GEOSPATIAL MODELLING FOR THE OPTIMAL LOCATION OF SOLAR PANELS FOR AGRIVOLTAIC SYSTEMS. A Case Study in Olive Groves.

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INTRODUCTION

Integrating solar energy with agriculture has a **challenge**: **effective site selection** for agrivoltaic projects.

- When we need to select an ideal location for solar plant, we have to **consider key factors** such as solar radiation, the topography of the land, the land use, and its proximity to important infrastructure like highways and cities.
- Studying the best location of anything is easier if we use spatial data.

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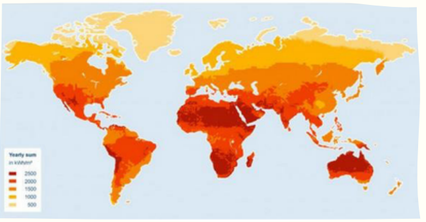
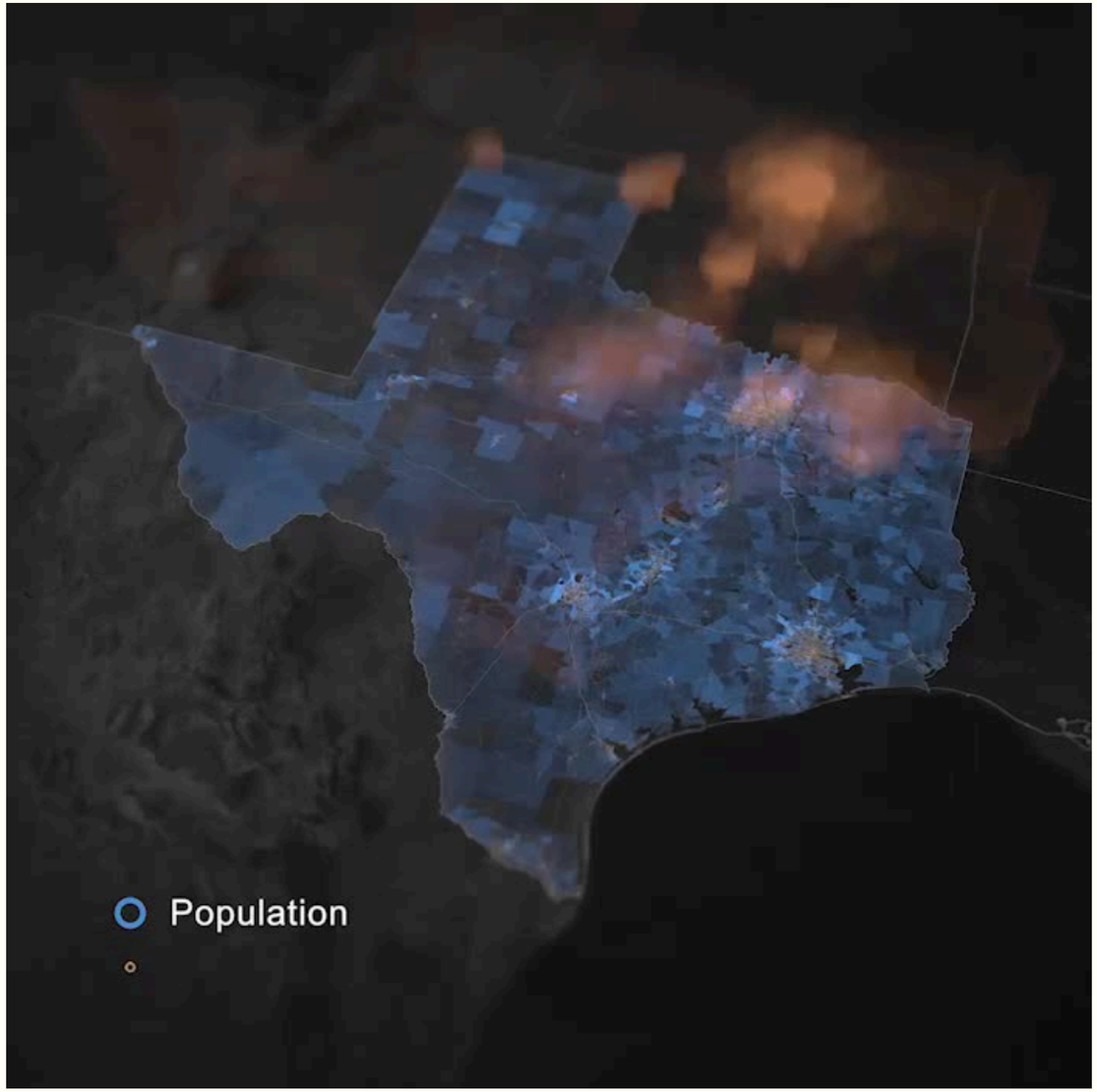


GIS (GEOGRAPHIC INFORMATION SYSTEM)

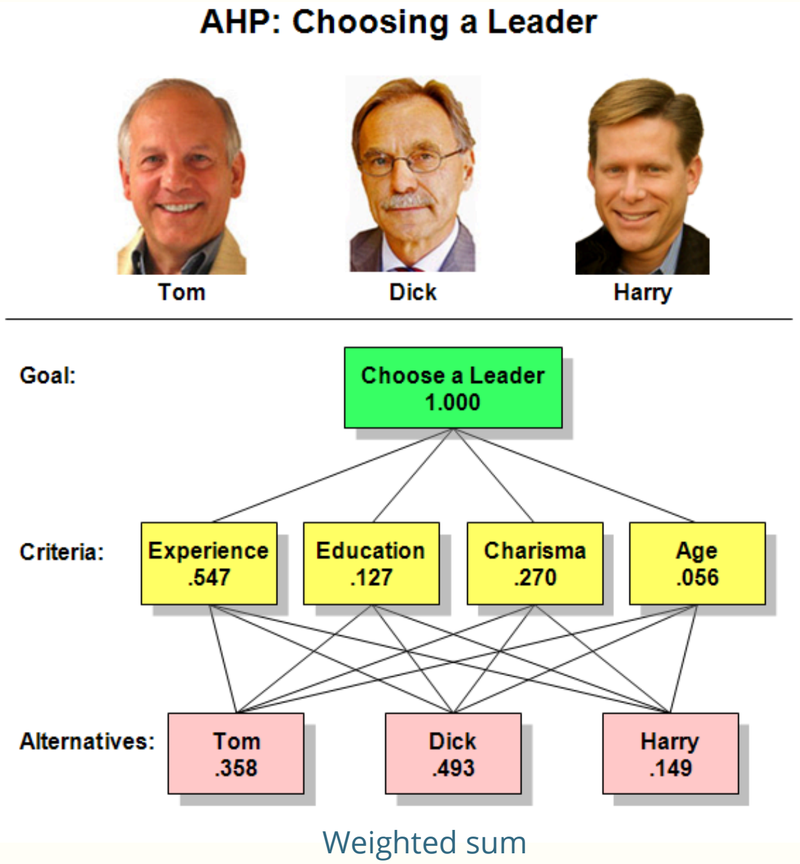
GIS is a technology used to create, manage, analyse and map all kinds of data. GIS **connects data to a map**, integrating location data (where things are) with all kinds of descriptive information (how things are).
This provides a basis for mapping and analysis that is used in science and almost every industry. **GIS helps users understand patterns**, relationships and geographical context.

