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

Task 5. Technical Analysis Report for Development of RAA

Renewable energy potential and infrastructure readiness for REAAs

Prepared by: Valentyn Didyk, RE planning specialist

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ACRONYMS

DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
EML	Electricity Market Law
EnC	Energy Community
EU	European Union
IPS	Integrated Power System
kW	Kilowatt
MW	Megawatt
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

REPORT
ON RENEWABLE ENERGY POTENTIAL AND INFRASTRUCTURE READINESS: CAPACITY, TECHNICAL FEASIBILITY, AND ALIGNMENT WITH RES TARGETS

INTRODUCTION

In accordance with Task 5, the Report contains the technical analysis of renewable energy potential and infrastructure readiness, evaluating renewable capacity in five oblasts in Ukraine (Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia).

The Report contains:

SUMMARY

The total available solar capacity of the REAAs in five oblasts (Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia) is estimated at over 24,17 GW. This is in line with the National Energy and Climate Plan for the period up to 2030, which provides for an increase in the share of renewable energy generation in total electricity production to 25% in 2030, and the National Renewable Energy Action Plan for the period up to 2030, which aims to increase solar generation capacity mainly on a market basis by 4.074 GW (from 8,126 GW in 2025 to 12.2 GW in 2030). Lviv oblast has the greatest solar potential capacity (8,047.2 MW), followed by Vinnitsa oblast (7 360,3 MW), Ivano-Frankivsk oblasts (3 847,0 MW), Chernivtsi oblast (2 838,7 MW) and Zakarpatia oblast (2 086,4 MW). In in five oblasts, REAAs with the sufficient solar potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (7 685,54 MW, 8 673,32MW, 3 139,09 MW and 4 532,58 MW, respectively). Parking areas could have a significant capacity of 111.44 MW. Relatively small amount of solar capacity could be installed on the degraded land that is not usable for agriculture (24,63 MW). Urban wastewater treatment sites cannot provide any solar capacity.

The total available wind capacity of the REAAs in five oblasts is estimated at 264,69 MW. Vinnytsia oblast has the greatest wind potential capacity (94,8 MW) followed by Lviv oblast (73,9 MW), Chernivtsi oblast (53,2 MW), Ivano-Frankivsk oblast (41,0 MW) and Zakarpatia oblast (1,8 MW).The REAA with the available wind potential are Farms and Industrial sites at 91 MW and 173,69 MW.

Potential of REAAs in Lviv oblast. The total available solar capacity of the REAAs in the Lviv oblast could be estimated at over 8,04 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (2 148,7 MW, 3 412,8 MW, 972,2 MW and 1 451,3 MW, respectively). The

REAA with the sufficient wind potential are Industrial sites at 67,18 MW. Farms could provide 6,73 MW.

Potential of REAAs in Zakarpattia oblast. The total available solar capacity of the REAAs in the Zakarpattia oblast could be estimated at over 2,08 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (893,7 MW, 584,6 MW, 226,4 MW and 376,9 MW, respectively). The REAA with the some wind potential are Farms at 1,36 MW.

Potential of REAAs in Ivano-Frankivsk oblast
The total available solar capacity of the REAAs in the Ivano-Frankivsk oblast could be estimated at over 3,8 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (1 674,9 MW, 811,4 MW, 583,4 MW and 762,0 MW, respectively). Parking areas could have a capacity of 15,2 MW. Total wind capacity in the oblast is estimated at 41,02 MW. Industrial sites have the wind potential at 24,74 MW. Farms could provide 16,27 MW.

Potential of REAAs in Chernivtsi oblast. The total available solar capacity of the REAAs in the Cherivtsi oblast could be estimated at over 2,8 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (812,4 MW, 961,7 MW, 509,2 MW and 531,9 MW, respectively). Parking areas could have a capacity of 17,6 MW. Degraded land that are not usable for agriculture can provide a small solar capacity at 5,9 MW. Total wind capacity in the oblast is estimated at over 53,1 MW. Farms have the greatest wind potential, at 41.1 MW, while Industrial sites could provide 12.07 MW.

Potential of REAAs in Vinnytsia oblast. The total available solar capacity of the REAAs in the Vinnytsia oblast could be estimated at over 7,3 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (2 155,8 MW, 2 902,8 MW, 847,9 MW and 1 410,4 MW, respectively). Parking areas could have a capacity of 19,9 MW. Degraded land that are not usable for agriculture can provide a small solar capacity at 16,4 MW. Waste sites/Landfill, Mines/quarries, Artificial inland water bodies (lakes/reservoirs, could each provide 2,3 MW. Total wind capacity in the oblast is estimated at over 94,8 MW. Industrial sites have the wind potential at 69,27 MW, Farms could provide 25,55 MW.

Infrastructure readiness. On the the ECS'requests, NPC Ukrenergo has informed that the information on the location of substations, their installed autotransformer capacity and reserve capacity for connecting power generation facilities is included in the list of restricted information on critical infrastructure facilities and, in view of the above, cannot be provided. DSOs (PrJSC Lvivoblenergo, PrJSC Zakarpattyaoblenergo, JSC Prykarpattyaoblenergo, JSC Chernivtsioblenergo, and JSC Vinnytsiaoblenergo) did not provide any infornation on their infrastructure. Under these circumstances, an alternative data source was used, such as OpenStreetMap (OSM). To obtain data on the locations of 35 kV and 110 kV overhead electric lines, as 35 kV and 110/35 kV power substations, and also on grid connection at 6 kV and 10 kV points, the QGIS geographic information system toolkit is used. Data is downloaded directly from OpenStreetMap (OSM) servers using built-in QGIS tools (QuickOSM plugin).

1. DATA AND APPROACHES TO TECHNICAL ANALYSIS OF RENEWABLE ENERGY POTENTIAL

1.1. Data for assessment of renewable energy potential and infrastructure readiness

Data for assessment of renewable energy potential based on the criteria for each zones are the following:

- Data on REAAs location. Total area of each REAA.
- Global Horizontal Irradiation: not less than 1100 kWh/m2, kWp.
- Wind speed data: average annual wind speed at a height of 100 m, m/s, not less than 5.0 m/s.
- Data on powerlines at 35 kV and 110 kV; substations at 35 kV, 110 kV and 330/110/35/10 kV for 5 oblasts; grid connection points at 6 kV and 10 kV for Lviv oblast.

1.2. Approaches to designation of REAAs location. Total area of each REAA

REAA locations were designated in vector layers obtained by modelling in the QGIS geoinformation environment according to the criteria of the document: "RAAs CRITERIA Ukraine_high level".

List of layers with descriptions from QGIS is the following:

- Rooftops_and_Facades_of_Buildings - This layer identifies rooftops and facades of buildings suitable for the installation of solar panels.
- Transport_Infrastructure_Corridor - This layer identifies roadside adjacent territories suitable for the installation of solar panels.
- Parking_Areas - This layer identifies open parking lots suitable for the installation of solar canopies.
- Farms_solar – These layer identify farm territories suitable for solar installations.
- Farms_wind - These layer identify farm territories suitable for wind installations
- Waste_sites - This layer identifies solid waste landfills suitable for the installation of solar power panels.
- Industrial_Sites_Solar - These layers identify industrial zones suitable for the installation of solar facilities.
- Industrial_Sites_Wind - These layers identify industrial zones suitable for the installation of wind facilities.
- Mines_and_quarries - This layer identifies post-mining sites suitable for the installation of solar power panels.
- Artificial_Inland_Water_Bodies - This layer identifies artificial water bodies suitable for the installation of floating solar power plants.
- Urban_Wastewater_Treatment_Sites - This layer identifies wastewater treatment plant sites suitable for the installation of solar panels.
- Degraded_Land_Not_Usable_for_Agriculture_solar - This layer identifies degraded and low-productivity lands suitable for solar installations.
- Degraded_Land_Not_Usable_for_Agriculture_wind - This layer identifies degraded and low-productivity lands suitable for wind installations.

Annex 1 contains the detailed description of the REAAs selection.

1.3. Approaches to evaluation of solar energy capacity in the REAAs

Solar energy capacity in a REAA is determined by using the total square of the REAA and an equivalent unit square of the solar installation.

Csi - solar energy capacity in the REAAi is calculated using the following equation:

$$Csi = Ssi / Ssti, \quad (1)$$

where:

- Ssi - total square of a REAAi with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp, which is defined as the results of REAA mapping according to the "CRITERIA: Environmental Criteria and Constrains, Renewable Energy Criteria and Infrastructure Readiness" using the tool PVGIS5.3;
- Ssti - total equivalent square for 1.0 kW solar installation in the i-REAA (including: Sspi - panel square, m2/kW; Ssii – related infrastructure square, m2/kW; Ssiim2 - storage square, m2/kW);
- i - a number of REAA assessed (1- Artificial and built surfaces (rooftops and facades); 2 - Transport infrastructure; 3 - Parking areas; 4 - Farms; 5 - Waste sites; 6 - Industrial sites; 7 - Mines, quarries; 8 - Artificial inland water bodies, lakes / reservoirs; 9 - Urban waste water treatment sites; 10 - Degraded land not usable for agriculture).

1.4. Approaches to evaluation of wind energy capacity in the REAAs

Wind energy capacity in a REAA is determined by the total area and equivalent unit area of the wind installation.

Cwi - wind energy capacity in the REAAi is calculated using the following equation:

$$Cwi = Swi / Swti, \quad (2)$$

where:

- Swi - total square of a REAAi with the average annual wind speed at a height of 100 m, m/s, not less than 5.0 m/s, which is defined as the results of REAA mapping according to the "CRITERIA: Environmental Criteria and Constrains, Renewable Energy Criteria and Infrastructure Readiness" using the tool …;
- Swti - total equivalent square for 4,5 MW turbine in a wind farm, km2/MW.
- wind installation in the i-REAA including related infrastructure and storage;
- i - a number of REAA assessed (4 - Farms; 6 - Industrial sites; 10 - Degraded land not usable for agriculture).

2. DESIGNATING REAA LOCATIONS AND SQUARES

Methodology for determining REAAs and calculating total areas was the following:

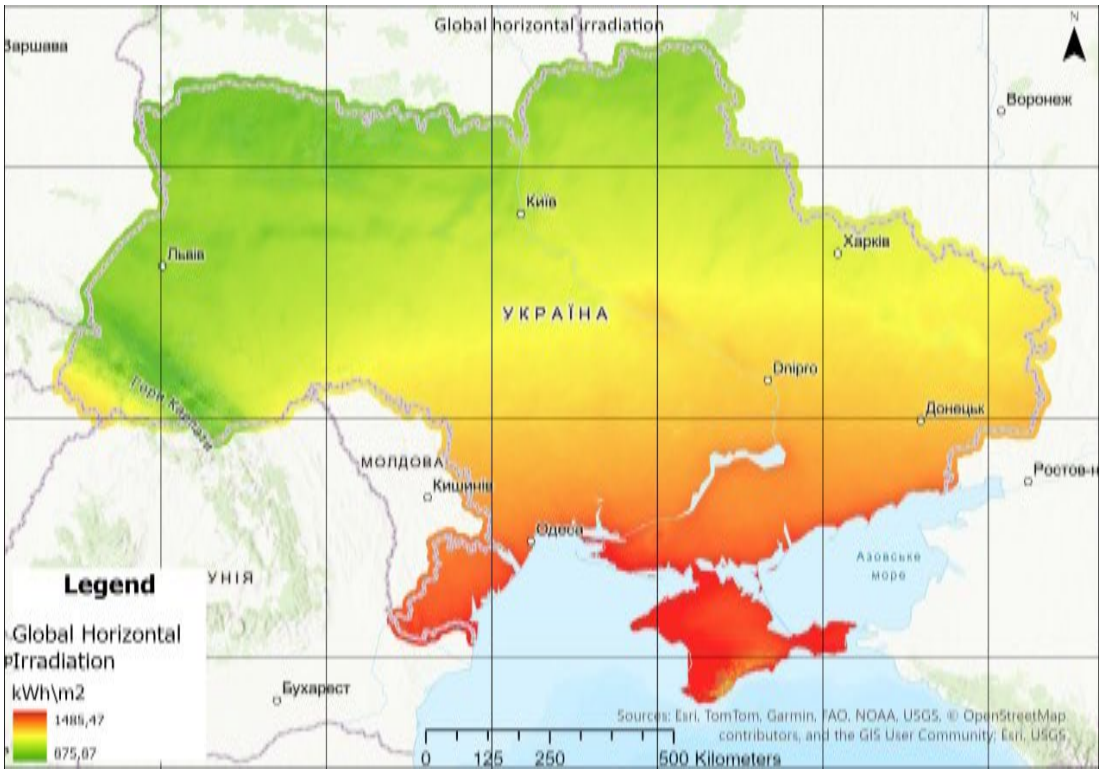
- Based on administrative-territorial data, a mask of the study area was prepared, covering the territory of five pilot regions of Ukraine. The mask is then used to download data from open data sources, in particular the OpenStreetMap (OSM) project map.

- Open data based on OSM was prepared for the study area. Based on the region mask, data was selected, downloaded and converted into Geopackage format layers using thematic queries to the OSM database for each group of objects.
- Data on solar insolation levels and wind speeds were downloaded in raster format. The rasters were reclassified to identify areas with solar insolation of at least 1,100 kWh/m² and wind speeds of at least 5.0 m/s.
- A sample of objects was created for each criterion group that met the proposed criteria for each group. A detailed description for each group is provided below. As a result, a set of polygonal objects was formed for each group that met the selection (filtering) rules.
- Basic selection rules: the site is located in an area with acceptable levels of solar insolation and wind strength, acceptable parameters of height and slope steepness, and sufficient proximity to energy infrastructure facilities.
- In the next step, the objects that do not fall within the zone of environmental restrictions, which was formed on the basis of a set of layers describing environmental criteria, were selected from the already selected objects. If an object falls within the zone of environmental restrictions, it is not taken into account in further analysis.
- The areas were calculated for the final set of objects. The areas were calculated in the UCS-2000 metric coordinate system in m2 using the $area function in QGIS. Each object in each group selected as a result of the analysis was assigned an area value.
- In the final step, the area data was aggregated by summing within each region and each REAA, taking into account the difference between solar and wind energy placement.

