

Cross-Border Sustainable Renewable Energy Acceleration in Ukraine - Mapping Synergy Renewable Energy Acceleration Areas between Ukraine, EU Member States, and Moldova

Task 4. Data Collection and Analysis

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ACRONYMS

DSO	Distribution System Operators (Distribution utilities)
ENTSO-E	European Network of Transmission System Operators for Electricity
ECS	Energy Community Secretariat
EU	European Union
IPS	Integrated Power System
kW	Kilowatt
MS	Member States
MW	Megawatt
OSA	Oblast State Administration
PV	Photovoltaic
RE	Renewable Energy
RED II	Renewable Energy Directive (EU) 2018/2001
RED III	Renewable Energy Directive (EU) 2023/2413
RES	Renewable Energy Sources
TSO	Transmission System Operator
UAH	Ukrainian hryvnia



INTRODUCTION

In accordance with “Task 4 Data Collection and Analysis”, the Report represents results and analysis for data collection from diverse stakeholder groups focusing on renewable energy planning and addressing key issues such as policy priorities, feasibility, and barriers in five regions/oblasts in Ukraine (Lviv, Zakarpattia, IvanoFrankivsk, Chernivtsi, and Vinnytsia).

Collected data will be used for: RAAs spatial planning process (RE potential and infrastructure readiness); technical analysis of renewable energy potential and infrastructure readiness, evaluating capacity, feasibility, and alignment with RES targets; preliminary economic analysis on the feasibility of renewable energy projects in RAAs.

The information obtained within the scope of the Project will not be utilized by specialist for any commercial purposes and is intended for open-source sharing. Upon request from stakeholders who hold relevant information and data, a Non-Disclosure Agreement (NDA) can be signed to provide reassurance regarding confidentiality in line with the internal rules of the Energy Community Secretariat.

The Report contains two sections: Section 1. Results of data collection regarding renewable energy planning and Section 2. Apply methods for the analysis and processing of geospatial layers.

1. RESULTS OF DATA COLLECTION REGARDING RENEWABLE ENERGY PLANNING

1.1. Source of data collection

Collected data	Data sources	Data formats	Coordinate systems	Resolution	Metadata
Criterion: Artificial and built surfaces					
Geospatial data in vector format on the location and footprints of buildings.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map) and META AI Building Footprints (https://github.com/microsoft/GlobalMLBuildingFootprints)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of transport infrastructure.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of parking areas.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of farms.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of waste sites.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of industrial sites.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of mines and quarries.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in vector format on the location of artificial water bodies.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Geospatial data in	OpenStreetMap (OSM) collaborative	GeoPac	WGS-	Not	

vector format on the location of wastewater treatment sites.	database (https://www.openstreetmap.org/export#map)	kage (.gpkg)	84	applicable	Available
Geospatial data in vector format on the location of the power grid.	OpenStreetMap (OSM) collaborative database (https://www.openstreetmap.org/export#map)	GeoPackage (.gpkg)	WGS-84	Not applicable	Available
Criterion: Solar Potential					
Raster data on Global Horizontal Irradiation (GHI).	Global Solar Atlas, provided by Solargis for The World Bank (https://globalsolaratlas.info/download/ukraine)	GeoTIFF	WGS-84	Gridded data (~250 m)	Available
Criterion: Wind Potential					
Raster data on mean wind speed at 100m height.	Global Wind Atlas, provided by the Technical University of Denmark (DTU) for The World Bank Group (https://globalwindatlas.info/en/area/Ukraine)	GeoTIFF	WGS-84	Gridded data (~250 m)	Available
Criterion: Elevation and Steep slopes					
Digital Elevation Model (Digital Surface Model).	Copernicus DEM (GLO-30), derived from TanDEM-X mission data. Provided by the Copernicus Programme of the European Union (https://portal.opentopography.org/aster?opentopoID=OTSDEM.032021.4326.3) (https://dataspace.copernicus.eu/explore-data/data-collections/copernicus-contributing-missions/collections-description/COP-DEM#:~:text=The%20Copernicus%20DEM%20is%20a%20Digital%20Surface%20Model,through%20the%20TanDEM-X%20mission%20between%202011%20and%202015.)	GeoTIFF	WGS-84	30 m	Available
Criterion: Land Use / Land Cover					
Global estimates of land use/land cover (LULC).	Esri and Impact Observatory, derived from Sentinel-2 imagery (https://livingatlas.arcgis.com/landcover/)	GeoTIFF	WGS-84	10 m	Available

2. APPLIED METHODS FOR THE ANALYSIS AND PROCESSING OF GEOSPATIAL LAYERS

This chapter presents a detailed methodology for the creation and processing of

geospatial layers to identify potential Renewable Energy Acceleration Areas (RAA) in Ukraine. All operations are performed in the QGIS environment, adhering to unified technical standards: GeoPackage (.gpkg) format and the WGS-84 (EPSG:4326) coordinate system.