For example, a GIS can be used to create maps that show areas with high solar potential, the distribution of photovoltaic installations, optimal routes for connecting solar plants to the electrical grid, among others.



AHP

The AHP (Analytic Hierarchy Process) is a tool that helps in decision-making when you need to choose between several alternatives and criteria at the same time. First, you define the problem and the options. Next, the problem is divided into criteria and you need to define a weight for each one. Using a weighted sum, in a summarised way, you define the best option. AHP helps with complex decisions involving several options and factors.



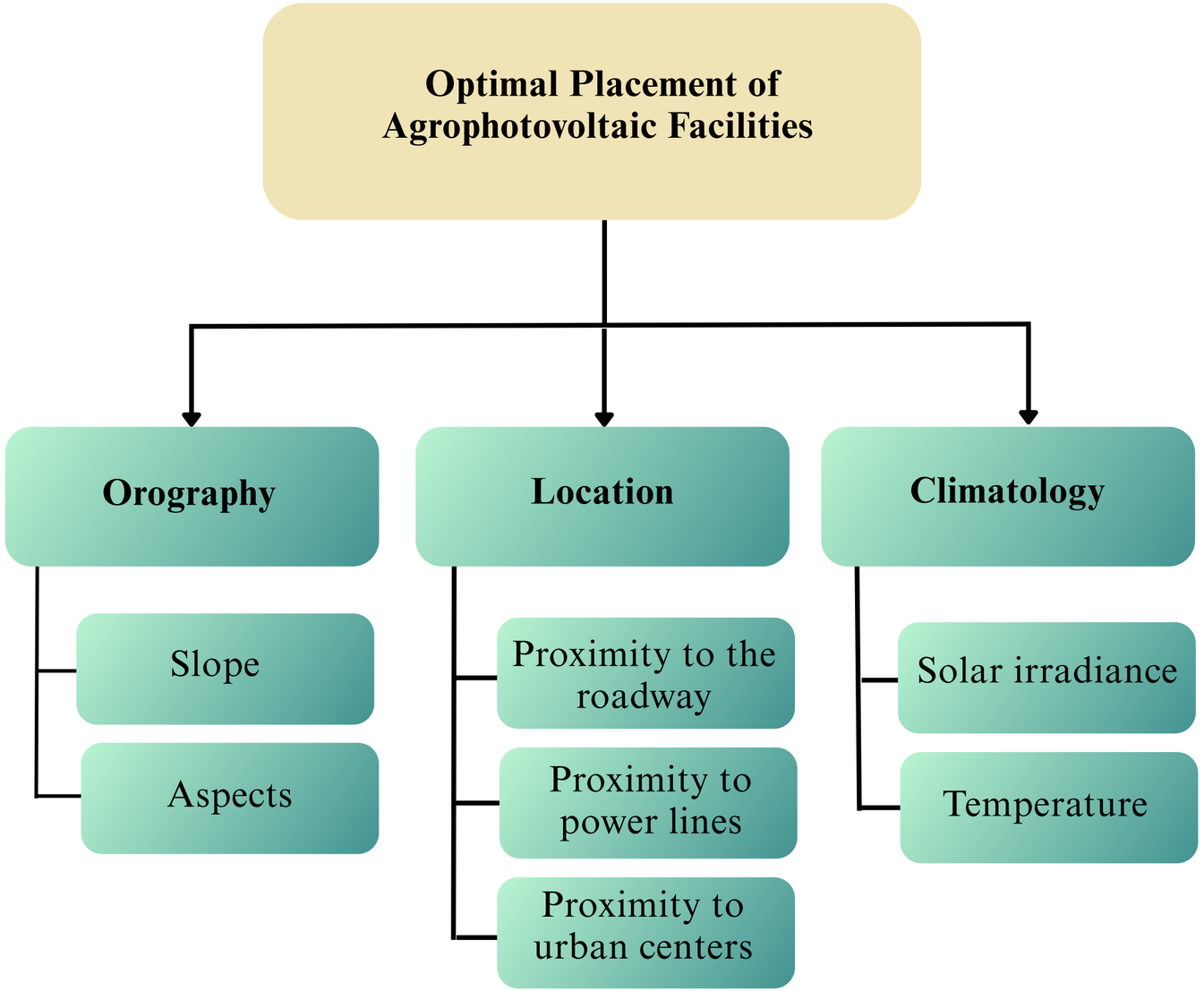
Weighted sum

Evaluation Criteria

Factors influencing site suitability.

These factors directly influence the performance of solar power plants and the costs associated with solar projects.

The criteria vary slightly from one study to another, influenced by the researchers' points of view.



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- **Criterion C1** - Global Horizontal Irradiation (kWh/m2): A higher value is preferable.
- **Criterion C2** - Average temperature (°C): The efficiency of photovoltaic cells can be negatively impacted by elevated temperatures.
- **Criterion C3** - Slope (%): Steep slopes should be avoided, as they complicate the installation of solar panels, while flatter terrain will capture more radiation.
- **Criterion C4** - Orientation: The optimal orientation for a photovoltaic plant is for its solar panels to face south (in the Northern Hemisphere), with an angle of inclination corresponding to the site's latitude. This orientation enables the panels to absorb the maximum amount of solar radiation throughout the day.

- **Criterion C5** - Proximity to residential areas (m)
- **Criterion C6** - Proximity to roads (m)
- **Criterion C7** - Proximity to transmission lines (m)