The results of square evaluation are represented in the Annex 2.

3. EVALUATION OF REAA SOLAR CAPACITY IN 5 UKRAINIAN OBLASTS

Solar potential (GHI) in Ukraine is represented at the picture below. Here, GHIs range from 876 kWh/m2, kWp to 1485 kWh/m2, kWp.



Picture 3-1. Solar potential (GHI) in Ukraine

3.1. Assumptions

Assumptions applied to the evaluation of solar capacity are the following:

- Types of modules: crystalline silicon cells[1]: Mono PERC Module Risen solar panels 500 W. The size is 1,910*1,134 m2.
- Fixed (non-tracking) systems: free-standing modules are mounted on a rack with air flowing freely behind the modules; roof added / building-integrated, which means that the modules are completely built into the structure of the wall or roof of a building, with little or no air movement behind the modules.
- The slope: the optimal values for slope and orientation (assuming fixed angles for the entire year).
- Orientation angle or azimuth: the angle of the PV modules relative to the direction due South is 0°.
- Ssti, 1,0 kW, square, m2/kW includes:
    - Sspi, 1,0 kW equivalent panel square - 4,33 m2/kW;
    - Si1, infrastructure square, zone 1 - 7,20 m2/kW;
    - Si2-10, infrastructure square, zones 2-10 - 4,10 m2/kW (including Constructions, cabling - 1,00 m2/kW; Protection area, internal roads - 1,00 m2/kW; Anti-shading distance/maintenance access - 2,00 m2/kW; Invertors, controllers, local substation - 0,10 m2/kW)
    - Sssi, storage square for capacity at 1kWh/1kW, m2/kW - 0,093.
- Sst1, 1,0 kW, square, m2/kW for zone 1 (1- Artificial and built surfaces) – 11,6 m2/kW;
- Sst2-10, 1,0 kW, square, m2/kW for zone 2-10 (2 - Transport infrastructure; 3 -

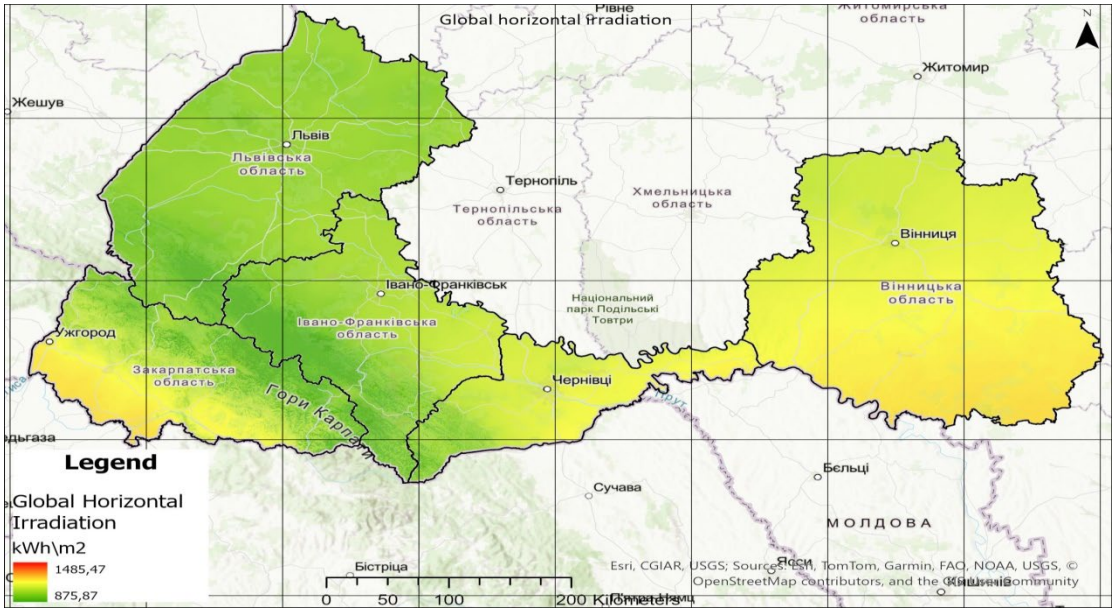
[1] https://www.pretapower.com/mono-perc-module-risen-solar-panels-500w/.

Parking areas; 4 - Farms; 5 - Waste sites; 6 - Industrial sites; 7 - Mines, quarries; 8 -Artificial inland water bodies, lakes / reservoirs; 9 - Urban waste water treatment sites; 10 - Degraded land not usable for agriculture). – 8,5 m2/kW.

3.2. Evaluation of solar capacity in 5 oblasts of Ukraine

Evaluation of solar capacity in 5 oblasts of Ukraine (Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia) is provided for: artificial and built surfaces, such as rooftops and facades of buildings; transport infrastructure and their direct surroundings; parking areas; farms; waste sites (landfill for solid waste); industrial sites; mines; artificial inland water bodies, lakes or reservoirs; urban waste water treatment sites; degraded land not usable for agriculture.

Solar potential (GHI) in 5 targeted oblasts of Ukraine is represented at the picture below.



Picture 3-2. Solar potential (GHI) in 5 targeted oblasts

Total squares of each REAA with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia oblasts are represented in the table below.

Table 3-1. Squares of REAAs in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia oblasts

REAAs/Ssi, km2	Total	Lviv	Zakarpatia	Iv-Frankivsk	Chrnivtsi	Vinnitsia
Artificial and built surfaces (rooftops and facades)	89,3	24,98	10,4	19,5	9,4	25,1
Transport infrastructure	73,9	29,09	5,0	6,9	8,2	24,7
Parking areas	1,0	0,47	0,0	0,1	0,2	0,2
Farms	26,8	8,29	1,9	5,0	4,3	7,2
Waste sites	0,0	0,02	0,0	0,0	0,0	0,0
Industrial sites	38,6	12,37	3,2	6,5	4,5	12,0
Mines, quarries	0,0	0,01	0,0	0,0	0,0	0,0

Artificial inland water bodies, lakes/reservoirs	0,0	0,01	0,0	0,0	0,0	0,0
Urban waste water treatment sites	0,0	0,00	0,0	0,0	0,0	0,0
Degraded land not usable for agriculture	0,2	0,02	0,0	0,0	0,1	0,1
Total	229,95	75,26	20,56	37,99	26,72	69,43

Total available square of REAAs in 5 oblasts where solar generation could be installed is estimated at 229,95 km2. The most acceptable REAAs are Artificial and built surfaces (rooftops and facades), Transport infrastructure, Farms and Industrial sites (89,3 km2, 73,9 km2, 26,8 km2 and 38,6 km2, respectively). Solar installations are not suitable for urban wastewater treatment sites.

The evaluation of solar capacity was performed using equation (1). The results of the calculation are provided in table below.

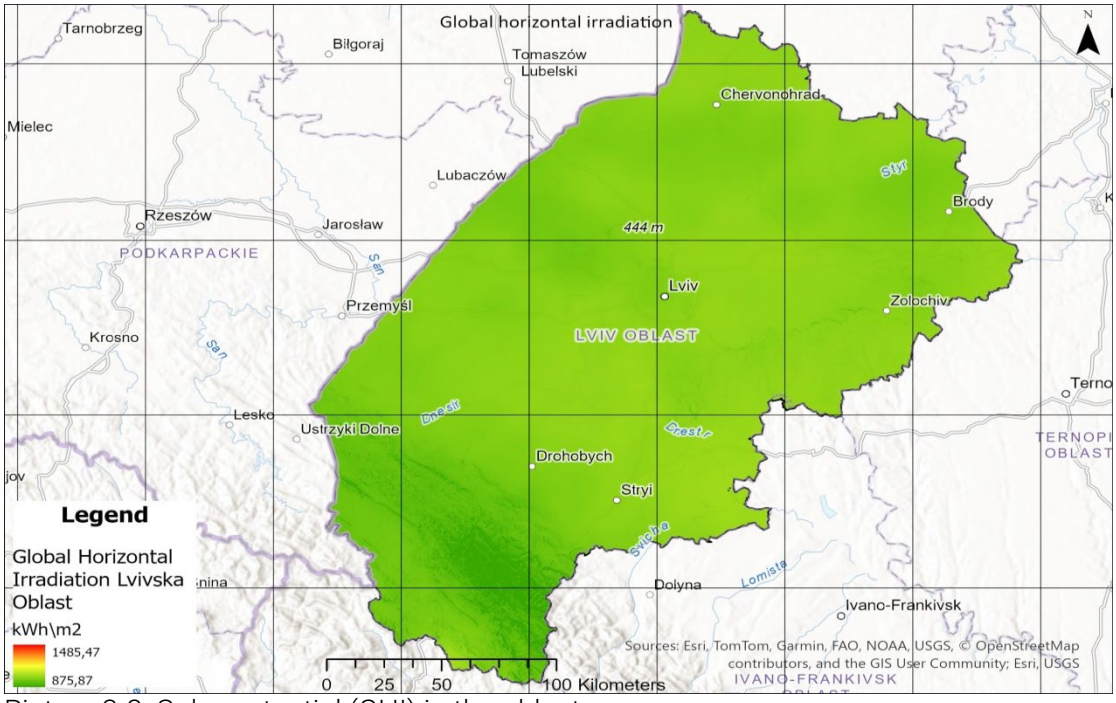
Table 3-2. REAA solar capacity in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia oblasts

REAA/Csi, MW	Total, MW	Lviv	Zakarpatia	Iv-Frankivsk	Chrnivtsi	Vinnitsia
Artificial and built surfaces (rooftops and facades)	7 685,54	2 148,70	893,70	1 674,89	812,45	2 155,81
Transport infrastructure	8 673,32	3 412,82	584,62	811,39	961,68	2 902,81
Parking areas	111,44	55,13	3,52	15,25	17,60	19,94
Farms	3 139,09	972,22	226,41	583,41	509,16	847,89
Waste sites	4,69	2,35	0,00	0,00	0,00	2,35
Industrial sites	4 532,58	1 451,31	376,94	762,03	531,93	1 410,37
Mines, quarries	4,69	1,17	1,17	0,00	0,00	2,35
Artificial inland water bodies, lakes/reservoirs	3,52	1,17	0,00	0,00	0,00	2,35
Urban waste water treatment sites	0,00	0,00	0,00	0,00	0,00	0,00
Degraded land not usable for agriculture	24,63	2,35	0,00	0,00	5,87	16,42
Total, MW	24 179,51	8 047,22	2 086,36	3 846,96	2 838,68	7 360,28

The total available solar capacity of the REAAs in the five oblasts could be estimated at over 24,179 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (7 685,54 MW, 8 673,32MW, 3 139,09 MW and 4 532,58 MW, respectively). Parking areas could have a significant capacity of 111.44 MW. Relatively small amount of solar capacity could be installed on the degraded land that is not usable for agriculture (24,63 MW). Urban wastewater treatment sites cannot provide any solar capacity.

3.2.1. Evaluation of solar capacity in the Lviv oblast

Solar potential (GHI) in the Lviv oblast is represented at the picture below.



Picture 3-3. Solar potential (GHI) in the oblast

Total square of each REAA with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp is provided in the table below.