2.1. Rooftops_and_Facades_of_Buildings

This layer identifies rooftops and facades of buildings suitable for the installation of solar photovoltaic panels.

2.1.1. Data sources from OpenStreetMap (OSM) and other open sources.

Category	OSM (key=value)	Description
Residential Buildings	building=apartments	A multi-story residential building with several separate apartments.
	building=bungalow	A single-story residential building.
	building=detached	A stand-alone house not connected to other buildings.
	building=dormitory	A building with rooms for students or workers to live in.
	building=house	A private house for a single family.
	building=residential	A general-purpose residential building.
	building=semidetached_house	A house that shares one common wall with an adjacent house.
Commercial Buildings	building=commercial	A building used for commercial activities.
	building=industrial	An industrial building for manufacturing.
	building=office	A building with office spaces.
	building=retail	A building for retail trade.
	building=supermarket	A large self-service retail building.
	building=warehouse	A commercial building for storing goods.
Civic/Amenity Buildings	building=civic	A public building for civic purposes (community centers).
	building=government	A building for government institutions.
	building=hospital	A hospital for medical services.
	building=kindergarten	A building for preschool education.
	building=school	A building for general education.
	building=train_station	A railway station building.

	building=university	A university building.
	building=public	A public building (town hall, police, courthouse).
Other Sources	META AI Building Footprints	A global dataset of building footprints identified using AI.

2.1.2. Detailed Processing Methodology in QGIS:

Creating the Base Layer:

Data Import: Using the QuickOSM plugin, all objects with the building key are downloaded. The META AI Building Footprints layer is added to the project separately.

Merge: The OSM and META layers are combined using the "Merge vector layers" tool (Processing Toolbox -> Vector general -> Merge vector layers).

Cleaning: To eliminate duplicates and overlaps, the "Dissolve" tool is applied (Vector -> Geoprocessing Tools -> Dissolve). Topological correctness is ensured with the "Fix geometries" tool (Processing Toolbox -> Vector geometry -> Fix geometries). The result is saved as Buildings_Base.

1. Filtering by Technical Suitability Criteria:

GHI \geq 1100 kWh/m²: The Global Horizontal Irradiation raster layer from the Global Solar Atlas is downloaded. Using "Zonal Statistics" (Processing Toolbox -> Raster analysis -> Zonal Statistics), the average GHI value is calculated for each building. Objects with GHI < 1100 are filtered out.

Area: The area of each building is calculated in the "Field Calculator" (\$area). Objects with an area insufficient for effective installation (< 100 m²) are filtered out.

Grid Availability (\leq 5 km): The power grid layer is downloaded from OSM (power=line, power=substation). The "Distance to nearest hub" tool (Processing Toolbox -> Vector analysis -> Distance to nearest hub) is used to calculate the distance to the grid. Buildings farther than 5 km are filtered out.

2. Filtering by Legal Constraints:

Exclusion of Cultural Heritage Sites: The official layer of cultural heritage sites is loaded. Using the "Difference" tool (Vector -> Geoprocessing Tools -> Difference), these areas are cut out from the layer of potential buildings.

4. To determine the orientation of buildings relative to the cardinal directions, the "Oriented minimum bounding box" tool from the Processing Toolbox (Vector geometry - Oriented minimum bounding box) was used. This tool created an oriented bounding rectangle for each building with an "angle" field, which contains the rotation angle of the building's main axis relative to the north direction.

The input layer was the "Buildings" layer, and the result was saved as "Buildings_oriented_bbox". The resulting angle was then transferred to the original buildings layer using the "Join attributes by location" tool. After the join, azimuth normalization was performed in the Field Calculator to adjust the values to a 0-360 degree range. To determine the building's suitability based on the orientation criterion (south, southeast, southwest – a range of 135-225 degrees), a conditional CASE expression was used.

5. Verification: Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

6. Final result: A polygonal layer Rooftops_and_Facades_of_Buildings, containing buildings that have passed all filtering stages.

2.2. Transport_Infrastructure_Corridor

This layer identifies roadside adjacent territories suitable for the installation of solar panels. For the analysis of transport corridors, a linear vector layer of highways (highway) from the OpenStreetMap database was used. This layer serves as the primary source for identifying any type of roads, streets, or pathways. The transport infrastructure includes land within the right-of-way boundaries (excluding the roadway directly intended for vehicle movement and shoulders), as well as land outside the right-of-way if it contains facilities that ensure the functioning of highways (such as parking and rest areas) in relation to roads of national importance.

