

Assessing Ukrainian Territory Suitability for Solar Power Station Placement Using Satellite Data on Climate and Topography

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Abstract — This research aims to assess the suitability of Ukrainian territories for the placement of solar power stations using satellite data on climate and topographic characteristics. The suitability of the territories was determined using a weighted sum method, incorporating input parameters from climate maps sourced from ERA5-Land dataset, which included data on annual global horizontal solar irradiation (GHI), accumulated annual temperature above 25°C, average annual wind speed, and maps of accumulated annual precipitation. Additionally, topographic maps from the SRTM dataset were utilized, providing information on elevations, slopes, and terrain shading. Furthermore, data from Wikimapia on the locations of existing major solar power stations in Ukraine were used to verify the placement optimization.

The results of the study revealed that the largest portion of the country (over 48%) exhibits moderate suitability scores (0.3-0.4). Favorable territories (suitability score above 0.3) outweigh unsuitable ones for solar power stations. The southern regions and the Crimean Peninsula offer the most favorable conditions for the placement of solar farms. Overall, all analyzed major solar power stations in Ukraine were located in optimal territories.

Furthermore, it was found that certain regions such as Odessa, Poltava, Kharkiv, Zaporizhia, Dnipropetrovsk, Donetsk, and Luhansk demonstrate good suitability scores (0.3-0.4), yet they are not fully exploited. These regions hold significant potential for the future construction of powerful and productive solar power stations.

Keywords — *solar power, satellite data, climate and topographic characteristics, territory suitability.*

I. INTRODUCTION

The war in Ukraine has caused significant destruction in the energy sector. As of May 2023, Ukraine has lost about 27 GW of installed power generation capacity [1]. The most affected energy facilities are located in the eastern and southern parts of the country, including Zaporizhia Nuclear Power Plant and Kakhovska Hydroelectric Power Station. Solar energy has also suffered, with approximately half of the solar power stations taken out of operation.

Restoring the energy infrastructure is crucial for the country's well-being and development. However, constructing traditional energy sources like hydroelectric or thermal power plants requires substantial resources. On the other hand, building solar power stations can be fast and relatively affordable, thanks to modern technologies and standardized components.

Solar power stations offer flexibility and can be installed in various territories, including areas that have previously been affected by war. They can function independently of the centralized electrical grid, providing electricity to local communities and industries. Solar energy helps reduce dependence on imports and improves energy security.

Selecting suitable locations for solar installations is crucial to maximize electricity generation and efficiency. Remote sensing data, such as satellite imagery, provides valuable information about climate, topography, and land use [2]. Analyzing this data [3-7] helps determine optimal locations for efficient solar power stations. In particular, a good idea for automating the selection of a place for the placement of solar panels will be the application of AI models of intelligence with high quality [8].

Our study analyzes the suitability of Ukrainian territories for installing efficient solar power stations using remote sensing data. **The main aim of our research** is to identify territories with the highest potential for solar energy production. Additionally, we assess the suitability of placement of existing solar power stations in Ukraine to evaluate the overall effectiveness of solar energy in the country.

II. DATA AND MATERIALS

The performance of solar farms depends on the interaction of several key geological and climatic factors. In this study, we will attempt to assess the suitability of areas for the installation of solar power plants, focusing on the most important factors among them. The climatic factors we will consider in this research include data on global horizontal solar irradiance (GHI) [9], air temperature [11], precipitation [9], and wind strength [9]. As for the geological factors [7] [13], we will take into account elevation, slope steepness, and terrain shading in our investigation.

To construct climate maps, we used hourly data from the ERA5-Land global dataset with a spatial resolution of 9 km, provided by the Copernicus Climate Data Store. Analyzing data from 2015 to 2022, we generated the following maps:

- 1) Map of the annual accumulated GHI (Fig. 1);
- 2) Map of the annual accumulated temperature at a height of 2m exceeding 25 degrees Celsius (based on the fact that solar panels experience reduced productivity at temperatures exceeding this threshold) (Fig. 2);

- 3) Map of the annual accumulated precipitation (rain and snow) (Fig. 3);
- 4) Map of the average annual wind speed at a height of 10m, calculated based on the u- and v-components of wind (Fig. 4).