Table 3-3. Squares of REAAs in the Lviv oblast

Zone number	REAAs	REAA square, km²
Zone 1	Artificial and built surfaces (rooftops and facades)	24,98
Zone 2	Transport infrastructure	29,09
Zone 3	Parking areas	0,47
Zone 4	Farms	8,29
Zone 5	Waste sites	0,02
Zone 6	Industrial sites	12,37
Zone 7	Mines, quarries	0,01
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,01
Zone 9	Urban waste water treatment sites	0,00
Zone 10	Degraded land not usable for agriculture	0,02
	Total, km2	75,26

The evaluation of solar capacity was performed using equation (1). The results of the calculation are provided in table below

Table 3-4. REAA solar capacity in the Lviv oblast

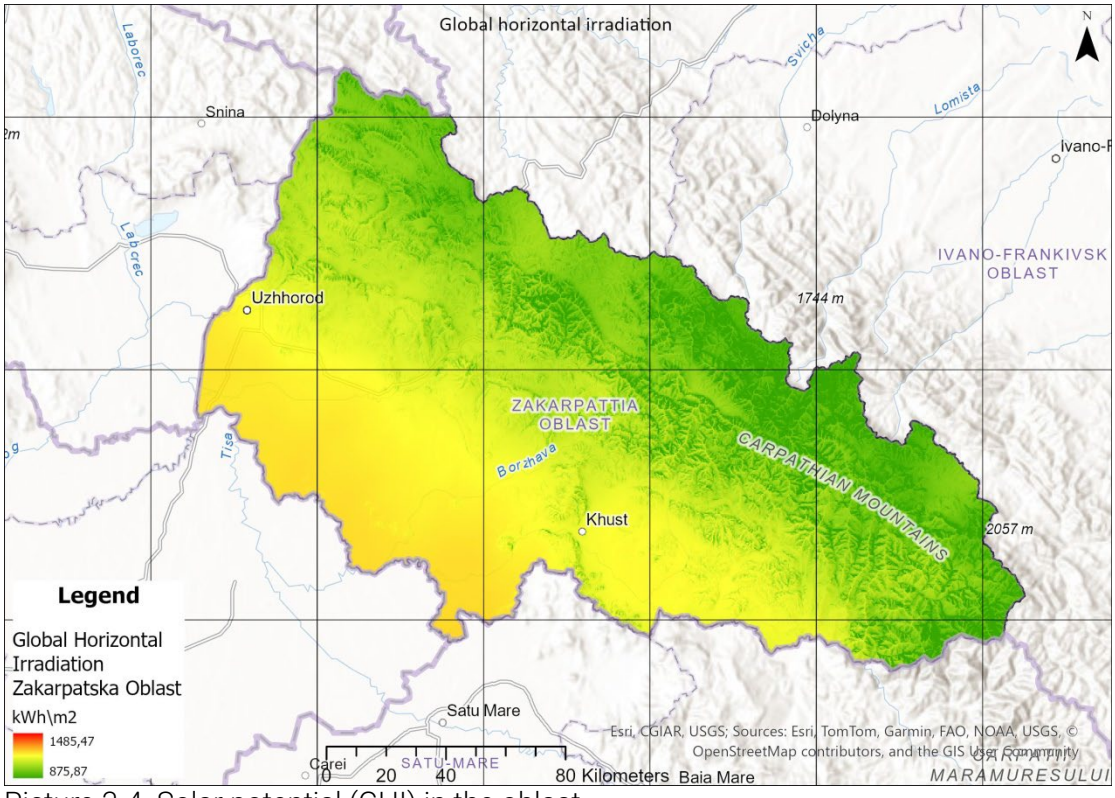
Zone number	REAA square	Ssi, km2	Sst, total square, km2/MW	Csi, MW
Zone 1	Artificial and built surfaces (rooftops and facades)	25,0	0,0116	2 148,7

Zone 2	Transport infrastructure	29,1	0,0085	3 412,8
Zone 3	Parking areas	0,5	0,0085	55,1
Zone 4	Farms	8,3	0,0085	972,2
Zone 5	Waste sites	0,0	0,0085	2,3
Zone 6	Industrial sites	12,4	0,0085	1 451,3
Zone 7	Mines, quarries	0,0	0,0085	1,2
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,0	0,0085	1,2
Zone 9	Urban waste water treatment sites	0,0	0,0085	0,0
Zone 10	Degraded land not usable for agriculture	0,0	0,0085	2,3
	Total	75,3		8 047,2

The total available solar capacity of the REAAs in the Lviv oblast could be estimated at over 8,04 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (2 148,7 MW, 3 412,8 MW, 972,2 MW and 1 451,3 MW, respectively). Urban wastewater treatment sites cannot provide any solar capacity.

3.2.2. Evaluation of solar capacity in the Zakarpattia oblast

Solar potential (GHI) in the Zakarpattia oblast is represented at the picture below.



Picture 3-4. Solar potential (GHI) in the oblast

Total square of each REAA with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp is provided in the table below.

Table 3-5. Squares of REAAs in the Zakarpattia oblast

Zone number	REAAs	REAA square, km²
Zone 1	Artificial and built surfaces (rooftops and facades)	10,39
Zone 2	Transport infrastructure	4,98
Zone 3	Parking areas	0,03
Zone 4	Farms	1,93
Zone 5	Waste sites	0,00
Zone 6	Industrial sites	3,21
Zone 7	Mines, quarries	0,01
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,00
Zone 9	Urban waste water treatment sites	0,00
Zone 10	Degraded land not usable for agriculture	0,00
	Total, km2	20,56

The evaluation of solar capacity was performed using equation (1). The results of the calculation are provided in the table below

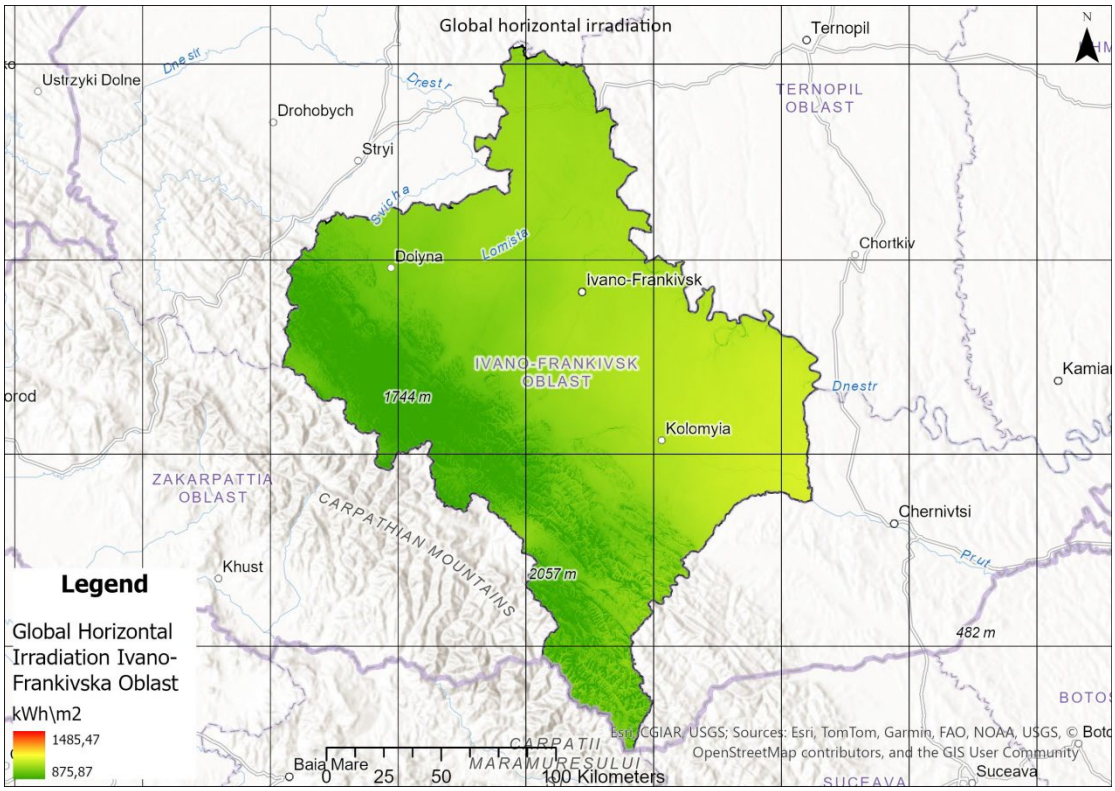
Table 3-6. REAA solar capacity in the Zakarpattia oblast

Zone number	REAA square	Ssi, km2	Sst, total square, km2/MW	Csi, MW
Zone 1	Artificial and built surfaces (rooftops and facades)	10,4	0,0116	893,7
Zone 2	Transport infrastructure	5,0	0,0085	584,6
Zone 3	Parking areas	0,0	0,0085	3,5
Zone 4	Farms	1,9	0,0085	226,4
Zone 5	Waste sites	0,0	0,0085	0,0
Zone 6	Industrial sites	3,2	0,0085	376,9
Zone 7	Mines, quarries	0,0	0,0085	1,2
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,0	0,0085	0,0
Zone 9	Urban waste water treatment sites	0,0	0,0085	0,0
Zone 10	Degraded land not usable for agriculture	0,0	0,0085	0,0
	Total	20,6		2 086,4

The total available solar capacity of the REAAs in the Zakarpattia oblast could be estimated at over 2,08 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (893,7 MW, 584,6 MW, 226,4 MW and 376,9 MW, respectively). Waste sites/Landfill, Artificial inland water bodies (lakes/reservoirs, Urban wastewater treatment sites and Degraded land that are not usable for agriculture cannot provide any solar capacity.

3.2.3. Evaluation of solar capacity in the Ivano-Frankivsk oblast

Solar potential (GHI) in the Ivano-Frankivsk oblast is represented at the picture below.



Picture 3-5. Solar potential (GHI) in the oblast

Total square of each REAA with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp is provided in the table below.

Table 3-7. Squares of REAAs in the Ivano-Frankivsk oblast

Zone number	REAAs	REAA square, km²
Zone 1	Artificial and built surfaces (rooftops and facades)	19,47
Zone 2	Transport infrastructure	6,92
Zone 3	Parking areas	0,13
Zone 4	Farms	4,97
Zone 5	Waste sites	0,00
Zone 6	Industrial sites	6,50
Zone 7	Mines, quarries	0,00
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,00
Zone 9	Urban waste water treatment sites	0,00
Zone 10	Degraded land not usable for agriculture	0,00
	Total, km2	37,99

The evaluation of solar capacity was performed using equation (1). The results of the calculation are provided in the table below.

Table 3-8. REAA solar capacity in the Ivano-Frankivsk oblast

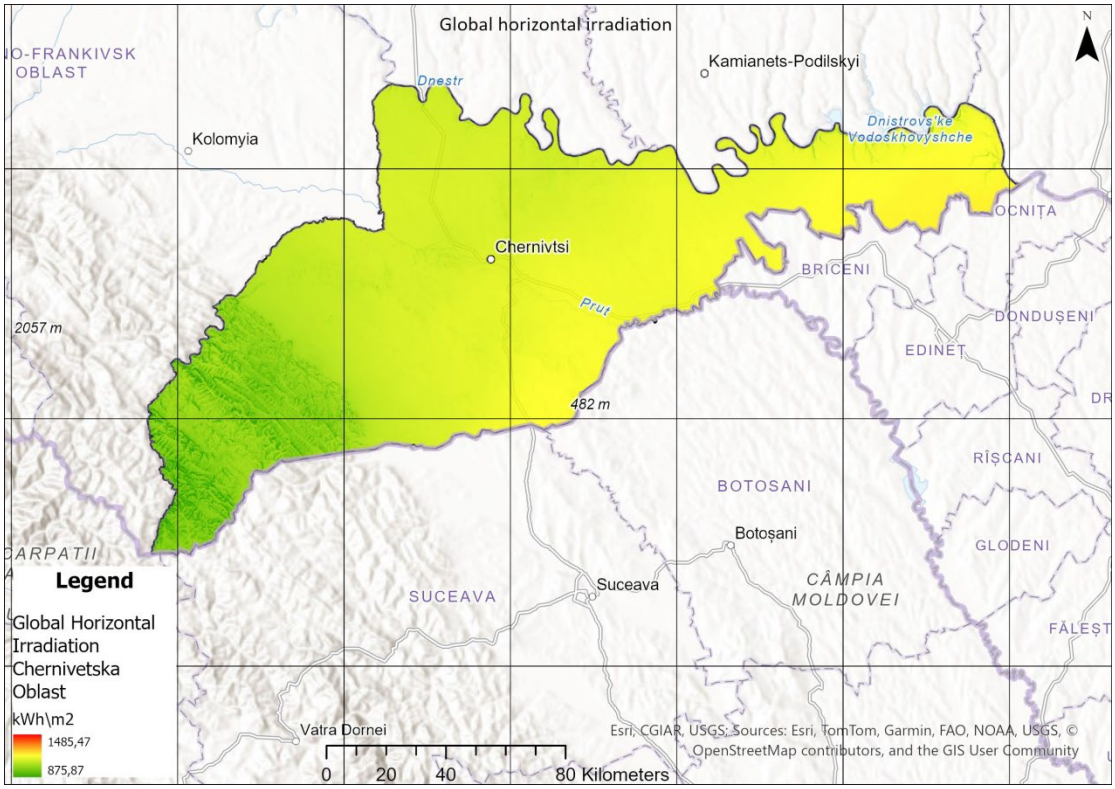
Zone number	REAA square	Ssi, km2	Sst, total square, km2/M	Csi, MW

			W	
Zone 1	Artificial and built surfaces (rooftops and facades)	19,47	0,0116	1 674,9
Zone 2	Transport infrastructure	6,92	0,0085	811,4
Zone 3	Parking areas	0,13	0,0085	15,2
Zone 4	Farms	4,97	0,0085	583,4
Zone 5	Waste sites	0,00	0,0085	0,0
Zone 6	Industrial sites	6,50	0,0085	762,0
Zone 7	Mines, quarries	0,00	0,0085	0,0
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,00	0,0085	0,0
Zone 9	Urban waste water treatment sites	0,00	0,0085	0,0
Zone 10	Degraded land not usable for agriculture	0,00	0,0085	0,0
	Total	38,0		3 847,0

The total available solar capacity of the REAAs in the Ivano-Frankivsk oblast could be estimated at over 3,8 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (1 674,9 MW, 811,4 MW, 583,4 MW and 762,0 MW, respectively). Parking areas could have a capacity of 15,2 MW. Waste sites/Landfill, Mines/quarries, Artificial inland water bodies (lakes/reservoirs, Urban wastewater treatment sites and Degraded land that are not usable for agriculture cannot provide any solar capacity.

3.2.4. Evaluation of solar capacity in the Chernivtsi oblast

Solar potential (GHI) in Chernivtsi oblast is represented at the picture below.



Picture 3-6. Solar potential (GHI) in the oblast

Total square of each REAA with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp is provided in the table below.

Table 3-9. Squares of REAAs in the Cherivtsi oblast

Zone number	REAAs	REAA square, km²
Zone 1	Artificial and built surfaces (rooftops and facades)	9,44
Zone 2	Transport infrastructure	8,20
Zone 3	Parking areas	0,15
Zone 4	Farms	4,34
Zone 5	Waste sites	0,00
Zone 6	Industrial sites	4,53
Zone 7	Mines, quarries	0,00
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,00
Zone 9	Urban waste water treatment sites	0,00
Zone 10	Degraded land not usable for agriculture	0,05
	Total, km2	26,72

The evaluation of solar capacity was performed using equation (1). The results of the calculation are provided in the table below.