2.2.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Roads	highway=motorway	A high-class road with controlled access.
	highway=trunk	A road of international and national importance.
	highway=primary	A road of regional importance.
	highway=secondary	A road of oblast-level importance.
	highway=service	A service road that provides access to specific facilities, such as industrial sites, parking areas, buildings, or other infrastructure objects

2.2.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer:

Data Import: Linear objects of roads are downloaded using QuickOSM.

Corridor Creation: Using the "Buffer" tool (Vector -> Geoprocessing Tools -> Buffer), a polygonal zone 20 meters wide is created on both sides of the linear features, with the "Dissolve result" option enabled.

2. Filtering by Technical Suitability Criteria:

Buildings with Global Horizontal Irradiation (GHI) ≥ 1100 kWh/m² were retained. The same methodology as described in Group 1 was applied.

Exclusion of Slopes > 15° and Altitudes > 1900 m:

The Copernicus DEM (GLO-30) digital elevation model is loaded.

A slope layer is calculated using the "Slope" tool (Raster -> Analysis -> Slope).

A binary raster of suitable areas is created in the "Raster Calculator" ("Slope@1" ≤ 15 AND "Copernicus_DEM@1" ≤ 1900).

The raster is converted to a vector (Raster -> Conversion -> Polygonize).

Using the "Intersection" tool (Vector -> Geoprocessing Tools -> Intersection), only the parts of the corridor that meet the criteria are retained.

Grid Availability (≤ 30 km):

Distance analysis to the power grid is applied with a 30 km threshold.

3. Verification: Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final result: Polygon layer Transport_Infrastructure_Corridor.

2.2. Parking_Areas

This layer identifies open parking lots suitable for the installation of solar canopies.

2.3.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Parking Lots	amenity=parking	A general-purpose parking area.
	parking=surface	An open, surface-level parking lot.
Related Areas	landuse=retail	Retail land use areas (often with large parking lots).
	landuse=commercial	Commercial zones.
	parking=multi-storey	multi-storey car park;
	parking=underground	underground parking
	amenity=parking_space	single parking space for one vehicle

2.3.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer (Parking_Base)

Importing Data from OSM:

Tool: QuickOSM Plugin. Action: A query is created to extract all polygonal features with the tag amenity = parking within the study area. This provides an initial dataset including all types of parking facilities. Filtering for Suitable Parking Types: Tool: "Select by expression".

Action: From the initial layer, it is necessary to exclude features that are not open, surface-level parking lots. An expression is applied to filter out multi-story and underground parking: "parking" NOT IN ('multi-storey', 'underground') OR "parking" IS NULL. The IS NULL condition is important as many surface parking lots are tagged only with amenity=parking without additional specifiers.

Result: The selected features are saved into a new layer named Parking_Base.

Verifying and Fixing Geometry

Tool: "Fix geometries" (Processing Toolbox -> Vector geometry -> Fix geometries).

Action: This tool is applied to the Parking_Base layer to correct any topological errors (self-intersections), ensuring the validity of subsequent overlay analysis operations.

2. Filtering by Technical Suitability Criteria

Analysis of Global Horizontal Irradiation ($GHI \geq 1100 \text{ kWh/m}^2$):

Data Source: GHI raster layer from the Global Solar Atlas.

Tool: "Zonal Statistics" (Processing Toolbox -> Raster analysis -> Zonal Statistics).

Action: The average GHI value is calculated for each polygon in the Parking_Base layer. The result is written to a new field (GHI_mean). Filtering: Using "Select by expression", features that satisfy the condition "GHI_mean" ≥ 1100 are selected.

Area Analysis

Tool: "Field Calculator".

Action: A new field area_sqm is created, and the area of each parking lot is calculated using the expression \$area. Filtering: Only parking lots large enough for economically viable solar canopy installations are selected. A filter is applied using an expression such as "area_sqm" > 17 (17 m^2).

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Data Source: A power grid layer obtained from OSM (power=line, power=substation) and merged into a single power_grid layer.

Tool: "Distance to nearest hub (line to hub)" (Processing Toolbox -> Vector analysis -> Distance to nearest hub (line to hub)).

Action: The distance from each parking lot to the nearest element of the power grid is calculated.

Parking areas located between 20 m and 30 km from the nearest grid connection point were retained, ensuring both technical safety and cost-effective power connectivity. A

combined expression is used for this: "HubDist" >= 20 AND "HubDist" <= 30000.