Accumulated GHI (Wkh/m²) over the year (mean 2015-2022)

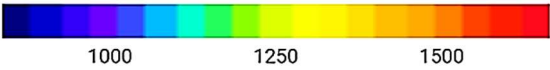
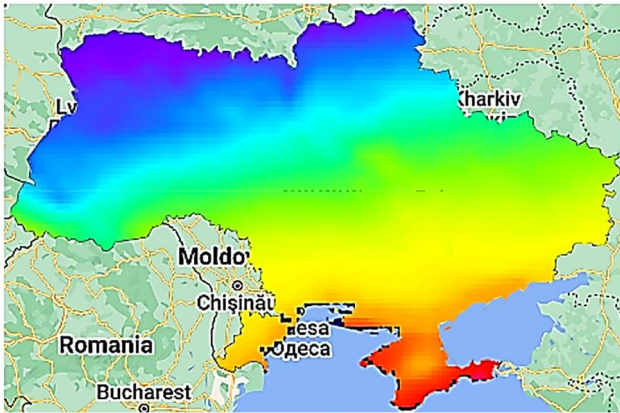



Fig. 1. Map of accumulated annual global horizontal solar irradiation (GHI).

Accumulated hourly temperature 2m > 25°C over the year (mean 2015-2022)

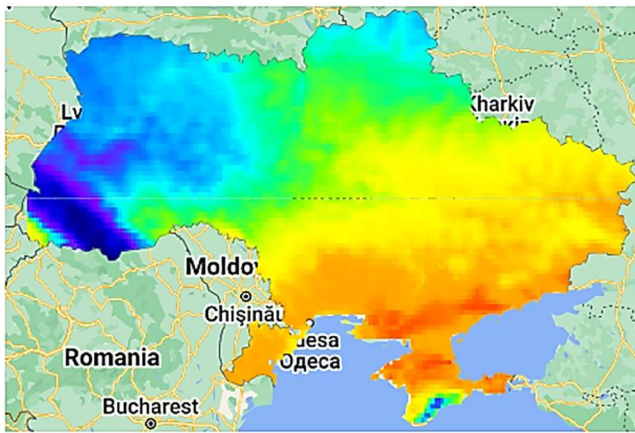



Fig. 2. Map of accumulated annual temperatures above 25°C (averaged data for 2015-2022).

Total precipitation over the year (mm) (mean 2015-2022)

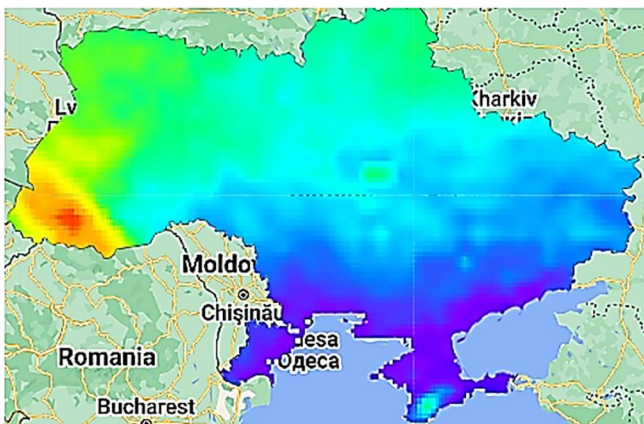
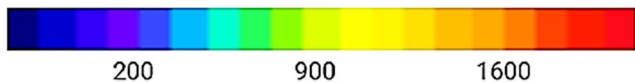


Fig. 3. Map of annual precipitation (averaged data for 2015-2022).