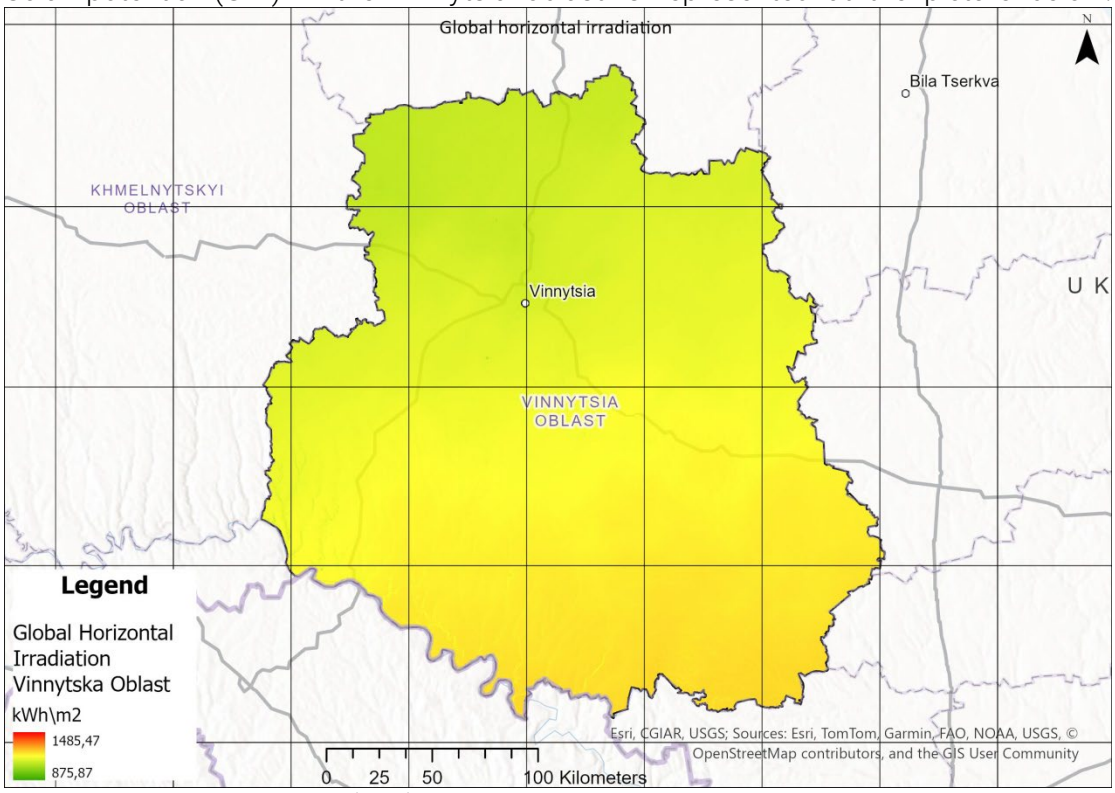
Table 3-10. REAA solar capacity in the Chernivtsi oblast

Zone number	REAA square	Ssi, km2	Sst, total square, km2/MW	Csi, MW
Zone 1	Artificial and built surfaces (rooftops and facades)	9,4	0,0116	812,4
Zone 2	Transport infrastructure	8,2	0,0085	961,7
Zone 3	Parking areas	0,2	0,0085	17,6
Zone 4	Farms	4,3	0,0085	509,2
Zone 5	Waste sites	0,0	0,0085	0,0
Zone 6	Industrial sites	4,5	0,0085	531,9
Zone 7	Mines, quarries	0,0	0,0085	0,0
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,0	0,0085	0,0
Zone 9	Urban waste water treatment sites	0,0	0,0085	0,0
Zone 10	Degraded land not usable for agriculture	0,1	0,0085	5,9
	Total	26,7		2 838,7

The total available solar capacity of the REAAs in the Cherivtsi oblast could be estimated at over 2,8 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (812,4 MW, 961,7 MW, 509,2 MW and 531,9 MW, respectively). Parking areas could have a capacity of 17,6 MW. Degraded land that are not usable for agriculture can provide a small solar capacity at 5,9 MW. Waste sites/Landfill, Mines/quarries, Artificial inland water bodies (lakes/reservoirs, Urban wastewater treatment sites cannot provide any solar capacity.

3.2.5. Evaluation of solar capacity in the Vinnytsia oblast

Solar potential (GHI) in the Vinnytsia oblast is represented at the picture below.



Picture 3-7. Solar potential (GHI) in the oblast

Total square of each REAA with the Global horizontal irradiation (GHI) - not less than 1100 kWh/m2, kWp is provided in the table below.

Table 3-11. Squares of REAAs in the Vinnytsia oblast

Zone number	REAAs	REAA square, km²
Zone 1	Artificial and built surfaces (rooftops and facades)	25,06
Zone 2	Transport infrastructure	24,75
Zone 3	Parking areas	0,17
Zone 4	Farms	7,23
Zone 5	Waste sites	0,02
Zone 6	Industrial sites	12,02
Zone 7	Mines, quarries	0,02
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,02
Zone 9	Urban waste water treatment sites	0,00
Zone 10	Degraded land not usable for agriculture	0,14
	Total, km2	69,43

To evaluate solar capacity the equation (1) was used. The results of the mathematic modeling by the REAAs are provided in table below.

Table 3-12. REAA solar capacity in the Vinnytsia oblast

Zone number	REAA square	Ssi, km2	Sst, total square,	Csi, MW

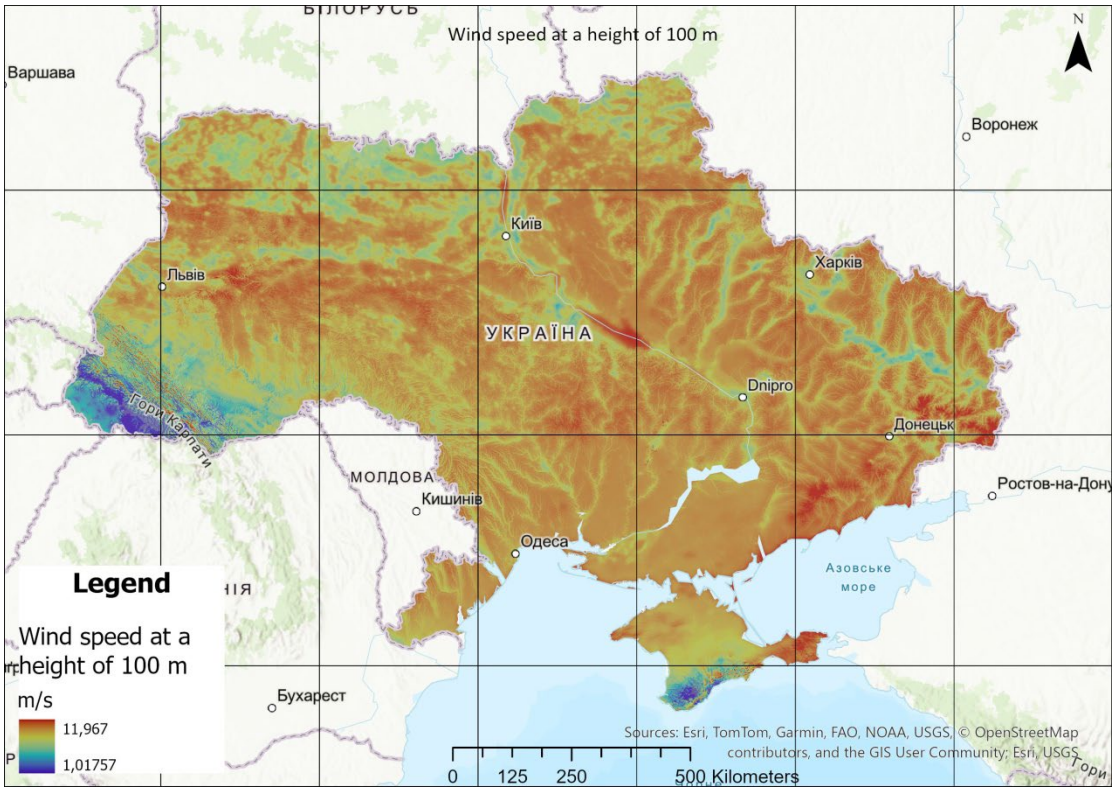
			km2/MW	
Zone 1	Artificial and built surfaces (rooftops and facades)	25,1	0,0116	2 155,8
Zone 2	Transport infrastructure	24,7	0,0085	2 902,8
Zone 3	Parking areas	0,2	0,0085	19,9
Zone 4	Farms	7,2	0,0085	847,9
Zone 5	Waste sites	0,0	0,0085	2,3
Zone 6	Industrial sites	12,0	0,0085	1 410,4
Zone 7	Mines, quarries	0,0	0,0085	2,3
Zone 8	Artificial inland water bodies, lakes/reservoirs	0,0	0,0085	2,3
Zone 9	Urban waste water treatment sites	0,0	0,0085	0,0
Zone 10	Degraded land not usable for agriculture	0,1	0,0085	16,4
	Total	69,4		7 360,3

The total available solar capacity of the REAAs in the Vinnytsia oblast could be estimated at over 7,3 GW.

The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (2 155,8 MW, 2 902,8 MW, 847,9 MW and 1 410,4 MW, respectively). Parking areas could have a capacity of 19,9 MW. Degraded land that are not usable for agriculture can provide a small solar capacity at 16,4 MW. Waste sites/Landfill, Mines/quarries, Artificial inland water bodies (lakes/reservoirs, could each provide 2,3 MW. Urban wastewater treatment sites cannot provide any solar capacity.

4. EVALUATION OF REAA WIND CAPACITY IN 5 UKRAINIAN OBLASTS

Wind potential in Ukraine is represented at the picture below. Here, the wind speeds range from 1,017 m/s to 11,97 m/s.



Picture 4-1. Wind potential in Ukraine

4.1. Assumptions

Assumptions applied to the evaluation of wind capacity are the following:

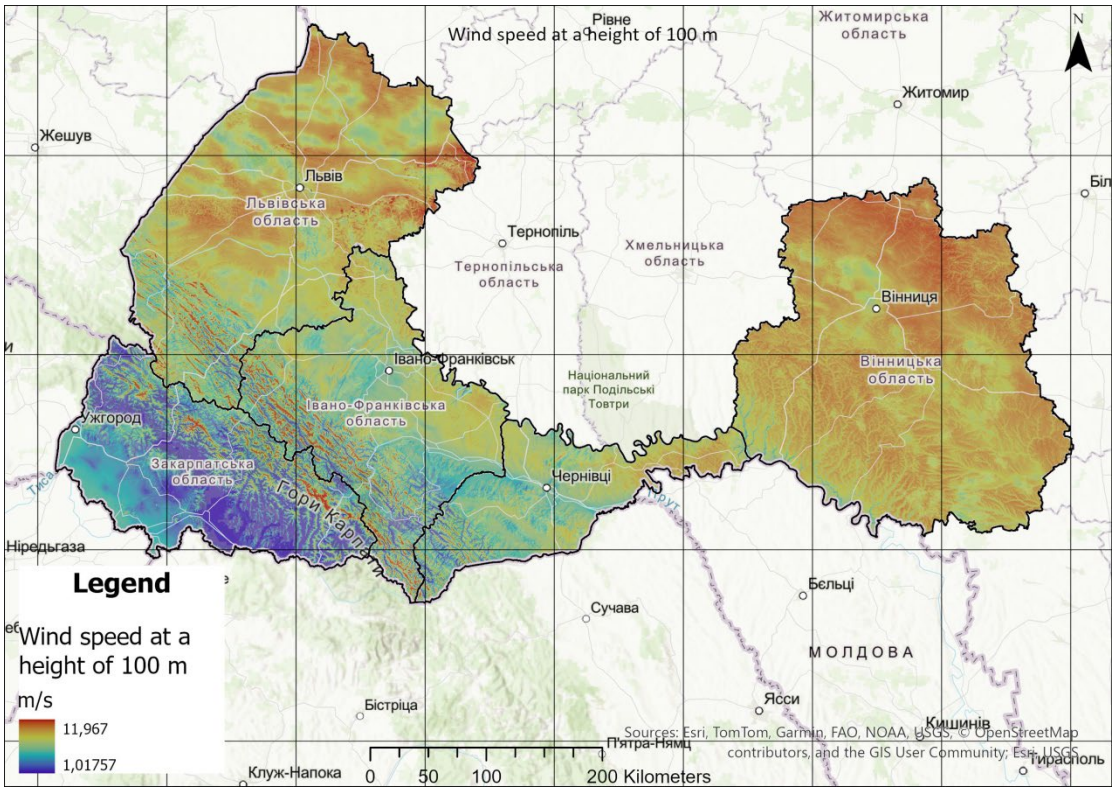
- Equipment: the Vestas V136-4.5 MW wind turbine: Rotor diameter (m) – 136 m; Hub heights; 100 m; Design annual average wind speed (m/s): 8,5 m/s; Cut-in wind speed - 3m/s; Cut-out wind speed - 32m/s; Re cut-in wind speed - 28m/s.
- Swti, 4,5 MW/turbine, equivalent direct impact area (permanent and temporary), wind farm - 0,11 km2/MW[2].

4.2. Evaluation of wind capacity in 5 oblasts of Ukraine

Evaluation of wind capacity by five oblasts in Ukraine (Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia) is provided for: farms; industrial sites; degraded land not usable for agriculture.