3. Verification: Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final result: Polygon layer Parking_Areas.

2.4. Farms (solar and wind)

These layers identify farm territories suitable for solar and wind installations. For the analysis of potential in agricultural areas, polygon layers of land use and buildings from the OpenStreetMap database were used. Farmlands are represented by two main land use layers and associated building layers.

2.4.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Farm Areas	landuse=farmyard	The operational area of a farm with buildings.
	landuse=farmland	Agricultural land used for cultivation.
Agri. Buildings	building=farm	A farmhouse.
	building=farm_auxiliary	An auxiliary farm building.
	building=barn	A large storage building.
	building=cowshed	A building for housing cows.
	building=greenhouse	A greenhouse for growing plants.

2.4.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer (Farms_Base)

Importing Data from OSM: Tool: QuickOSM Plugin.

Action: A query is executed to extract all polygonal features matching the tags landuse=farmyard and landuse=farmland, as well as polygonal and point features for building tags (building=farm, building=barn).

Consolidation and Cleaning:

Tool: "Merge vector layers" (Processing Toolbox -> Vector general -> Merge vector layers).

Action: All resulting layers (land use and building polygons) are combined into a single layer.

Tool: "Dissolve" (Vector -> Geoprocessing Tools -> Dissolve).

Action: This is applied to merge adjacent or overlapping features, which helps define the boundaries of individual farm complexes.

Tool: "Fix geometries" (Processing Toolbox -> Vector geometry -> Fix geometries).

Action: Ensures the topological correctness of the layer. The result is saved as Farms_Base.

2. Creating the farms_solar layer

This process is applied to the Farms_Base layer to identify zones suitable for solar energy.

Analysis of Global Horizontal Irradiation (GHI \geq 1100 kWh/m²):

Tool: "Zonal Statistics".

Action: The average GHI value is calculated for each polygon from the Global Solar Atlas raster. Features with "GHI_mean" \geq 1100 are selected.

Area Analysis: Tool: "Field Calculator".

Action: The area is calculated ($\$area$). Small farms unsuitable for significant installations are filtered out (" $area_sqm > 100$ ").

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Data Source: power_grid layer (merged power=line and power=substation from OSM).

Tool: "Distance to nearest hub".

Action: The distance to the nearest grid element is calculated. A combined filter is applied: " $HubDist \geq 20$ AND " $HubDist \leq 30000$ ".

Assessment of Potential for BESS/PCS Installation:

Rationale: Farms that have passed the area filter are assumed to have sufficient open space to accommodate energy storage systems. This criterion is considered met for all selected features.

3. Creating the farms_wind layer

This process is also applied to the Farms_Base layer to identify zones suitable for wind energy.

Analysis of Wind Speed (≥ 5.0 m/s at 100m height):

Data Source: Average wind speed raster from the Global Wind Atlas.

Tool: "Zonal Statistics".

Action: The average wind speed is calculated for each polygon. Features with " $wind_speed_mean \geq 5.0$ " are selected.

Exclusion of Orographic Constraints (slopes $> 15^\circ$):

Data Source: Copernicus DEM.

Tools: "Slope", "Raster Calculator", "Polygonize", "Intersection".

Action: A vector layer of suitable slopes ($\leq 15^\circ$) is created and then intersected with the farms layer to exclude areas on steep slopes.

Analysis of Road Accessibility (≤ 5 km):

Data Source: Layer of state and local roads from OSM.

Tool: "Distance to nearest hub".

Action: Farms located no more than 5 km from roads are selected.

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Action: The same methodology as for the solar layer is applied, using the filter " $HubDist \geq 20$ AND " $HubDist \leq 30000$ ".

Application of Exclusion Buffer Zones (Overlay Analysis):

Tool: "Buffer".

Action: Buffer zones are created around infrastructure features: 60 meters around roads, 500 meters around railways, and 10 km around airports (aeroway=aerodrome).

Tool: "Merge vector layers" and "Dissolve".

Action: All buffer zones are combined into a single exclusion_zones layer.

Tool: "Difference" (Vector -> Geoprocessing Tools -> Difference).

Action: The exclusion_zones layer is "cut out" from the layer of potential farms to exclude areas where wind turbine construction is restricted.

4. Verification

Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final Result: Two separate polygonal layers: farms_solar and farms_wind.

2.5. Waste_sites

This layer identifies solid waste landfills suitable for the installation of solar power plants.

2.5.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Landfills	landuse=landfill	An area used for waste disposal.

2.5.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer: Polygons with the landuse=landfill are downloaded using QuickOSM.

2. Filtering by Technical Suitability Criteria

Analysis of Global Horizontal Irradiation ($GHI \geq 1100 \text{ kWh/m}^2$):

Tool: "Zonal Statistics".