Mean wind speed at 10m 2015-2022 (m/s)

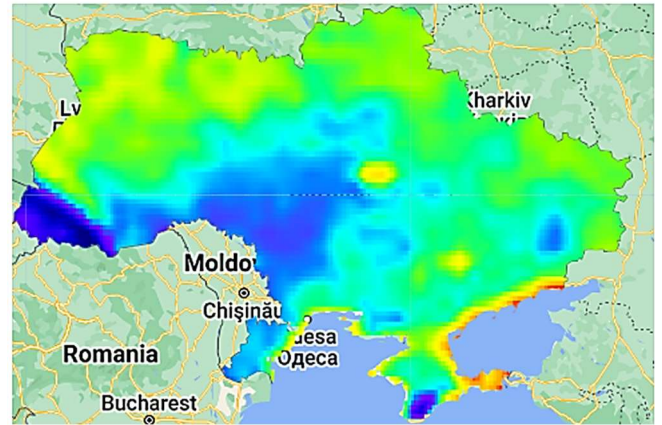


Fig. 4. Map of average annual wind speed (averaged data for 2015-2022).

To check the accuracy of the constructed GHI map, we compared our results with the Global Solar Atlas data for the GHI of Ukraine for the years 1994-2018 [14]. The indicators of the correlation coefficient reached 0.97, and the relative error did not exceed 13% for the data averaged by region. The wind speed map was compared with the Global Wind Atlas data [15]. The correlation coefficient was 0.5. Precipitation data were compared with Meteo Farm data [16] (total annual precipitation averaged by region for 2015-2021). The correlation coefficient was 0.95 with an average data difference of 23%.

For the analysis of the relief features of Ukrainian territories, we used the Shuttle Radar Topography Mission (SRTM) dataset with a resolution of 90 meters. This dataset contains information only about elevations (Fig. 5). Using built-in functions in the Google Earth Engine (GEE) cloud environment, we were able to calculate the slope of the terrain (Fig. 6) and the hillshade (Fig. 7), which provide additional valuable information for our research.

To assess the suitability of the existing largest solar power plants in Ukraine, data on the geolocation of these facilities is necessary. To obtain information on the location of the key solar energy objects in Ukraine, we utilized the Wikimapia platform. From Wikimapia, we downloaded vector contours of 230 major solar power plants in Ukraine, which include information on their geographical coordinates, names, and types (solar farm, solar array, etc.).

Elevation (m)

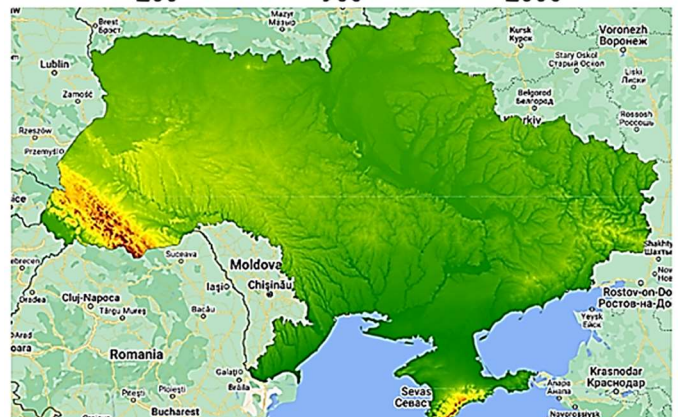


Fig. 5. Map of elevations.

Slope (degree)



Fig. 6. Map of slope.

Hillshade



Fig. 7. Map of hillshade.

III. METHODOLOGY

To determine the most optimal areas for the placement of solar panels, we use the weighted sum method, which allows us to estimate the resulting impact of all climatic and relief factors described in the previous section. Before applying this method, climate and terrain data for Ukraine are normalized in the range from 0 to 1 to bring the values of different parameters in different units of measurement to the same scale.

Subsequently, each parameter is assigned a specific weight. Weight coefficients for GHI [17], temperature [18], and wind speed [18] are established based on correlation analyses with solar panel productivity, derived from previous scientific studies. For precipitation and topographic parameters, where no such correlation studies exist, weights are determined through an analysis of general information regarding their influence on solar power station productivity. The coefficients for each parameter are provided in Table 1.

Parameters with positive coefficients (such as GHI, Wind speed, Elevation) are considered desirable for increasing the productivity of solar panels, while parameters with negative coefficients (such as Temperature, Precipitation, Slope,

Hillshade) are considered undesirable and can have a negative impact on productivity.