Restrictions

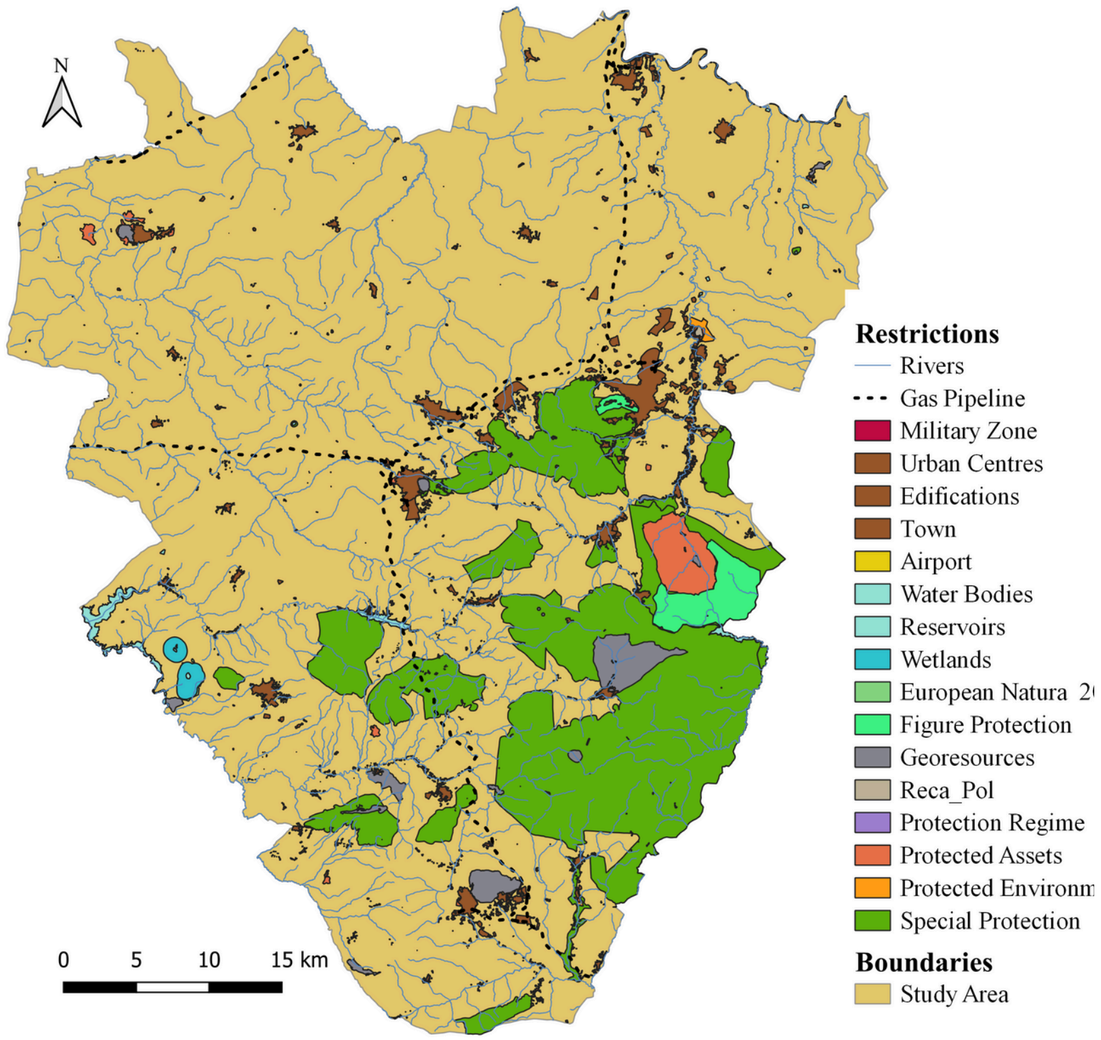
Constraints are established to refine a study area by excluding regions that do not comply with these limitations. Initially, constraints can be applied to eliminate unsuitable areas. They may also be utilized to restrict ranges for all evaluation criteria.Factors influencing site suitability.

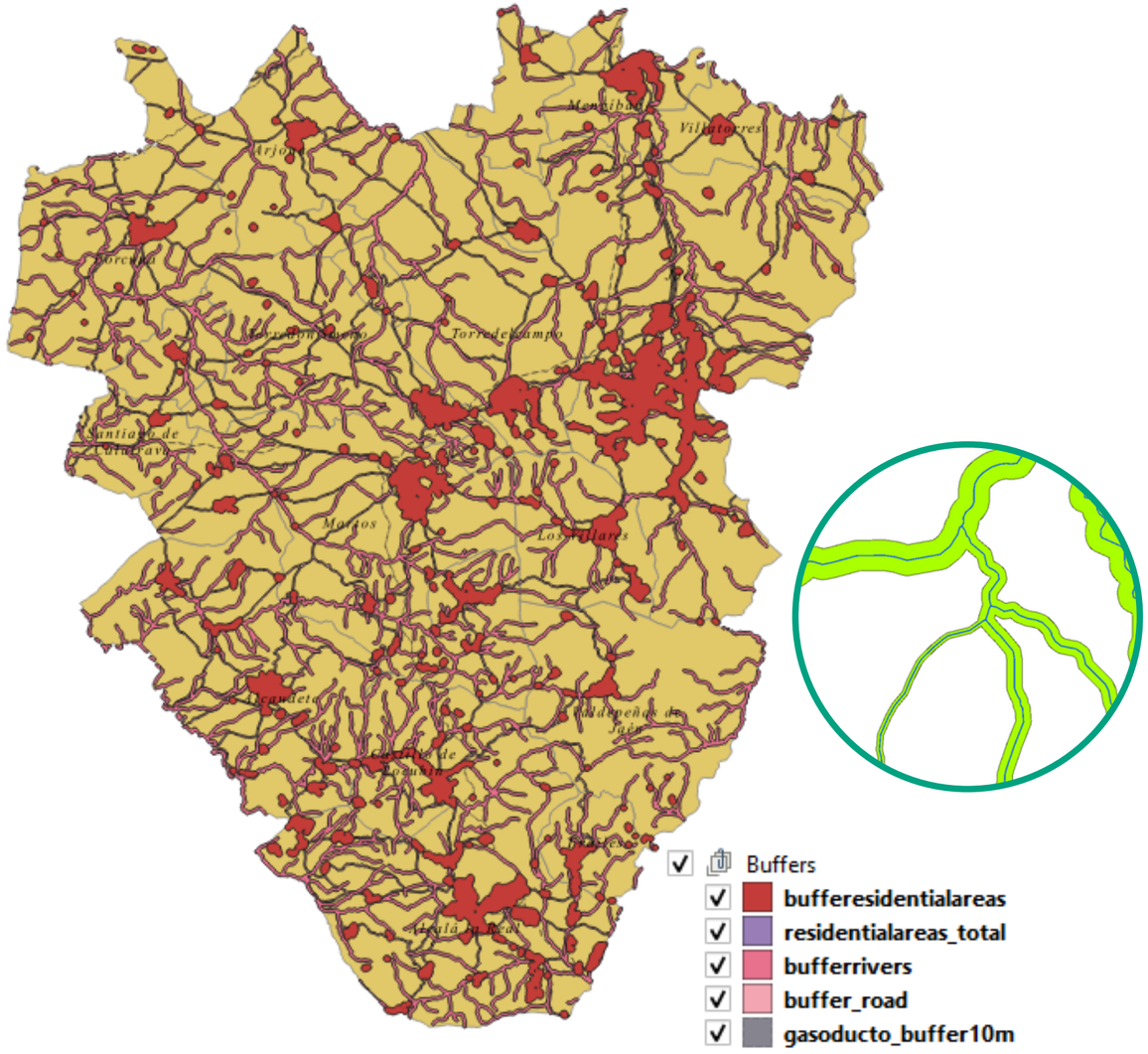
N°	Naming of constraint layers
1	Urban Centres/Towns/Edifications
2	Water Bodies/Reservoirs/Rivers
3	Military Zone
4	Airport
5	Wetlands
6	European Ecological Network Natura 2000
7	Figure Protection
8	Georesources
9	Cultural Spaces
10	Protection Regime
11	Protected Assets
12	Protected Environments
13	Special Protection
14	Gas Pipeline

N°	Naming of constraint layers
1	50 m buffer from roads
2	100 m buffer from rivers
3	200 m buffer from residential areas
5	10 m from Gas pipeline
6	Non-south oriented aspects
7	Areas with slopes of more than 5°.