Action: The average GHI value is calculated for each polygon in the Waste_Sites_Base layer. Features that satisfy the condition "GHI_mean" ≥ 1100 are selected.

Area Analysis:

Tool: "Field Calculator"

Action: The area of each feature is calculated (\$area). Small plots unsuitable for industrial-scale solar farms are filtered out ("area_sqm" > 100).

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Tool: "Distance to nearest hub (line to hub)".

Availability of substations: Including power=substation features in the analysis directly addresses the availability of substations within the specified distance.

Action: The distance from each feature to the nearest element of the power grid is calculated.

Filtering: Features that meet two conditions are selected: located no more than 30 km away and no less than 20 m away. A combined expression is used for this: "HubDist" ≥ 20 AND "HubDist" ≤ 30000 .

3. Verification: Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final Result: A polygonal layer named Waste_sites, containing polygons of landfills and other waste management facilities that have passed all GIS-based filtering stages.

2.6. Industrial Sites solar and Industrial Sites wind

These layers identify industrial zones suitable for the installation of solar and wind facilities. Industrial areas were analyzed using the polygon layer landuse=industrial from the OpenStreetMap database, which includes land used for industrial purposes. This layer covers territories with main, auxiliary, and service buildings of industrial, mining, transport, and other enterprises, as well as their access roads, utility networks, administrative buildings, and related infrastructure.

2.6.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Industrial Zones	landuse=industrial	A general-purpose industrial area.
Industrial Objects	man_made=works	A factory or manufacturing complex.
	power=plant	A power plant.
	building=factory	A building used as a factory.

2.6.2. Detailed Processing Methodology in QGIS

1. Creating the Base Layer (Industrial_Base)

Importing Data from OSM: Tool: QuickOSM Plugin.

Action: A query is executed to extract all polygonal and point features matching the tags in the table.

Consolidation and Cleaning:

Tool: "Merge vector layers" and "Dissolve".

Action: All resulting polygons are merged into a single layer, and adjacent or overlapping features are dissolved. "Fix geometries" is applied to ensure topological correctness.

The result is saved as Industrial_Base

2 Creating the Industrial_Sites_solar layer

This process is applied to the Industrial_Base layer to identify zones suitable for solar energy.

Analysis of Global Horizontal Irradiation ($GHI \geq 1100 \text{ kWh/m}^2$):

Tool: "Zonal Statistics".

Action: The average GHI value is calculated for each polygon from the Global Solar Atlas raster. Features with "GHI_mean" ≥ 1100 are selected.

Area Analysis:

Tool: "Field Calculator".

Action: The area is calculated (\$area). Small plots unsuitable for industrial-scale solar farms are filtered out ("area_sqm" > 100).

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Data Source: power_grid layer (merged power=line and power=substation from OSM).

Tool: "Distance to nearest hub".

Action: The distance to the nearest grid element is calculated. A combined filter is applied to select features located no less than 20 m and no more than 30 km away: "HubDist" ≥ 20 AND "HubDist" ≤ 30000 .

Assessment of Potential for BESS/PCS Installation:

Rationale: Industrial zones that have passed the area filter are assumed to have sufficient open space to accommodate energy storage systems. This criterion is considered met for all selected features.

3. Creating the Industrial_Sites_wind layer

This process is also applied to the Industrial_Base layer to identify zones suitable for wind energy.

Analysis of Wind Speed ($\geq 5.0 \text{ m/s}$ at 100m height):

Data Source: Average wind speed raster from the Global Wind Atlas.

Tool: "Zonal Statistics".

Action: The average wind speed is calculated for each polygon. Features with "wind_speed_mean" ≥ 5.0 are selected.

Area Analysis for Wind Turbines: Tool: "Field Calculator".

The minimum viable area for wind turbine installation is set to 1.7 ha (17,000 m²). All smaller plots were excluded using the Field Calculator expression "area_sqm" > 17000 .

Filtering: A filter is applied using the expression "area_sqm" > 17000 (1,7 ha = 17,000 m²).

Exclusion of Orographic Constraints (slopes $> 15^\circ$):

Data Source: Copernicus DEM.

Tools: "Slope", "Raster Calculator", "Polygonize", "Intersection".

Action: A vector layer of suitable slopes ($\leq 15^\circ$) is created and then intersected with the industrial zones layer to exclude areas on steep slopes.

Analysis of Road Accessibility ($\leq 5 \text{ km}$):

Data Source: Layer of state and local roads from OSM.

Tool: "Distance to nearest hub".

