinction between model outputs and literature-derived implications is essential. The GIS framework does not quantify irrigation demand, evapotranspiration, crop yield, hydrological flows or water savings. Consequently, the maps cannot demonstrate that Agri-PV would reduce water use in any particular region. Nevertheless, several screened-in clusters in Uzbekistan, Turkmenistan and southern Kazakhstan coincide with irrigation-dependent agricultural systems. Experimental studies elsewhere have reported lower evapotranspiration or irrigation requirements under selected Agri-PV configurations [11–13]. The spatial coincidence identified here therefore indicates where such potential co-benefits warrant targeted field experiments and coupled crop–water modelling, rather than where water savings have already been demonstrated.

The energy dimension can be interpreted more directly. Specific PV yield is generally higher in southern parts of the study area than in northern Kazakhstan, while the latter contains much larger screened-in cropland areas. This creates different deployment propositions: broad dual-land-use opportunities in the north versus higher solar-electricity yield per installed unit in several southern regions. Existing utility-scale PV development in Uzbekistan, including projects in Navoi, Samarkand and Jizzakh, provides an external consistency check that parts of the country's solar and grid context are already relevant for large-scale PV deployment [23]. This comparison does not validate crop-specific Agri-PV feasibility, but it supports the plausibility of the broader energy-screening context.

The WEF interpretation is therefore hypothesis-generating. Quantification of irrigation savings, crop-yield responses, hydropower interactions or changes in transboundary water pressure would require additional crop-specific, hydrological and power-system modelling. The regional GIS results are best used to identify where such integrated follow-up studies would have the greatest planning value.

4.3. Limitations and Research Priorities

Several limitations define the appropriate interpretation of the results. First, the agricultural component is limited to the spatial occurrence of cropland and does not represent crop-specific shade tolerance, crop productivity, irrigation intensity, soil properties, salinity or farm management. The composite index is therefore a technical screening metric rather than a measure of agronomic Agri-PV suitability. Second, protected areas, land tenure, detailed grid-connection capacity, regulatory restrictions and project economics are not represented. Third, the multiplicative operator imposes a strict non-compensatory logic; alternative aggregation rules could produce different local rankings. The present sensitivity analysis evaluates the effect of increasingly strict composite-score thresholds but does not constitute a full criterion-by-criterion uncertainty analysis. Finally, the specific PV yield analysis characterizes resource quality but does not estimate absolute electricity generation because installed capacity density, row spacing, ground coverage ratio, module geometry and system losses are project-specific. Accordingly, the maps should be used for strategic regional screening and not directly for investment, permitting or farm-level siting decisions. The sensitivity analysis evaluates composite-score thresholds; it does not constitute a criterion-by-criterion assessment of alternative grid-distance, temperature or aggregation assumptions.

5. Conclusions

This study developed a harmonized GIS-based multi-criteria framework for regional screening of potential Agri-PV deployment across Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan and Afghanistan. Five spatial criteria were included: existing cropland, global horizontal irradiation, terrain slope, maximum air temperature and proximity to electricity-grid infrastructure. Criterion-specific membership scores were combined through a multiplicative rule to identify locations where agricultural land, solar-resource, terrain, thermal and infrastructure conditions spatially coincide. Under the baseline formulation, approximately 207,276 km^2 of cropland received a non-zero composite screening score. Kazakhstan contains the largest absolute extent, with Qostanay, North Kazakhstan and Aqmola forming the dominant regional cluster, while several regions in Uzbekistan and Turkmenistan exhibit higher median composite scores. The regional ranking is highly stable for moderate threshold changes, with Spearman correlations of 0.998, 0.992 and 0.976 relative to the baseline for minimum composite scores of 0.1, 0.2 and 0.3, respectively. The analysis also demonstrates that the extent of screened-in cropland and PV resource quality represent different dimensions of regional potential. Northern Kazakhstan combines very large retained areas with comparatively moderate specific PV yields, whereas several Afghan and southern Central Asian regions exhibit higher specific yields over smaller agricultural areas. The results should be interpreted as regional strategic screening rather than evidence of crop-specific agronomic or project-level feasibility. Crop type, shade tolerance, irrigation demand, soils, salinity, protected areas, land tenure and detailed grid constraints are not explicitly represented, and potential water savings or crop-yield benefits are not outputs of the GIS model. The identified spatial clusters instead provide a basis for prioritizing locations where field experiments, crop–water modelling and project-specific technical and economic assessments would be most valuable. Overall, the framework pro-

vides a consistent cross-border comparison of Agri-PV screening potential while making explicit the distinction between spatial technical evidence and broader WEF benefits that require subsequent quantitative investigation.

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