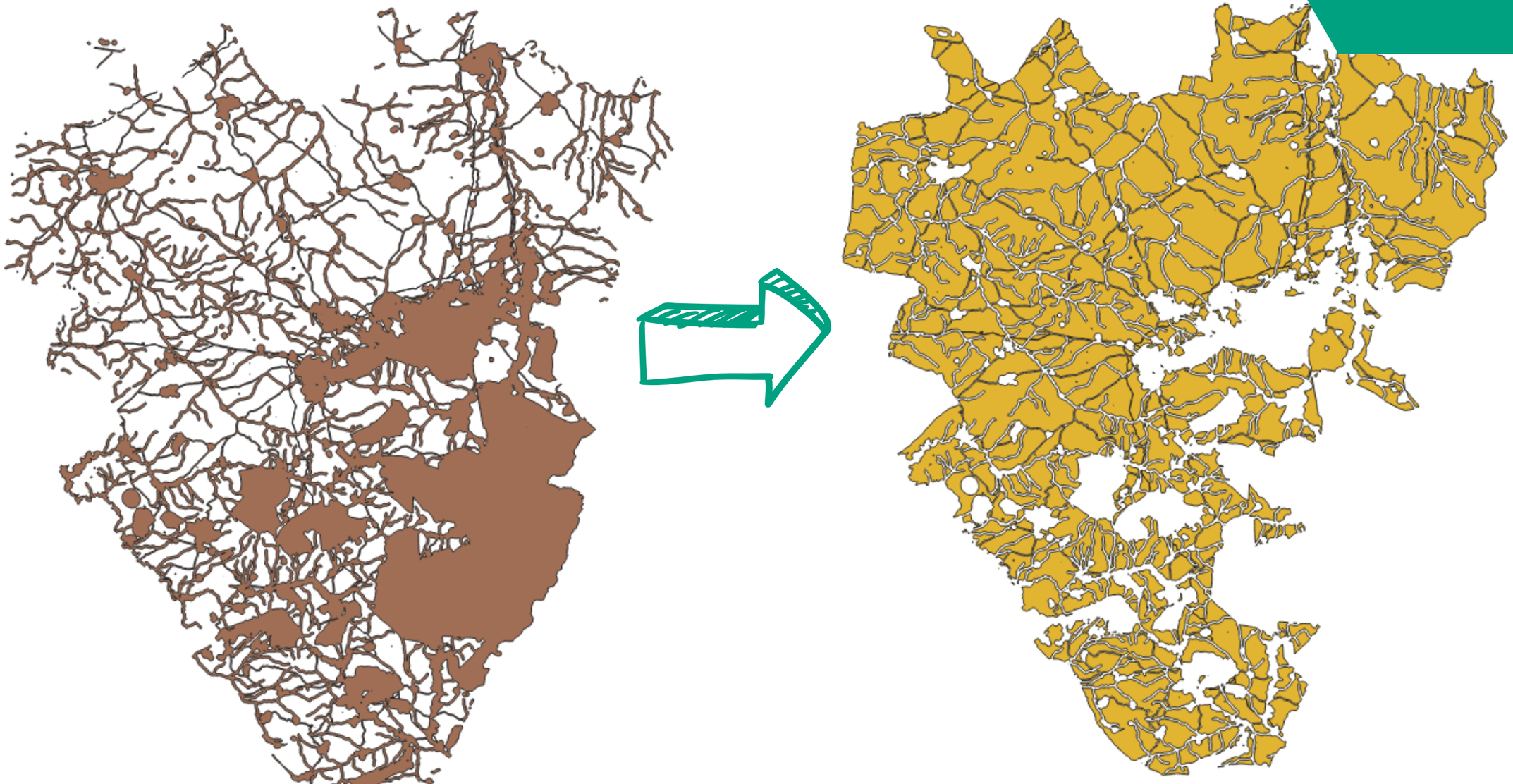
https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/guiaelaboracionesiaplantasfotovoltaicassgea_tcm30-538300.pdf