Action: Industrial zones located no more than 5 km from roads are selected.
 Analysis of Grid Connection Point Availability (from 20 m to 30 km):
 Action: The same methodology as for the solar layer is applied, using the filter "HubDist" ≥ 20 AND "HubDist" ≤ 30000 .
 Application of Exclusion Buffer Zones (Overlay Analysis):
 Tool: "Buffer".
 Action: Buffer zones are created around infrastructure features: 60 meters around roads, 500 meters around railways, and 10 km around airports (aeroway=aerodrome).
 Tool: "Merge vector layers" and "Dissolve".
 Action: All buffer zones are combined into a single exclusion_zones layer.
 Tool: "Difference" (Vector -> Geoprocessing Tools -> Difference).
 Action: The exclusion_zones layer is "cut out" from the layer of potential industrial zones to exclude areas where wind turbine construction is restricted.
 4. Verification: Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).
 Final result: Two layers - Industrial_Sites_Solar and Industrial_Sites_Wind.

2.7. Mines_and_quarries

This layer identifies post-mining sites suitable for the installation of solar power plants. For the analysis of exhausted mining areas, specialized layers from the OpenStreetMap database were used, representing quarries, mines, and spoil heaps.

2.7.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Quarries & Mines	landuse=quarry	An open-pit mine.
	landuse=mine	An area related to mineral extraction.
Spoil Heaps	man_made=spoil_heap	A pile of waste rock from mining operations.

2.7.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer (Mines_Quarries_Base)

Importing Data from OSM: Tool: QuickOSM Plugin.

Action: A query is executed to extract all polygonal features matching the tags listed in the table (landuse=quarry, landuse=mine, man_made=spoil_heap, and their disused/abandoned variations). This ensures a comprehensive dataset of areas impacted by mining activities.

Consolidation and Cleaning:

Tool: "Merge vector layers" (Processing Toolbox -> Vector general -> Merge vector layers).

Action: All retrieved layers are combined into a single layer.

Tool: "Dissolve" (Vector -> Geoprocessing Tools -> Dissolve).

Action: This is applied to merge adjacent or overlapping features (a quarry and its associated spoil heap) into single, contiguous zones.

Tool: "Fix geometries" (Processing Toolbox -> Vector geometry -> Fix geometries).

Action: Ensures the topological correctness of the layer for subsequent analysis. The result is saved as Mines_Quarries_Base.

2 Filtering by Technical Suitability Criteria

Analysis of Global Horizontal Irradiation (GHI ≥ 1100 kWh/m²):

Data Source: GHI raster layer from the Global Solar Atlas.
 Tool: "Zonal Statistics".
 Action: The average GHI value is calculated for each polygon. Features that satisfy the condition "GHI_mean" >= 1100 are selected.
 Area Analysis:
 Tool: "Field Calculator".
 Action: The area of each feature is calculated (\$area). Small plots unsuitable for industrial-scale solar farms are filtered out ("area_sqm" > 10)
 Analysis of Grid Connection Point Availability (from 20 m to 30 km):
 Data Source: power_grid layer (merged power=line and power=substation from OSM).
 Tool: "Distance to nearest hub".
 Action and Rationale: Including substations (power=substation) in the analysis directly addresses the criterion of substation availability. The distance to any grid element serves as a proxy for the feasibility of laying cables.
 Filtering: A combined expression is used to select features located no less than 20 m (safety buffer) and no more than 30 km (economic viability) away: "HubDist" >= 20 AND "HubDist" <= 30000.
 Availability to install BESS/PCS: Sites that have passed the area filter (> 100M2) are, by definition, large enough to accommodate energy storage systems. This criterion is considered met for all selected territories.
 Stage 3: Verification
 Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).
 Final Result: A polygonal layer named Mines_and_quarries, containing polygons of post-mining sites that have passed all GIS-based filtering stages.

2.7. Artificial_Inland_Water_Bodies

This layer identifies artificial water bodies suitable for the installation of floating solar power plants.

2.7.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Artificial Water Bodies	water=reservoir	A water reservoir.
	landuse=reservoir	The area of a reservoir.
	landuse=basin	A technical basin or settling pond.

2.7.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer (Artificial_Water_Base)

Importing Data from OSM:

Tool: QuickOSM Plugin.

Action: A query is executed to extract all polygonal and linear features matching the tags listed in the table.

Tool: "Difference" (Vector -> Geoprocessing Tools -> Difference).

Action: To ensure the exclusion of natural water bodies, features tagged as natural (downloaded via a natural=water query from OSM) are "cut out" from the All_Water_Bodies layer. This is a critical step to avoid conflicts with water fund protection criteria.