Wind potential in 5 targeted oblasts of Ukraine is represented at the picture below.

[2] REZOMA – renewable energy zone mapping



Picture 4-2. Wind potential in 5 targeted oblasts

Total squares of each REAA with the wind speed at a height of 100 m not less than 5.0 m/s in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia oblasts are represented in the table below.

Table 4-1. Squares of REAAs in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia oblasts

REAA square	Swi, km2	Lviv	Zakarpatia	Iv-Frankivsk	Chrnivtsi	Vinnitsia
Farms	10,01	0,74	0,15	1,79	4,52	2,81
Industrial sites	19,11	7,39	0,05	2,72	1,33	7,62
Total	29,12	8,13	0,20	4,51	5,85	10,43

Total available square of REAAs in 5 oblasts where wind generation could be installed is estimated at 29,12 km2. The acceptable REAAs are Farms and Industrial sites with the square at 10,01 km2 and 19,11 km2, respectively. Any other REAAs cannot provide any wind capacity.

The evaluation of wind capacity was performed using equation (2). The results of the calculation are provided in table below.

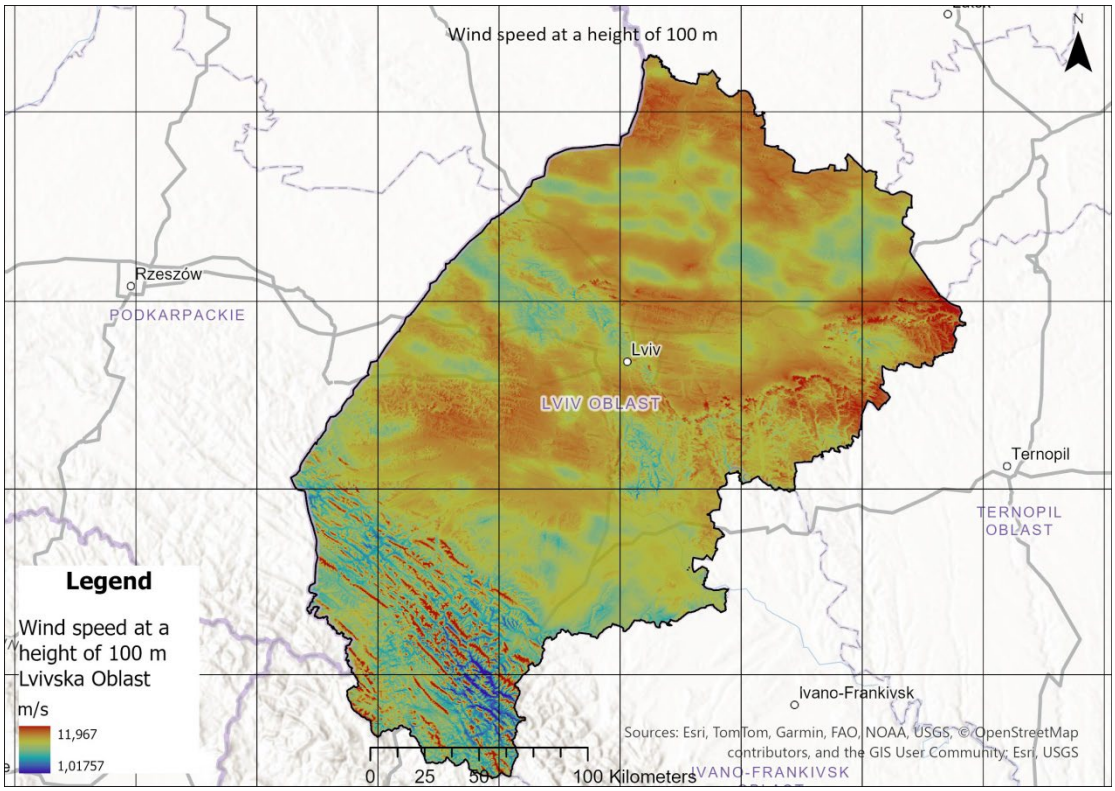
Table 4-2. REAA wind capacity in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Vinnytsia oblasts

REAAs	Cwi, wind capacity, MW	Lviv	Zakarpatia	Iv-Frankivsk	Chrnivtsi	Vinnitsia
Farms	91,00	6,73	1,36	16,27	41,09	25,55
Industrial sites	173,69	67,18	0,43	24,74	12,07	69,27
Total, MW	264,69	73,91	1,79	41,02	53,16	94,81

The total available wind capacity of the REAAs in the Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi and Vinnytsia oblasts could be estimated at 264,69 MW. The REAA with the wind potential are Farms and Industrial sites at 91 MW and 173,69 MW.

4.2.1. Evaluation of wind capacity in the Lviv oblast

Wind potential in the Lviv oblast is represented at the picture below.



Picture 4-3. Wind potential in the oblast

Total square of each REAA in the oblast with the wind speed at a height of 100 m not less than 5.0 m/s is provided in the table below.

Table 4-3. Square of each REAA in the oblast

Zone number	REAAs	REAA square, km²

Zone 4	Farms	0,74
Zone 6	Industrial sites	7,39
	Total, km2	8,13

The evaluation of wind capacity was performed using equation (2). The results of the calculation are provided in table below.

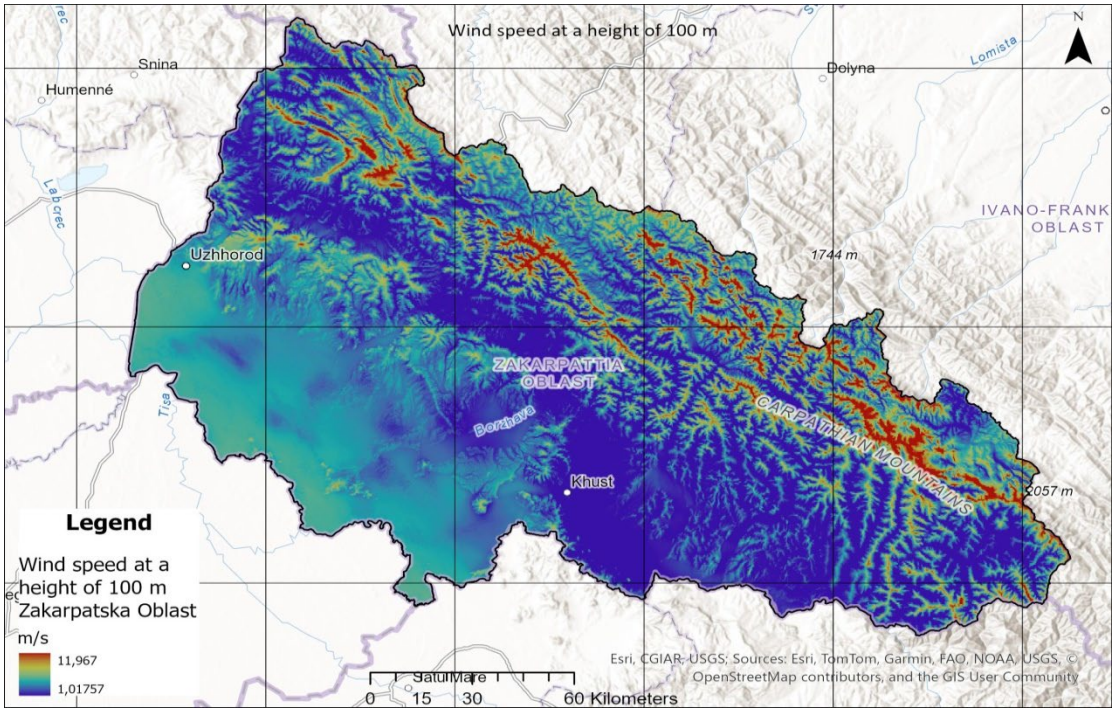
Table 4-4. REAA wind capacity in the oblast

Zone number	REAAs	Swi, km2	Swti, 4,5 MW wind farm /turbine square, km2/MW.	Cwi, MW
Zone 4	Farms	0,74	0,11	6,73
Zone 6	Industrial sites	7,39	0,11	67,18
	Total, MW	8,13		73,91

The REAA with the most wind potential are Industrial sites at 67,18 MW. Farms could provide 6,73 MW.

4.2.2. Evaluation of wind capacity in the Zakarpattia oblast

Wind potential in the Zakarpattia oblast is represented at the picture below.



Picture 4-4. Wind potential in the oblast

Total square of each REAA in the oblast with the wind speed at a height of 100 m not less than 5.0 m/s is provided in the table below.

Table 4-5. Square of each REAA in the oblast

Zone number	REAAs	REAA square, km²

Zone 4	Farms	0,15
Zone 6	Industrial sites	0,05
	Total, km2	0,20

Total square of REAAs for wind installation in the oblast is 0,2 km2.

The evaluation of wind capacity was performed using equation (2). The results of the calculation are provided in table below.

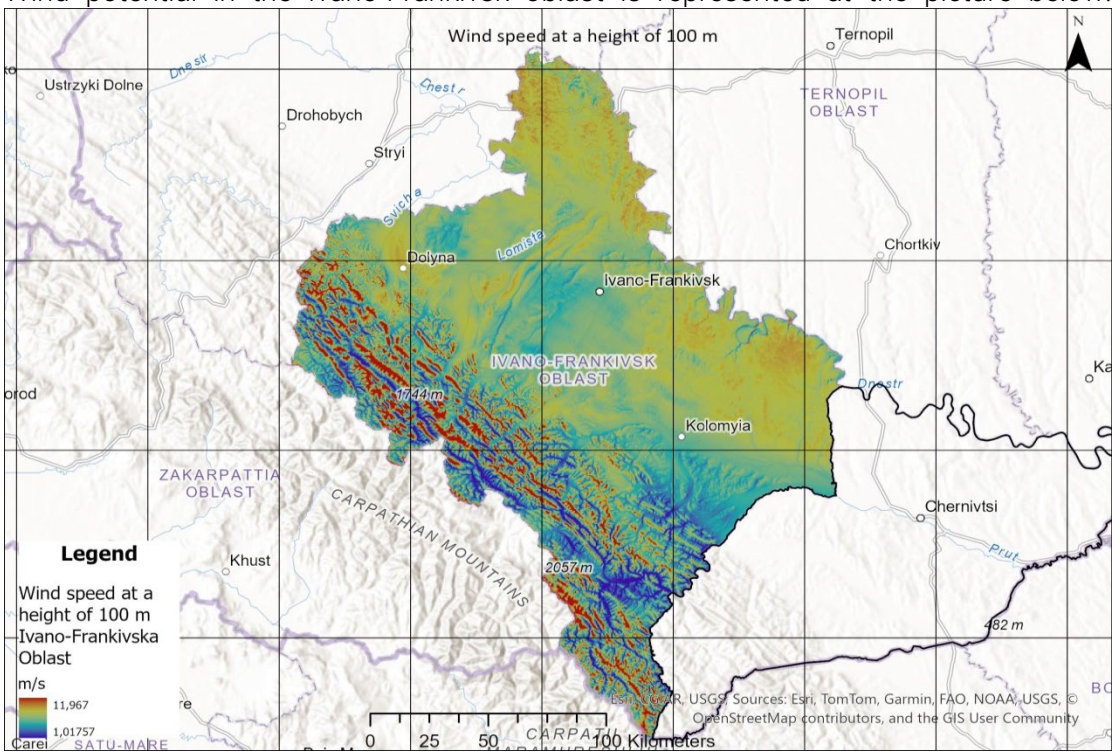
Table 4-6. REAA wind capacity in the oblast

Zone number	REAAs	Swi, km2	Swti, 4,5 MW wind farm /turbine square, km2/MW.	Cwi, MW
Zone 4	Farms	0,15	0,11	1,36
Zone 6	Industrial sites	0,05	0,11	0,43
	Total, MW	0,20		1,79

The REAA with the some wind potential are Farms at 1,36 MW.

4.2.3. Evaluation of wind capacity in the Ivano-Frankivsk oblast

Wind potential in the Ivano-Frankivsk oblast is represented at the picture below.



Picture 4-5. Wind potential in the oblast

Total square of each REAA in the oblast with the wind speed at a height of 100 m not less than 5.0 m/s is provided in the table below.

Table 4-7. Square of each REAA in the oblast

Zone number	REAAs	REAA square, km²
Zone 4	Farms	1,79
Zone 6	Industrial sites	2,72
	Total, km2	4,51

Total square of REAAs for wind installation in the oblast is 4,5 km2.

The evaluation of wind capacity was performed using equation (2). The results of the calculation are provided in table below.