Map of Restrictions

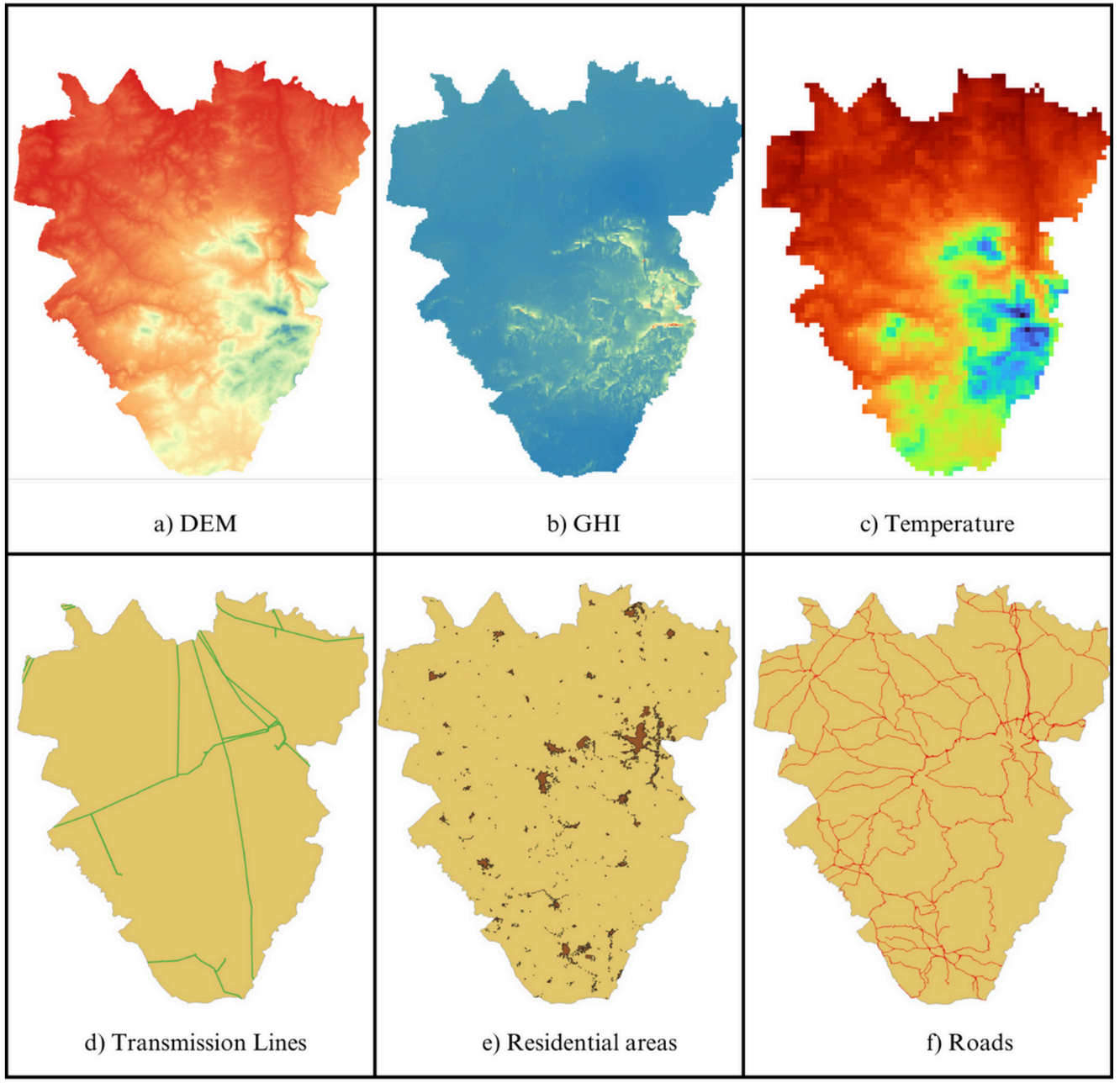




Suitable Areas

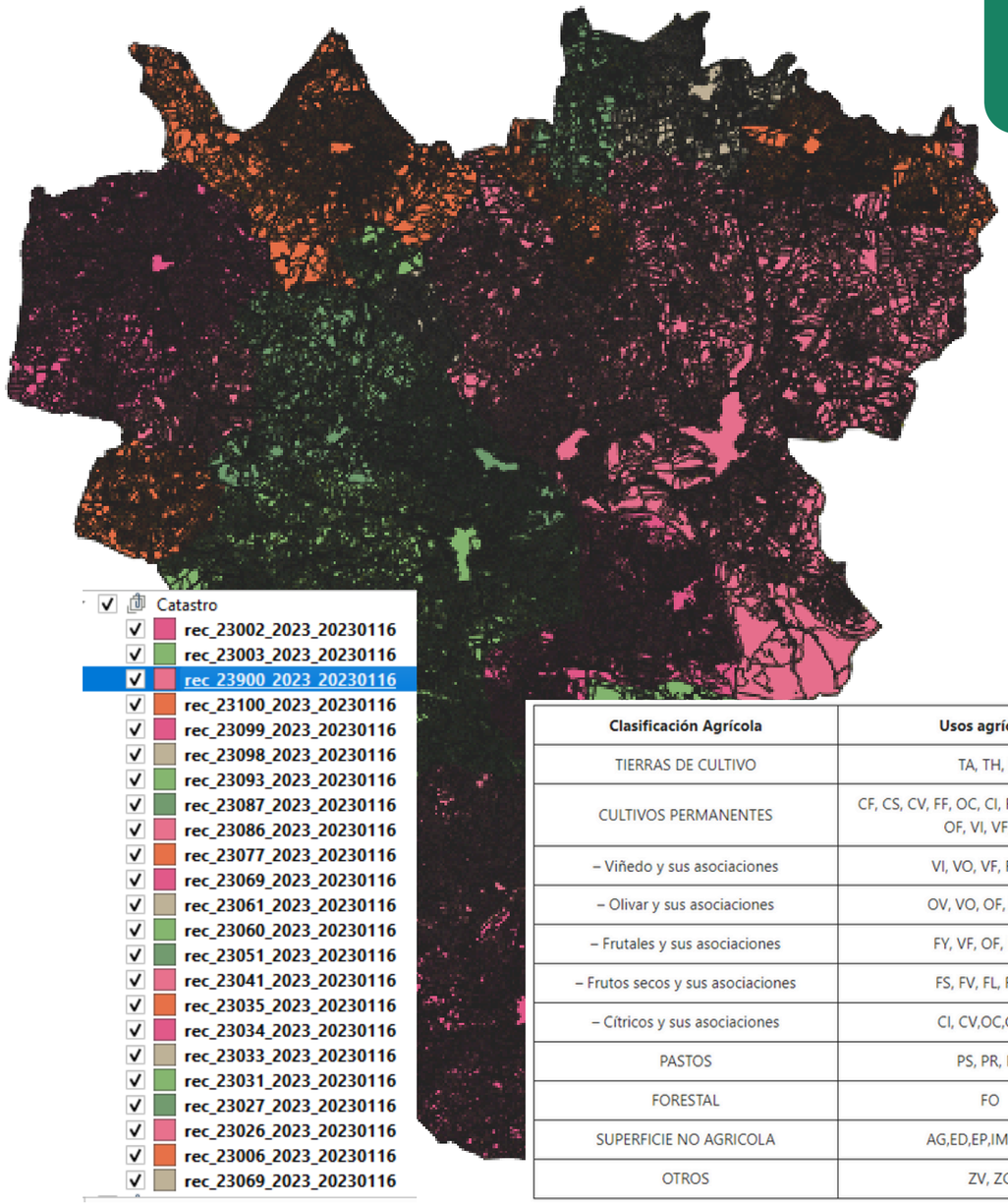


Criteria maps



Through geoprocessing, this data was converted into information: relief, aspect, and distance maps.

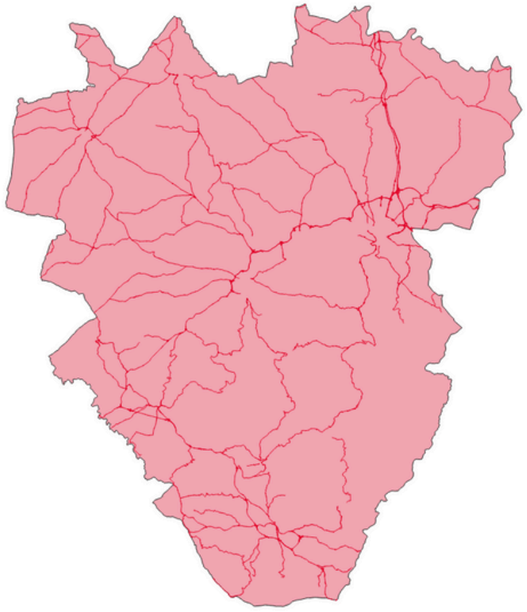
FILTERED: PROPERTIES CONTAINING OLIVE TREES