Final Cleaning:

Tool: "Dissolve" (Vector -> Geoprocessing Tools -> Dissolve).

Action: Applied to merge adjacent or overlapping features.

Tool: "Fix geometries".

Action: Ensures the topological correctness of the layer. The result is saved as Artificial_Water_Base.

2. Filtering by Technical Suitability Criteria

Analysis of Global Horizontal Irradiation (GHI \geq 1100 kWh/m²):

Tool: "Zonal Statistics".

Action: The average GHI value is calculated for each polygon from the Global Solar Atlas raster. Features with "GHI_mean" \geq 1100 are selected.

Area Analysis:

Tool: "Field Calculator".

Action: The area of each water body is calculated (\$area). Small features unsuitable for economically viable projects are filtered out ("area_sqm" > 100).

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Data Source: power_grid layer (merged power=line and power=substation from OSM).

Tool: "Distance to nearest hub".

Action: The distance to the nearest grid element is calculated. A combined filter is applied to select features located no less than 20 m and no more than 30 km away: "HubDist" \geq 20 AND "HubDist" \leq 30000.

Availability to install BESS/PCS: Floating solar farms require land-based infrastructure for inverters, transformers, and grid connection. It is assumed that the shoreline area of water bodies that have passed the area filter provides sufficient space for BESS/PCS installation. This criterion is considered met from a spatial availability perspective.

3. Verification

Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final Result: A polygonal layer named Artificial_Inland_Water_Bodies, containing polygons of artificial water bodies that have passed all GIS-based filtering stages.

2.9. Urban_Wastewater_Treatment_Sites

This layer identifies wastewater treatment plant sites suitable for the installation of solar panels.

2.9.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Treatment Plants	man_made=wastewater_plant	A wastewater treatment station.
	landuse=industrial + industrial=wastewater_treatment	Land used for industrial purposes, specifically dedicated to wastewater treatment activities. Includes treatment facilities, technical buildings, and associated infrastructure used for the purification and management of municipal or industrial sewage.

	man_made=storage_tank / natural=water + wastewater=pond	Artificial or natural tanks and ponds used for storing untreated or treated wastewater. These areas can include lagoons, stabilization ponds, or reservoirs within wastewater treatment systems.
	landuse=basin + basin=settlng / wastewater=pond	Basins or sedimentation ponds designed for mechanical or biological wastewater treatment. Used to settle suspended solids, remove impurities, or biologically purify wastewater before discharge or reuse.
	man_made=pumping_station	A facility equipped with pumps for transferring wastewater between different stages of the treatment process or lifting it to higher elevations within the sewage network.

2.9.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer (Wastewater_Base)

Importing Data from OSM:

Tool: QuickOSM Plugin.

Action: A query is executed to extract all features (polygons and points) matching the tag man_made=wastewater_plant.

Tool: "Dissolve" (Vector -> Geoprocessing Tools -> Dissolve).

Action: Applied to merge adjacent or overlapping features.

Tool: "Fix geometries" (Processing Toolbox -> Vector geometry -> Fix geometries).

Action: Ensures the topological correctness of the layer. The result is saved as Wastewater_Base.

2. Filtering by Technical Suitability Criteria

Analysis of Global Horizontal Irradiation ($GHI \geq 1100 \text{ kWh/m}^2$):

Tool: "Zonal Statistics".

Action: The average GHI value is calculated for each polygon from the Global Solar Atlas raster. Features with "GHI_mean" ≥ 1100 are selected.

Area Analysis:

Tool: "Field Calculator".

Action: The area of each feature is calculated (\$area). Small plots unsuitable for industrial-scale solar farms are filtered out ("area_sqm" > 100).

Analysis of Road Accessibility:

Data Source: Layer of roads (regional and district) from OSM.

Tool: "Distance to nearest hub".

Action: The presence of roads in the immediate vicinity is checked. Given that treatment plants typically have access roads, this criterion is considered met for most sites, but a filter can be applied to remove anomalously remote plots (distance to road $\leq 5 \text{ km}$).

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Data Source: power_grid layer (merged power=line and power=substation from OSM).

Tool: "Distance to nearest hub".

Action: The distance to the nearest grid element is calculated. A combined filter is applied: "HubDist" >= 20 AND "HubDist" <= 30000.

Assessment of Potential for BESS/PCS Installation:

Wastewater treatment plants that have passed the area filter are assumed to have sufficient open space (on the roofs of technical buildings or on open ground) to accommodate energy storage systems. This criterion is considered met for all selected features.

3. Verification

Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final Result: A polygonal layer named Urban_Wastewater_Treatment_Sites, containing polygons of wastewater treatment plants that have passed all GIS-based filtering stages.