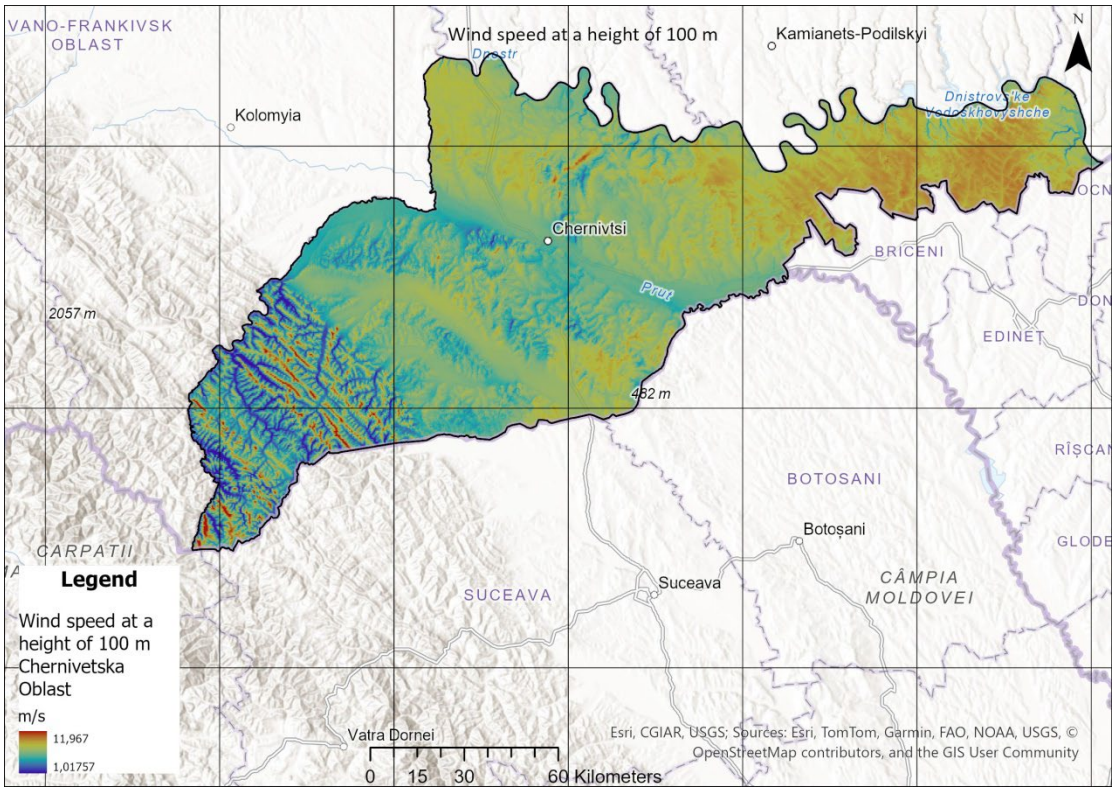
Table 4-8. REAA wind capacity in the oblast

Zone number	REAAs	Swi, km2	Swti, 4,5 MW wind farm /turbine square, km2/MW.	Cwi, MW
Zone 4	Farms	1,79	0,11	16,27
Zone 6	Industrial sites	2,72	0,11	24,74
	Total, MW	4,51		41,02

Total wind capacity in the oblast is estimated at 41,02 MW. Industrial sites have the wind potential at 24,74 MW. Farms could provide 16,27 MW.

4.2.4. Evaluation of wind capacity in the Chernivtsi oblast

Wind potential in the Chernivtsi oblast is represented at the picture below.



Picture 4-6. Wind potential in the oblast

Total square of each REAA in the oblast with the wind speed at a height of 100 m not less than 5.0 m/s is provided in the table below.

Table 4-9. Square of each REAA in the oblast

Zone number	REAAs	REAA square, km²
Zone 4	Farms	4,52
Zone 6	Industrial sites	1,33
	Total, km2	5,85

Total square of REAAs for wind installation in the oblast is over 5,8 km2.

The evaluation of wind capacity was performed using equation (2). The results of the calculation are provided in table below.

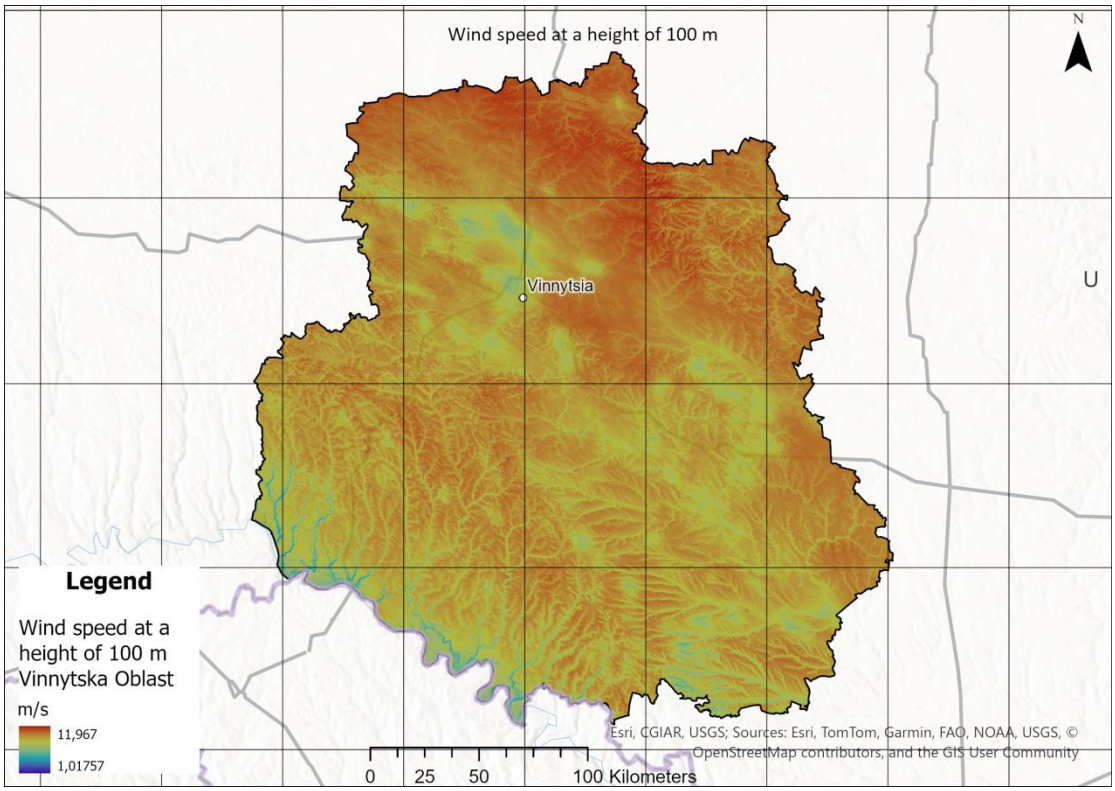
Table 4-10. REAA wind capacity in the oblast

Zone number	REAAs	Swi, km2	Swti, 4,5 MW wind farm /turbine square, km2/MW	Cwi, MW
Zone 4	Farms	4,52	0,11	41,09
Zone 6	Industrial sites	1,33	0,11	12,07
	Total, MW	5,85		53,16

Total wind capacity in the oblast is estimated at over 53,1 MW. Farms have the greatest wind potential, at 41.1 MW, while Industrial sites could provide 12.07 MW.

4.2.5. Evaluation of wind capacity in the Vinnytsia oblast

Wind potential in the Vinnytsia oblast is represented at the picture below.



Picture 4-7. Wind potential in the oblast

Total square of each REAA in the oblast with the wind speed at a height of 100 m not less than 5.0 m/s is provided in the table below.

Table 4-11. Square of each REAA in the oblast

Zone number	REAAs	REAA square, km²
Zone 4	Farms	2,81
Zone 6	Industrial sites	7,62
	Total, km2	10,43

Total square of REAAs for wind installation in the oblast is over 10,3 km2.

Zone number	REAAs	REAA square, km²	% of total REAAs squares in the oblast
Zone 4	Farms	2,81	2,21%
Zone 6	Industrial sites	0,02	0,01%
Zone 10	Degraded land not usable for agriculture	0	0,00%

The evaluation of wind capacity was performed using equation (2). The results of the calculation are provided in table below.

Table. REAA wind capacity in the oblast

Zone number	REAAs	Swi, km2	Swti, 4,5 MW wind farm /turbine square, km2/MW.	Cwi, MW
Zone 4	Farms	2,81	0,11	25,55
Zone 6	Industrial sites	7,62	0,11	69,27
	Total, MW	10,43		94,81

Total wind capacity in the oblast is estimated at over 94,8 MW. Industrial sites have the wind potential at 69,27 MW, Farms could provide 25,55 MW.

5. STATUS OF INFRASTRUCTURE READINESS

To obtaine data on the status of infrastructure readiness, the official ECS letters were sent to the transmission System Operator (NPC "Ukrenergo") and DSOs in the Ivano-Frankivsk, Lviv, Chernivtsi, Zakarpattia and Vinnytsia oblast.

The purpose and objectives of the REAAs project were explained in the letters, which also specified what data was requested (in the supplementary questionnaires) and the grounds for requesting it.

Requested data was the following: from NPC Ukrenergo - locations of power substations at 330/110/35 kV, power/capacity of designated substations at kVA; availability to connect and transmit additional RE capacity of each substation in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, Vinnytsia oblasts; from distribution system operators - locations of 35 kV and 110 kV overhead electric lines and locations of 35 kV, 110/35 kV power substations supplementing with data on current and potentially increased capacity in each of the following oblasts: Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi and Vinnytsia.

It was emphasised that the data chould be provided either in a geospatial data format or in a format that could be transformed into one. Data with a structure that can be transformed into geospatial data involves the processing of conversion into geospatial data format based on the use of existing coordinate references, digitization of raster images, geocoding of data based on the lists of toponyms.

DSOs (PrJSC Lvivoblenergo, PrJSC Zakarpattyaoblenergo, JSC Prykarpattyaoblenergo, JSC Chernivtsioblenergo, and JSC Vinnytsiaoblenergo) did not respond to the letters. The DSOs' sites don't contain any relevant infornation on their of infrastructure.

In its response (dated 1 October 2025), NPC Ukrenergo informed that "…the activities of NPC Ukrenergo as the transmission system operator, in terms of providing information on the operating modes of the network and its technical condition, is regulated by Resolution No. 349 of the National Energy and Utilities Regulatory Commission dated 26 March 2022 'On the protection of information that, under martial law, may be classified as restricted access information, including information on critical infrastructure facilities'. The requested information on the location of substations, their installed autotransformer capacity and reserve capacity for connecting power generation facilities is included in the list of restricted information on critical

infrastructure facilities and, in view of the above, cannot be provided as output data".

Under these circumstances, an alternative data source was used, such as OpenStreetMap (OSM)[3].

To obtain data on the locations of 35 kV and 110 kV overhead electric lines, 35 kV and 110/35 kV power substations, and also about grid connection at 6 kV and 10 kV points, the QGIS geographic information system toolkit is used.
Data is downloaded directly from OpenStreetMap (OSM) servers using built-in QGIS tools (QuickOSM plugin). In the process, a query is configured to select objects by the corresponding tags:

- power=line for power lines;
- power=substation for substations;
- power=transformer for transformers.

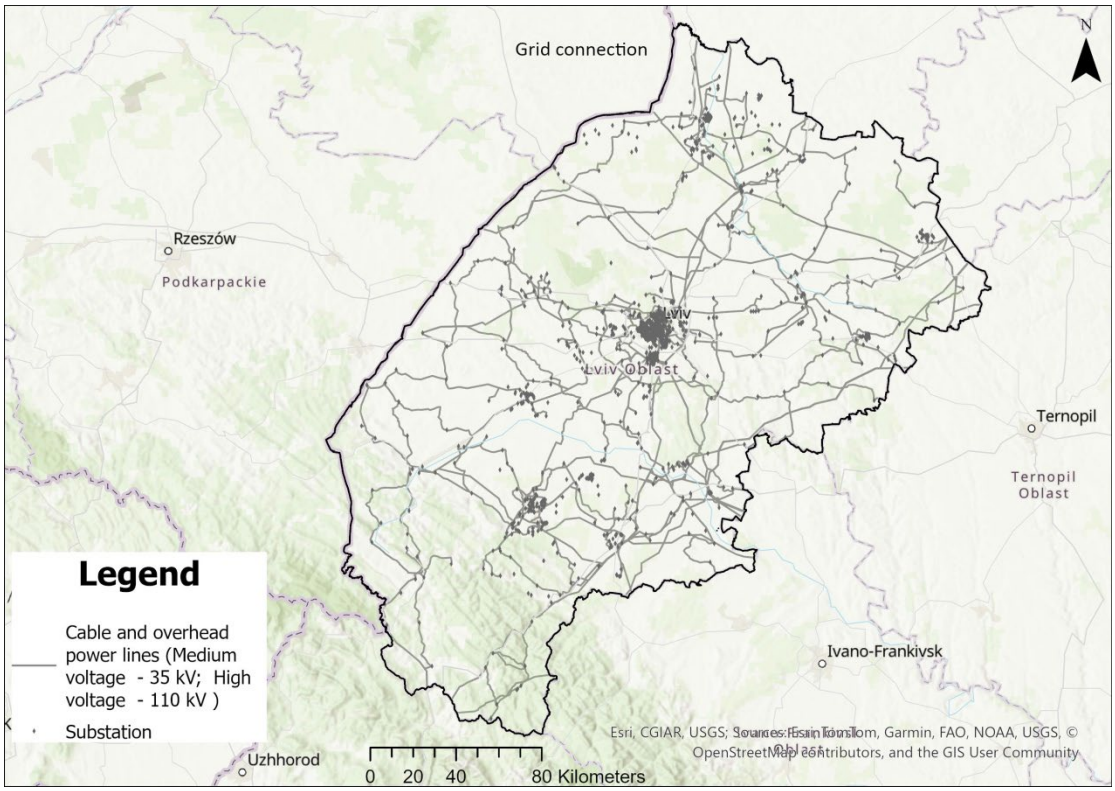
The data was downloaded simultaneously for the targeted regions: Lvivska, Zakarpatska, Ivano-Frankivska, Chernivetska and Vinnytska Oblasts.
Additionally, filtering by the voltage tag (voltage) is applied to obtain objects only for 35 kV and 110 kV.
The resulting vector data consists of:

- Linestring objects, representing power lines.
- Point and polygon objects, representing substations and transformers.