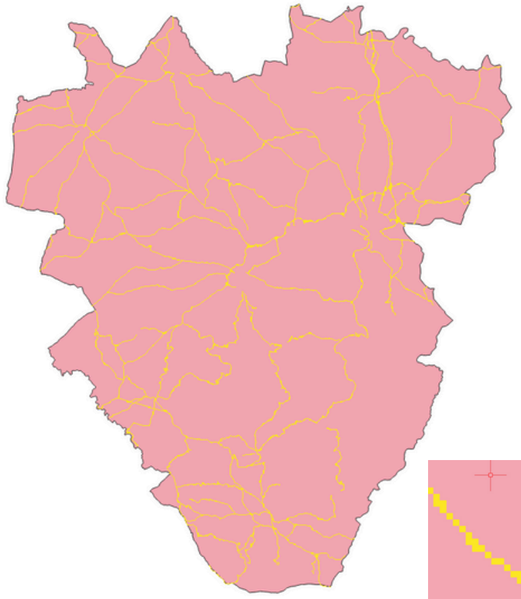


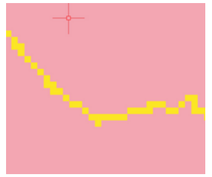
Clasificación Agrícola	Usos agrícolas
TIERRAS DE CULTIVO	TA, TH, IV
CULTIVOS PERMANENTES	CF, CS, CV, FF, OC, CI, FY, FS, FL, FV, OV, OF, VI, VF, VO
– Viñedo y sus asociaciones	VI, VO, VF, FV, CV
– Olivar y sus asociaciones	OV, VO, OF, FL, OC
– Frutales y sus asociaciones	FY, VF, OF, FF, CF
– Frutos secos y sus asociaciones	FS, FV, FL, FF, CS
– Cítricos y sus asociaciones	CI, CV,OC,CF,CS
PASTOS	PS, PR, PA
FORESTAL	FO
SUPERFICIE NO AGRICOLA	AG,ED,EP,IM,CA,ZU
OTROS	ZV, ZC

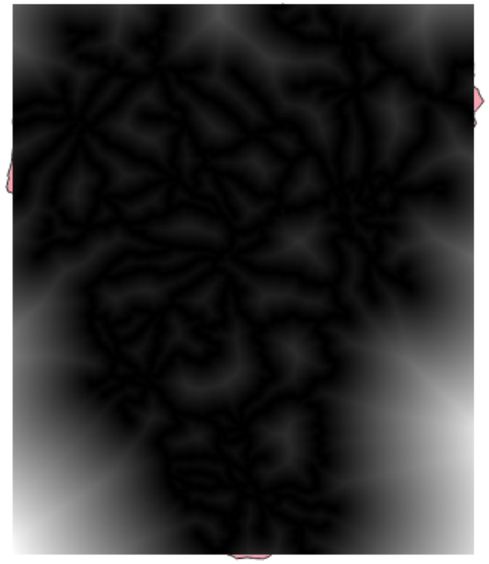
A filtering step was performed on the Cadastral Parcels layer, focusing on olive grove farms identified by SIGPAC land use codes: OV (Olive groves), VO (Olive grove– Vineyard), OF (Olive grove–Fruit trees), FL (Shell fruit trees–Olive grove), and OC (Olive grove–Citrus). These categories correspond to different types of agricultural land where olive cultivation is predominant, either alone or in combination with other crops. Only parcels larger than 1,000 m² were selected, as smaller plots are not suitable for photovoltaic installations

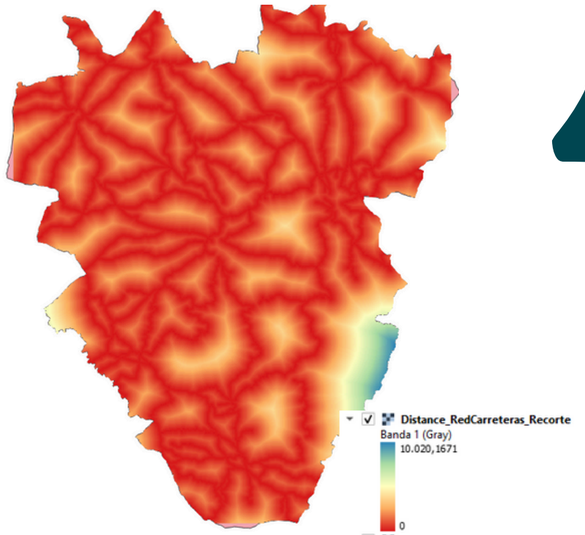
EUCLIDEAN DISTANCE CALCULATION









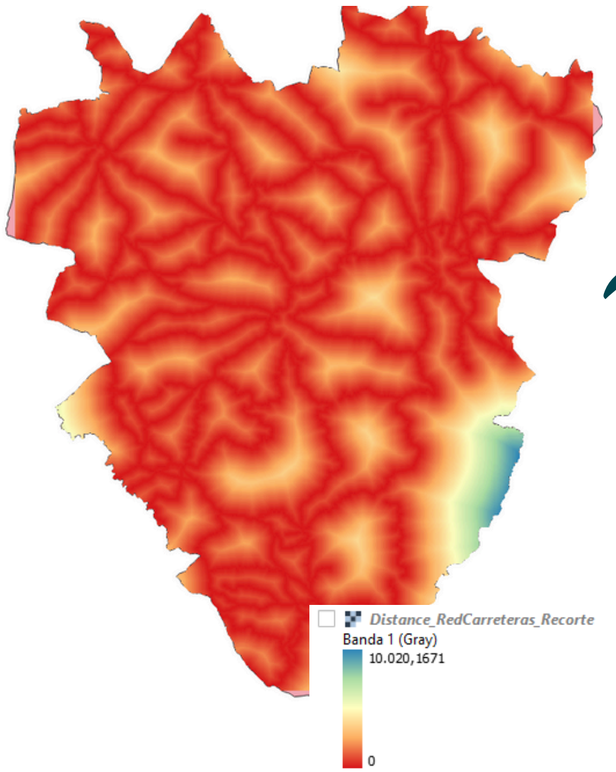


It is the most frequently employed method for generating rasters that assign a distance value to each cell, indicating the distance from the cell to vector-based data (such as roads).

QGIS

GEOPROCESSING - CREATION OF CLASSIFIED MAPS

Each level was assigned a quantitative score reflecting its relative suitability for a large-scale solar energy installation, with the least favorable level receiving a score of 0 and the most favorable level receiving a score of 10. The 0-to-10 scale serves merely as a relative representation, as it will be subject to the application of the MCDM method.