2.10. Degraded Land not usable for Agriculture solar

This layer identifies degraded and low-productivity lands suitable for solar and wind installations.

2.10.1. Data sources from OpenStreetMap (OSM):

Category	OSM (key=value)	Description
Naturally Degraded	natural=heath	Low-growing woody vegetation, often dominated by heather or similar shrubs, typically found on nutrient-poor, acidic soils – these are wastelands where almost nothing grows, characterized by poor, dry, and infertile soils with sparse low vegetation
	natural=bare_rock	Exposed rock outcrops.
	natural=scree	Slopes covered with rock fragments.
	natural=sand	Sandy areas.

2.10.2. Detailed Processing Methodology in QGIS:

1. Creating the Base Layer (Degraded_Lands_Base)

Importing Component Data from OSM:

Tool: QuickOSM Plugin.

Action: Several queries are executed to extract all polygonal features corresponding to each of the categories listed in the table.

Consolidation and Creation of a Single Composite Layer:

Tool: "Merge vector layers" (Processing Toolbox -> Vector general -> Merge vector layers).

Action: All the retrieved component layers are combined into a single layer representing the union of all types of degraded lands.

Tool: "Dissolve" (Vector -> Geoprocessing Tools -> Dissolve).

Action: This is applied to merge adjacent or overlapping polygons into single, contiguous zones of degraded land.

Tool: "Fix geometries" (Processing Toolbox -> Vector geometry -> Fix geometries).

Action: Ensures the topological correctness of the layer. The result is saved as Degraded_Lands_Base.

2. Creating the Degraded_Land_Not_Usable_for_Agriculture_solar layer

This process is applied to the Degraded_Lands_Base layer to identify zones suitable for solar energy.

Analysis of Global Horizontal Irradiation ($GHI \geq 1100 \text{ kWh/m}^2$):

Tool: "Zonal Statistics".

Action: The average GHI value is calculated for each polygon from the Global Solar Atlas raster. Features with "GHI_mean" ≥ 1100 are selected.

Area Analysis:

Tool: "Field Calculator".

Action: The area is calculated ($\$area$). Small plots unsuitable for industrial-scale solar farms are filtered out (" $area_sqm > 100$ ").

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Data Source: power_grid layer (merged power=line and power=substation from OSM).

Tool: "Distance to nearest hub".

Action: The distance to the nearest grid element is calculated. A combined filter is applied: "HubDist" ≥ 20 AND "HubDist" ≤ 30000 .

3. Creating the Degraded_Land_Not_Usable_for_Agriculture_wind layer

This process is also applied to the Degraded_Lands_Base layer to identify zones suitable for wind energy.

Analysis of Wind Speed ($\geq 5.0 \text{ m/s}$ at 100m height):

Data Source: Average wind speed raster from the Global Wind Atlas.

Tool: "Zonal Statistics".

Action: The average wind speed is calculated for each polygon. Features with "wind_speed_mean" ≥ 5.0 are selected.

Area Analysis for Wind Turbines:

Tool: "Field Calculator".

Action: The area is calculated ($\$area$). Plots with an area less than 1,7 ha are filtered out using the expression " $area_sqm > 17000$ ".

Exclusion of Orographic Constraints (slopes $> 15^\circ$):

Data Source: Copernicus DEM.

Tools: "Slope", "Raster Calculator", "Polygonize", "Intersection".

Action: A vector layer of suitable slopes ($\leq 15^\circ$) is created and then intersected with the degraded lands layer.

Analysis of Road Accessibility ($\leq 5 \text{ km}$):

Data Source: Layer of state and local roads from OSM.

Tool: "Distance to nearest hub".

Action: Zones located no more than 5 km from roads are selected.

Analysis of Grid Connection Point Availability (from 20 m to 30 km):

Action: The same methodology as for the solar layer is applied, using the filter "HubDist" ≥ 20 AND "HubDist" ≤ 30000 .

Application of Exclusion Buffer Zones (Overlay Analysis):

Tools: "Buffer", "Merge vector layers", "Dissolve", "Difference".

Action: Buffers are created (60 m around roads, 500 m around railways, 10 km around airports), merged into a single exclusion_zones layer, and "cut out" from the layer of potential sites.

4. Verification

Verification of the collected data will be carried out in the following steps: cross-comparison of information from open sources to identify discrepancies in the spatial location and classification of objects; topological control (verification of the correctness of connections between lines and nodes of the network).

Final Result: Two separate polygonal layers:



Degraded_Land_Not_Usable_for_Agriculture_solar
Degraded_Land_Not_Usable_for_Agriculture_wind.

and