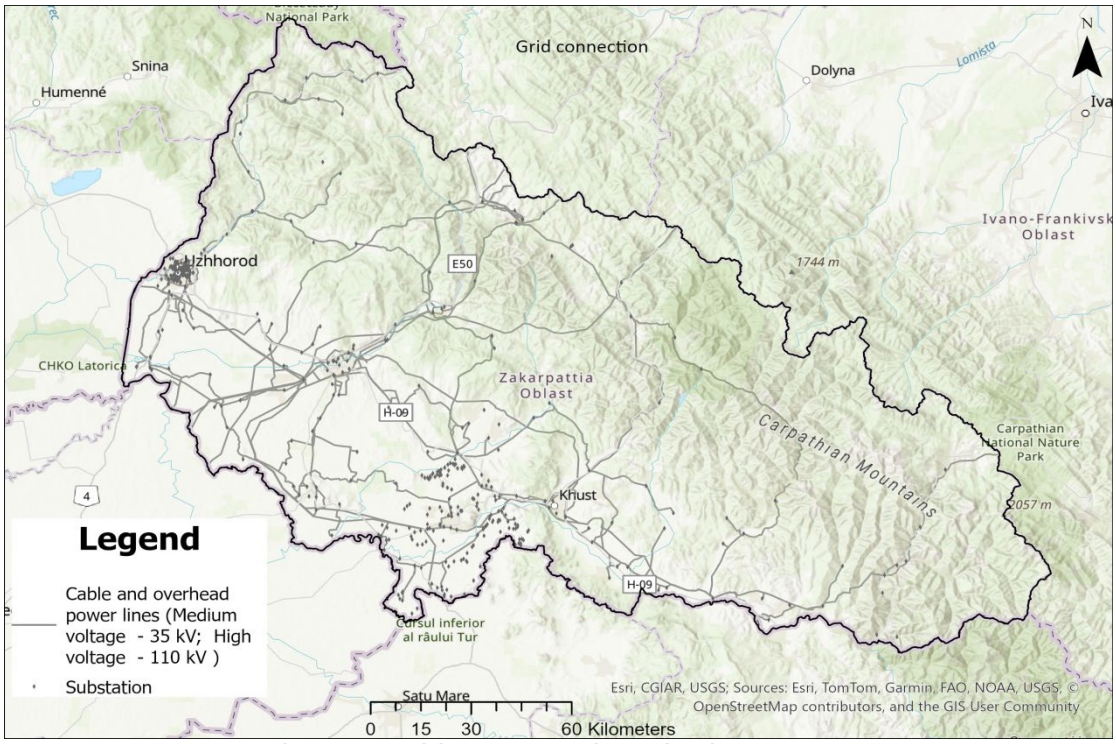
After being loaded into a QGIS project, the data is presented in the GeoPackage format, ready for verification, editing, and saving.

In the Report, the grids and substation maps were adopted for A5 format. The data presented on them have an overview character and do not display all fine details. The information shown on these maps is of a demonstrative nature and is intended for general familiarization with the territory. Small-scale objects such as power lines, transformer substations, and similar infrastructure, are displayed in a generalized form due to limitations of scale, resolution, and data generalization.

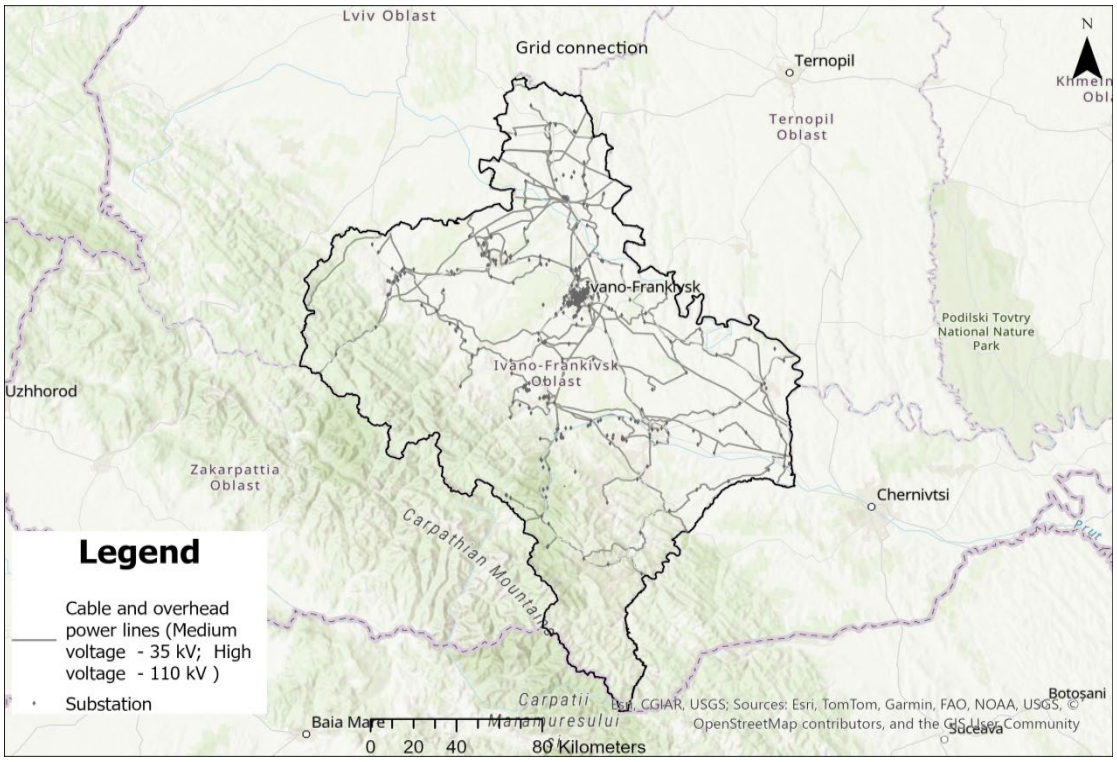
[3] https://www.openstreetmap.org/



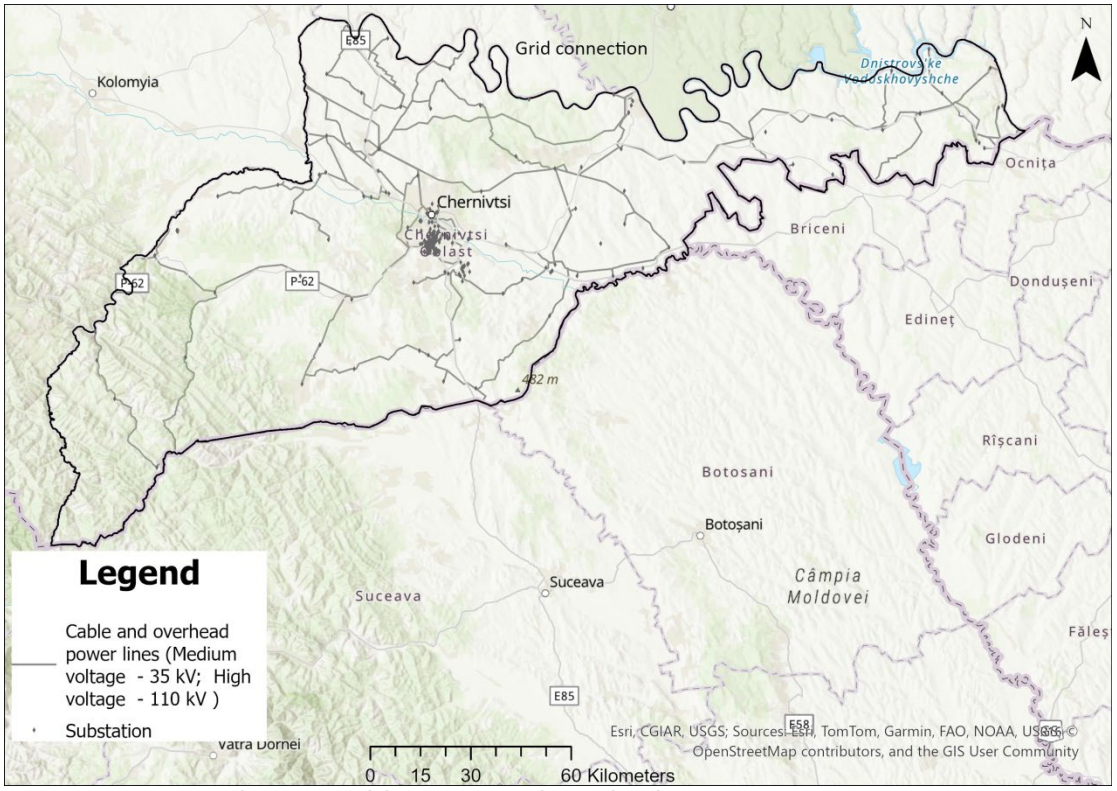
Picture 5-1. PrJSC Lvivoblenergo: grids and substations



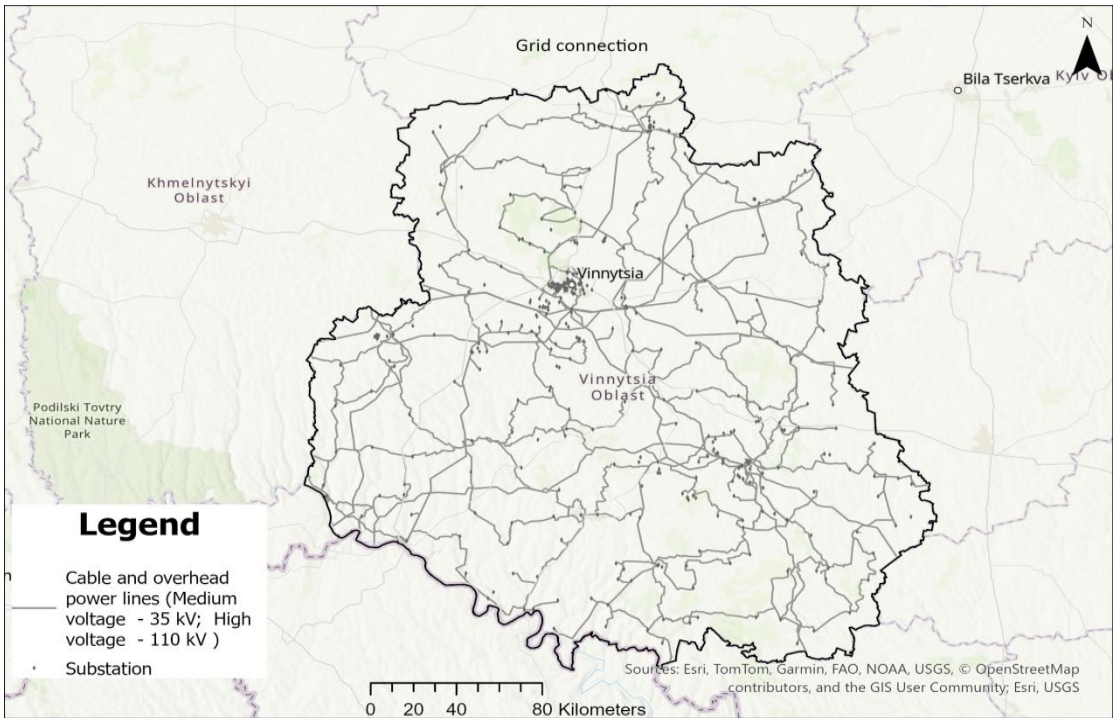
Picture 5-2. PrJSC Zakarpattyaoblenergo: grids and substations



Picture5-3. JSC Prykarpattyaoblenergo: grids and substations



Picture 5-4. JSC Chernivtsioblenergo: grids and substations



Picture 4-5. JSC Vinnytsiaoblenergo: grids and substations

6. KEY FINDINGS

Solar capacity of the REAAs in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi and Vinnytsia oblasts. Total available square of REAAs in 5 oblasts where solar generation could be installed is estimated at 229,95 km2. The most acceptable REAAs are Artificial and built surfaces (rooftops and facades), Transport infrastructure, Farms and Industrial sites (89,3 km2, 73,9 km2, 26,8 km2 and 38,6 km2, respectively). Solar installations are not suitable for urban wastewater treatment sites. The total available solar capacity of the REAAs in the five oblasts could be estimated at over 24,179 GW. The REAAs with the most potential are Artificial and built surfaces (rooftops and façades), Transport infrastructure, Farms and Industrial sites (7 685,54 MW, 8 673,32MW, 3 139,09 MW and 4 532,58 MW, respectively). Parking areas could have a significant capacity of 111.44 MW. Relatively small amount of solar capacity could be installed on the degraded land that is not usable for agriculture (24,63 MW). Urban wastewater treatment sites cannot provide any solar capacity.

Wind capacity of the REAAs in Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi and Vinnytsia oblasts. Total available square of REAAs in 5 oblasts where wind generation could be installed is estimated at 29,12 km2. The acceptable REAAs are Farms and Industrial sites with the square at 10,01 km2 and 19,11 km2, respectively. Any other REAAs cannot provide wind capacity. The total available wind capacity of the REAAs in the Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi and Vinnytsia oblasts could be estimated at 264,69 MW. The REAA with the wind potential are Farms and Industrial sites at 91 MW and 173,69 MW.

The status of infrastructure readiness. On the the ECS'requests, NPC Ukrenergo informed that the information on the location of substations, their installed

autotransformer capacity and reserve capacity for connecting power generation facilities is included in the list of restricted information on critical infrastructure facilities and, in view of the above, cannot be provided. DSOs (PrJSC Lvivoblenergo, PrJSC Zakarpattyaoblenergo, JSC Prykarpattyaoblenergo, JSC Chernivtsioblenergo, and JSC Vinnytsiaoblenergo) did not provide any infornation on their infrastructure. Under these circumstances, an alternative data source was used, such as OpenStreetMap (OSM). To obtain data on the locations of 35 kV and 110 kV overhead electric lines, as 35 kV and 110/35 kV power substations, and also on grid connection at 6 kV and 10 kV points, the QGIS geographic information system toolkit is used. Data is downloaded directly from OpenStreetMap (OSM) servers using built-in QGIS tools (QuickOSM plugin).