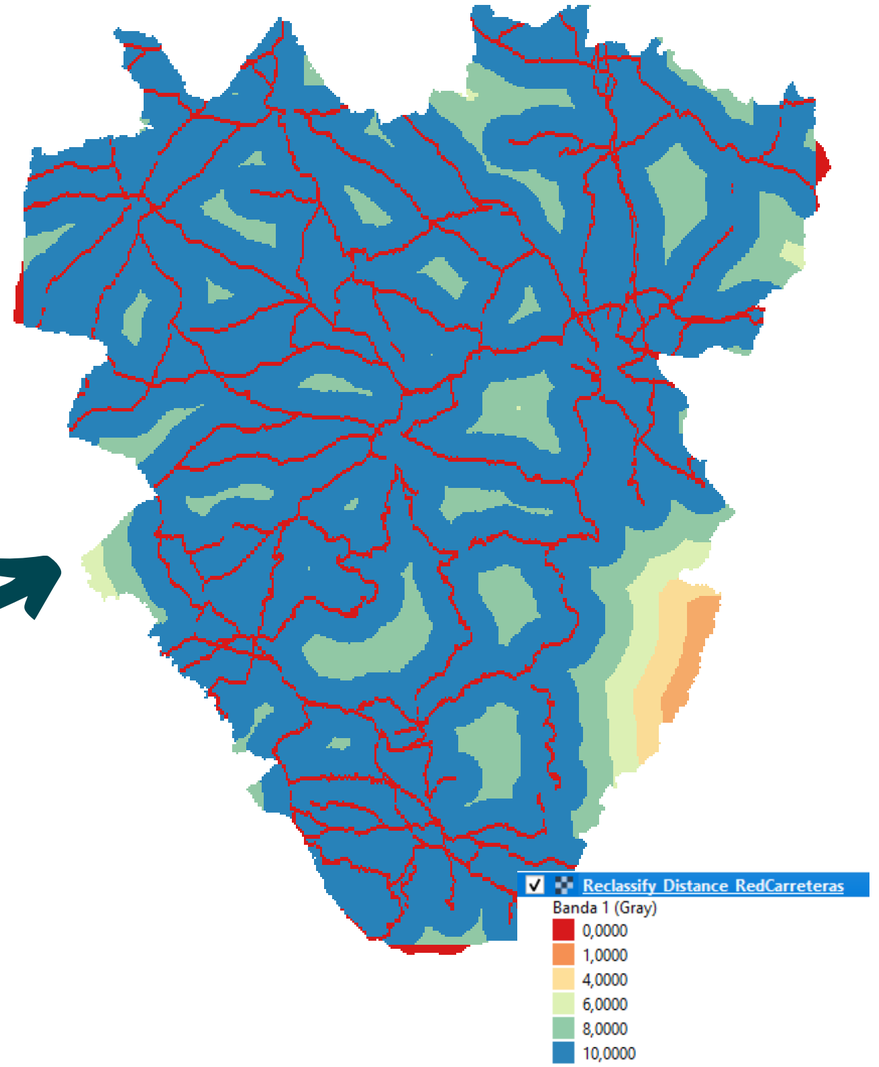


Reclasificar por tabla

Parámetros | Registro

Tabla de Reclasificación

	Mínimo	Máximo	
1	0	500	0
2	500	2000	10
3	2000	4000	8
4	4000	6000	6
5	6000	8000	4
6	8000	11000	1



Andres Cardoso

MCDM(AHP)

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	1	2	3	4	7	6	5
C2	$\frac{1}{2}$	1	2	3	6	5	4
C3	$\frac{1}{3}$	$\frac{1}{2}$	1	2	5	4	3
C4	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	1	4	3	2
C5	$\frac{1}{7}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	1	$\frac{1}{2}$	$\frac{1}{3}$
C6	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$	2	1	$\frac{1}{2}$
C7	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	3	2	1

N	Importance
Ci is equally important to Cj	1
Ci is slightly more important than Cj	3
Ci is strongly more important than Cj	5
V cCi is very strongly more important than Cj	7
Ci is extremely more important than Cj	9
Intermediate values	2,4,6,8

```python
# Definir la matriz de comparación de criterios
matriz_comparacion = np.array([[1.00, 2.00, 3.00, 4.00, 7.00, 6.00, 5.00],
                               [0.50, 1.00, 2.00, 3.00, 6.00, 5.00, 4.00],
                               [0.33, 0.50, 1.00, 2.00, 5.00, 4.00, 3.00],
                               [0.25, 0.33, 0.50, 1.00, 4.00, 3.00, 2.00],
                               [0.14, 0.17, 0.20, 0.25, 1.00, 0.50, 0.33],
                               [0.17, 0.20, 0.25, 0.33, 2.00, 1.00, 0.50],
                               [0.20, 0.25, 0.33, 0.50, 3.00, 2.00, 1.00]])

# Calcular los pesos de los criterios
pesos_criterios = np.mean(matriz_comparacion, axis=1)
pesos_normalizados = pesos_criterios / np.sum(pesos_criterios)

# Calcular el índice de consistencia (CR)
n = len(pesos_criterios)
lambda_max = np.max(np.linalg.eigvals(matriz_comparacion))
CI = (lambda_max - n) / (n - 1)
RI = np.array([0, 0, 0.58, 0.90, 1.12, 1.24, 1.32])  # Índices de aleatoriedad para diferentes tamaños de matriz
CR = CI / RI[n-1]

# Verificar la consistencia (CR <= 0.1)
if CR <= 0.1:
    print("La matriz de comparación es consistente.")
else:
    print("La matriz de comparación no es consistente.")

# Imprimir los pesos de los criterios
print("Pesos de los criterios:")
for i, peso in enumerate(pesos_normalizados):
    print(f"Criterio {i+1}: {peso}")
```

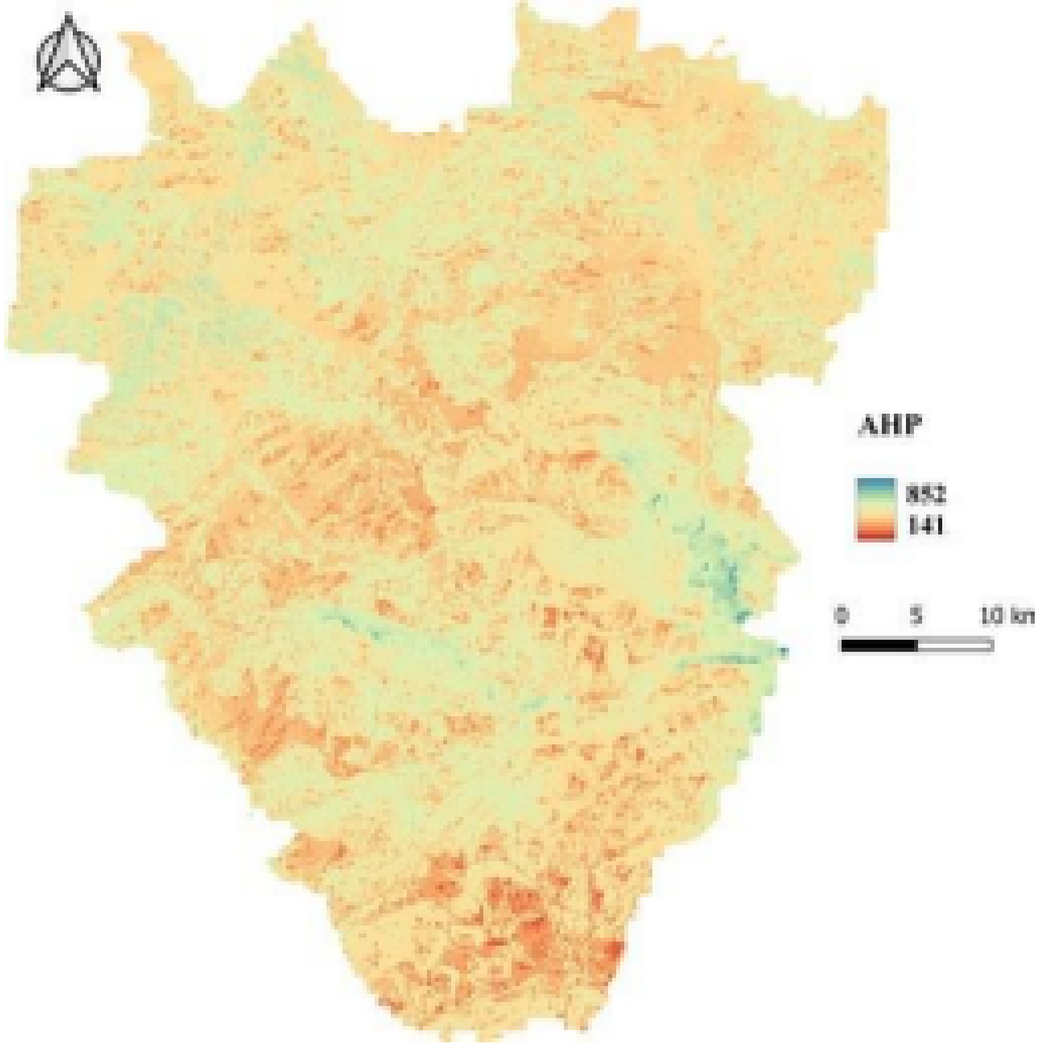
TABLE III. Final result of the ahp application

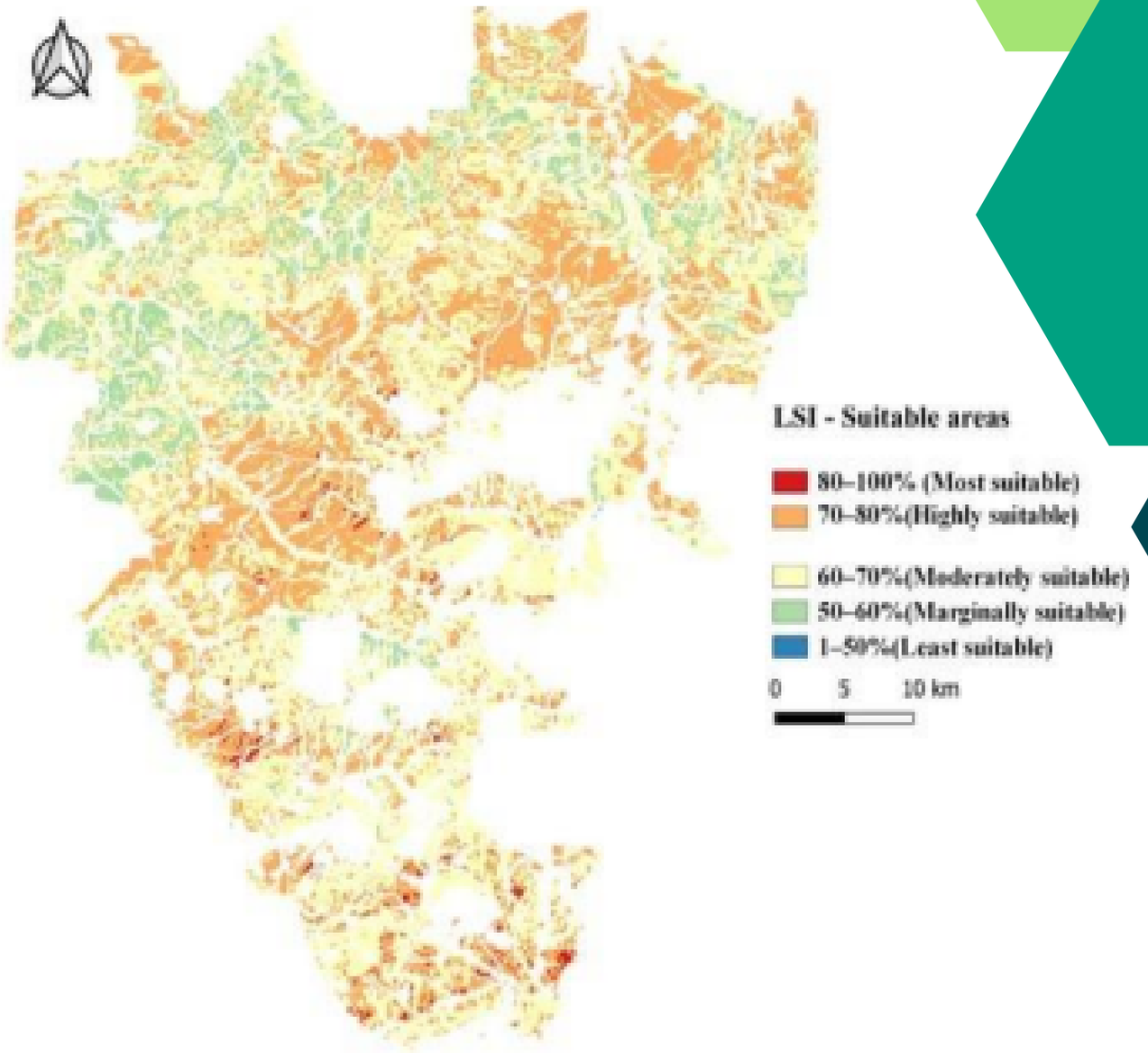
Criterion	Valor	Percentage
C1	0,354	35,44%
C2	0,240	24,00%
C3	0,159	15,85%
C4	0,104	10,36%
C5	0,031	3,11%
C6	0,045	4,49%
C7	0,068	6,75%

A weighted sum of the layers was computed using the weights determined by the AHP method.

C1*P1+C2*P2+C3*P3+C4*P4+C5*P5+C6*P6+C7*P7

Results


AHP
852
141
0 5 10 km


LSI - Suitable areas
80–100% (Most suitable)
70–80%(Highly suitable)
60–70%(Moderately suitable)
50–60%(Marginally suitable)
1–50%(Least suitable)
0 5 10 km

Thank you for your attention!