Annex 1. Detailed description of object selection for each REAA

GROUP 1: Rooftops and Facades of Buildings

Final layer: Rooftops_and_Facades_of_Buildings
The area in the table is the sum of the areas of all building contours remaining after applying the following filters:
1. Creation of a base layer: A single layer of buildings was created by combining data from OpenStreetMap (building) and META AI Building Footprints.
2. Filtering by technical criteria:
GHI: Only buildings with a solar insolation level of at least 1100 kWh/m² were retained.
Network accessibility: Only buildings located within 5 km of power lines or substations were retained.
Orientation: Buildings with a main axis azimuth in the range of 135-225 degrees (southeast, south, southwest) were selected.
3. Filtering by legal restrictions:
Cultural heritage: All buildings located on the territory of cultural heritage sites were removed from the dataset.
4. Filtering by environmental restrictions:
All buildings located in the zone of environmental restrictions were removed.

GROUP 2: Transport Infrastructure Corridor

Final layer: Transport_Infrastructure_Corridor
The area in the table is the sum of the areas of all sections along transport corridors remaining after applying the following filters:
1. Creating a base layer: A buffer zone 20 metres wide was created around linear objects of national importance (international, national, regional) (from OSM).
2. Filtering by technical criteria:
GHI: Only sections of the corridor with a solar insolation level of at least 1100 kWh/m² were retained.
Relief: Sections with a slope greater than 15° or an absolute height greater than 1900 m were excluded.
Network accessibility: Only areas located between 20 metres and 30 km from power grids were retained.
3. Filtering by environmental restrictions:
All areas that fell within the zone of environmental restrictions were removed.

GROUP 3: Parking Areas

GROUP 3: Parking Areas
Final layer: Parking_Areas
The area in the table is the sum of the areas of all open parking lots remaining after applying the following filters:
1. Creating a base layer: A layer of open ground parking lots (from OSM, amenity=parking and parking=surface) was created, excluding multi-storey car parks.
2. Filtering by technical criteria:
GHI: Only car parks with a solar insolation level of at least 1100 kWh/m² were retained.
Area: Car parks with an area of less than 17 m² were excluded.

Network accessibility: Only car parks located between 20 metres and 30 km from power grids were retained.
3. Filtering by environmental restrictions:
All sites that fell within the zone of environmental restrictions were removed.

GROUP 4: Farms (solar and wind)

Final layer 1: farms_solar
The area in the table is the sum of the areas of all farms remaining after applying the following filters for solar energy:
1. Creating a base layer: A single layer of farms was created by combining the landuse=farmyard, landuse=farmland areas and corresponding buildings from OSM.
2. Filtering by technical criteria:
GHI: Only areas with a solar insolation level of at least 1100 kWh/m² were retained.
Area: Small farms with an area of less than 100 m² were excluded.
Network accessibility: Only areas located between 20 metres and 30 km from power grids were retained.
3. Data on arable land was imported from ESRI's landcover layer. After the layer overlay procedure, those that intersect with this layer were excluded. This means that solar panels are not placed on arable land.
4. Filtering by environmental restrictions:
All areas that fell within the zone of environmental restrictions were removed.

Final layer 2: farms_wind

The area in the table is the sum of the areas of all farms remaining after applying the following filters for wind energy:
1. Creation of the base layer: The same Farms_Base base layer was used.
2. Filtering by technical criteria:
Wind speed: Only areas with an average annual wind speed of at least 5.0 m/s at a height of 100 m were retained.
Relief: Areas with a slope of more than 15° were excluded.
Road accessibility: Areas within 5 km of roads were retained.
Network accessibility: Areas within 20 metres to 30 km of power grids were retained.
Exclusion zones: Buffer zones were excluded from potential areas: 60 m from roads, 500 m from railways and 10 km from airports.
Area: Small farms with an area of less than 100 m² were excluded.
3. Filtering by environmental restrictions:
o All plots that fell within the zone of environmental restrictions were removed.

GROUP 5: Waste sites

Final layer: Waste_sites
The area in the table is the sum of the areas of all waste management facilities remaining after applying the following filters:
1. Creating the base layer: The layer was created by combining landuse=landfill polygons from OSM.
2. Filtering by technical criteria:
GHI: Only objects with a solar insolation level of at least 1100 kWh/m² were retained.
Area: Objects with an area of less than 100 m² were excluded.

Network accessibility: Only objects located between 20 metres and 30 km from power grids were retained.
3. Filtering by environmental restrictions:
All areas that fell within the zone of environmental restrictions were removed.

GROUP 6: Industrial Sites (solar and wind)

Final layer 1: Industrial_Sites_solar
The area in the table is the sum of the areas of all industrial zones remaining after applying filters for solar energy:
1. Creating a base layer: A single layer was created by combining industrial zones and objects from OSM.
2. Filtering by technical criteria:
GHI: at least 1100 kWh/m².
Area: more than 100 m².
Network availability: from 20 metres to 30 km.
3. Filtering by environmental restrictions:
All areas that fell within the zone of environmental restrictions were removed.
Final layer 2: Industrial_Sites_wind
The area in the table is the sum of the areas of all industrial zones remaining after applying filters for wind energy:
1. Creating a base layer: The same Industrial_Base base layer was used.
2. Filtering by technical criteria:
Wind speed: not less than 5.0 m/s.
Area: more than 1.7 hectares (17,000 m²).
Relief: slope not more than 15°.
Road accessibility: no more than 5 km.
Network accessibility: from 20 metres to 30 km.
Exclusion zones: Buffer zones were excluded: 60 m from roads, 500 m from railways and 10 km from airports.
3. Filtering by environmental restrictions:
All sites that fell within the zone of environmental restrictions were excluded.

GROUP 7: Mines and quarries

Final layer: Mines_and_quarries
The area in the table is the sum of the areas of all mines and quarries remaining after applying the following filters:
1. Creating the base layer: The layer was created by combining mines, quarries and dumps from OSM.
2. Filtering by technical criteria:
GHI: at least 1100 kWh/m².
Area: more than 100 m².
Network availability: from 20 metres to 30 km.
3. Filtering by environmental restrictions:
All areas that fell within the zone of environmental restrictions were removed.

GROUP 8: Artificial Inland Water Bodies

Final layer: Artificial_Inland_Water_Bodies

The area in the table is the sum of the areas of all artificial water bodies remaining after applying the following filters:
1. Creating a base layer: A layer of artificial water bodies (ponds, pools, etc.) was created from OSM, from which natural water bodies were excluded.
2. Filtering by technical criteria:
GHI: at least 1100 kWh/m².
Area: more than 100 m².
Network availability: from 20 metres to 30 km.
3. Filtering by environmental restrictions:
All areas that fell within the zone of environmental restrictions were removed.

GROUP 9: Urban Wastewater Treatment Sites

Final layer: Urban_Wastewater_Treatment_Sites
The area in the table is the sum of the areas of all treatment plants remaining after applying the following filters:
1. Creating a base layer: A layer of treatment plants was created from OSM.
2. Filtering by technical criteria:
GHI: at least 1100 kWh/m².
Area: more than 100 m².
Road accessibility: no more than 5 km.
Network accessibility: from 20 metres to 30 km.
3. Filtering by environmental restrictions:
All sites that fell within the zone of environmental restrictions were removed.

GROUP 10: Degraded Land Not Usable for Agriculture (solar and wind)

Final layer 1: Degraded_Land_Not_Usable_for_Agriculture_solar
The area in the table is the sum of the areas of all degraded land remaining after applying filters for solar energy:
1. Creating a base layer: A composite layer was created by combining degraded land from OSM.
2. Filtering by technical criteria:
GHI: at least 1100 kWh/m².
Area: more than 100 m².
Network availability: from 20 metres to 30 km.
3. Filtering by environmental restrictions:
All areas that fell within the environmental restrictions zone were removed.
Final layer 2: Degraded_Land_Not_Usable_for_Agriculture_wind
The area is calculated for degraded land that has been filtered according to the criteria for wind energy:
1. Creation of the base layer: The same Degraded_Lands_Base base layer was used.
2. Filtering by technical criteria:
Wind speed: not less than 5.0 m/s.
Area: more than 1.7 hectares (17,000 m²).
Relief: slope no more than 15°.
Road accessibility: no more than 5 km.
Network accessibility: from 20 metres to 30 km.
Exclusion zones: Buffer zones were excluded: 60 m from roads, 500 m from railways and 10 km from airports.

3. Filtering by environmental restrictions:
All sites that fell within the zone of environmental restrictions were excluded. -

Annex 2. Renewable Energy Potential in Ukrainian Regions. GIS square data

Lviv Oblast - Total REAAs: 83.40 km²; 75.3-Solar (km²); 8.1-Wind (km²)

Solar Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 1	Artificial and built surfaces (rooftops and facades)	24.98	SOLAR
Zone 2	Transport infrastructure	29.09	SOLAR
Zone 3	Parking areas	0.47	SOLAR
Zone 4	Farms	8.29	SOLAR
Zone 5	Waste sites	0.02	SOLAR
Zone 6	Industrial sites	12.37	SOLAR
Zone 7	Mines, quarries	0.01	SOLAR
Zone 8	Artificial inland water bodies, lakes/reservoirs	0.01	SOLAR
Zone 9	Urban waste water treatment sites	0.00	SOLAR
Zone 10	Degraded land not usable for agriculture	0.02	SOLAR

Wind Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 4	Farms	0.74	WIND
Zone 6	Industrial sites	7.39	WIND
Zone 10	Degraded land not usable for agriculture	0.00	WIND

Vinnytsia Oblast - Total REAAs: 79.85 km²; 69.4-Solar (km²); 10.4-Wind (km²)

Solar Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 1	Artificial and built surfaces (rooftops and facades)	25.06	SOLAR
Zone 2	Transport infrastructure	24.75	SOLAR
Zone 3	Parking areas	0.17	SOLAR
Zone 4	Farms	7.23	SOLAR
Zone 5	Waste sites	0.02	SOLAR
Zone 6	Industrial sites	12.02	SOLAR
Zone 7	Mines, quarries	0.02	SOLAR

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 8	Artificial inland water bodies, lakes/reservoirs	0.02	SOLAR
Zone 9	Urban waste water treatment sites	0.00	SOLAR
Zone 10	Degraded land not usable for agriculture	0.14	SOLAR

Wind Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 4	Farms	2.81	WIND
Zone 6	Industrial sites	7.62	WIND
Zone 10	Degraded land not usable for agriculture	0.00	WIND

Ivano-Frankivsk Oblast - Total REAAs: 42.50 km² 38.0 - Solar (km²); 4.5 - Wind (km²)

Solar Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 1	Artificial and built surfaces (rooftops and facades)	19.47	SOLAR
Zone 2	Transport infrastructure	6.92	SOLAR

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 3	Parking areas	0.13	SOLAR
Zone 4	Farms	4.97	SOLAR
Zone 5	Waste sites	0.00	SOLAR
Zone 6	Industrial sites	6.50	SOLAR
Zone 7	Mines, quarries	0.00	SOLAR
Zone 8	Artificial inland water bodies, lakes/reservoirs	0.00	SOLAR
Zone 9	Urban waste water treatment sites	0.00	SOLAR
Zone 10	Degraded land not usable for agriculture	0.00	SOLAR

Wind Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 4	Farms	1.79	WIND
Zone 6	Industrial sites	2.72	WIND

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 10	Degraded land not usable for agriculture	0.00	WIND

Chernivtsi Oblast - Total REAAs: 32.56 km²; 26.7-Solar (km²); 5.8-Wind (km²)

Solar Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 1	Artificial and built surfaces (rooftops and facades)	9.44	SOLAR
Zone 2	Transport infrastructure	8.20	SOLAR
Zone 3	Parking areas	0.15	SOLAR
Zone 4	Farms	4.34	SOLAR
Zone 5	Waste sites	0.00	SOLAR
Zone 6	Industrial sites	4.53	SOLAR
Zone 7	Mines, quarries	0.00	SOLAR
Zone 8	Artificial inland water bodies, lakes/reservoirs	0.00	SOLAR
Zone 9	Urban waste water treatment sites	0.00	SOLAR

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 10	Degraded land not usable for agriculture	0.05	SOLAR

Wind Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 4	Farms	4.52	WIND
Zone 6	Industrial sites	1.33	WIND
Zone 10	Degraded land not usable for agriculture	0.00	WIND

Zakarpattia Oblast - Total REAAs: 20.76 km²; 20.6-Solar (km²); 0.2-Wind (km²)

Solar Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 1	Artificial and built surfaces (rooftops and facades)	10.39	SOLAR
Zone 2	Transport infrastructure	4.98	SOLAR
Zone 3	Parking areas	0.03	SOLAR
Zone 4	Farms	1.93	SOLAR

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 5	Waste sites	0.00	SOLAR
Zone 6	Industrial sites	3.21	SOLAR
Zone 7	Mines, quarries	0.01	SOLAR
Zone 8	Artificial inland water bodies, lakes/reservoirs	0.00	SOLAR
Zone 9	Urban waste water treatment sites	0.00	SOLAR
Zone 10	Degraded land not usable for agriculture	0.00	SOLAR

Wind Energy Zones

Zone	REAA Square (Criteria)	Area (km²)	Type
Zone 4	Farms	0.15	WIND
Zone 6	Industrial sites	0.05	WIND
Zone 10	Degraded land not usable for agriculture	0.00	WIND