TABLE 1. WEIGHTS FOR CLIMATE AND RELIEF PARAMETERS

Variable	Weight coefficient
GHI	0.85
Temperature (>25°C)	-0.4
Wind speed	0.3
Precipitation	-0.3
Elevation	0.2
Slope	-0.2
Hillshade	-0.4

After determining the weight coefficients, we calculate the weighted sum by multiplying the normalized parameter values by their respective weight coefficients and summing the obtained values. The formula for calculating the weighted sum in our study is as follows:

$$Weighted_{sum} = 0.8 * GHI - 0.4 * Temp + 0.2 * Wind_{speed} - 0.3 * Prec + 0.3 * Eleva - 0.2 * Slope - 0.4 * Hillshade$$

where: $Weighted_{sum}$ - the weighted sum that describes the suitability of a location for solar power plant placement; GHI - annual cumulative global horizontal solar radiation, $Temp$ - annual cumulative active temperature above 25°C; $Wind_{speed}$ - average annual wind speed; $Prec$ - annual cumulative precipitation; $Eleva$ - elevation, $Slope$ - slope steepness of the terrain; $Hillshade$ - terrain shading.

After calculating the weighted sum, we normalize the results to obtain a suitability map for the territories in the range of 0 to 1, where 0 represents areas with the poorest climatic and geological characteristics, and 1 denotes the most suitable territories for the efficient placement of solar power plants.

IV. RESULTS

A. Assessment of the suitability of territories in Ukraine for the placement of efficient solar power plants.

As a result of our research, a map has been created that illustrates the suitability of territories for the efficient placement of solar power plants (Fig. 8).

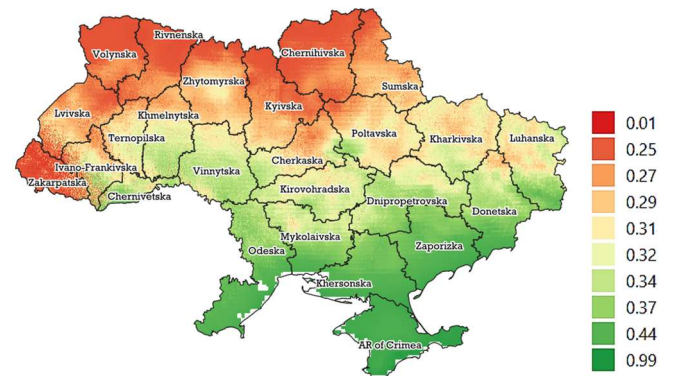


Fig. 8. Map of Solar Power Plant Placement Potential in Ukraine.

From the map of solar power plant placement potential, it is evident that particularly favorable areas for solar energy development in Ukraine are the territories in the southern regions, encompassing Odessa, Kherson, Mykolaiv, and Zaporizhzhia oblasts. The Crimean Peninsula, in particular, holds significant promise, as even the presence of mountains does not hinder the placement of productive solar farms.

Additionally, parts of central and eastern Ukraine, including Chernivtsi, Vinnytsia, Dnipropetrovsk, and Donetsk oblasts, also represent suitable zones for solar power plant installations. While the conditions here may not be as favorable as in the south, there is still potential for solar energy development.

The least favorable regions in terms of climate and topography are the northern areas of Ukraine, notably the Polissia region and Zakarpattia oblast. These regions experience a humid climate with a substantial amount of precipitation in the form of rain and snow, which reduces the availability of sunlight. Moreover, the Carpathian Mountains create unfavorable climatic and topographical conditions.

For quantitative assessment, we calculated the areas of Ukraine's territory within specific suitability intervals with a step of 0.1. It was found that the largest portion of Ukraine (over 288,484 km² or 48.36%) has a potential within the range of 0.3-0.4, which corresponds to the average range for the construction of efficient solar power plants. The interval of 0.2-0.3 corresponds to approximately 201,118 km² or 33.71% of the territory. Territories with a potential of 0.4-0.5 cover an area of 58,484 km². The total area of territories with a suitability below 0.2 is only 4,761 km², while the area of territories with a suitability above 0.5 is 43,748 km², indicating that the favorable territory exceeds the unfavorable territory by almost 10 times.

B. Evaluation of the Optimal Placement of Ukraine's Largest Solar Power Plants

To assess the optimality of the placement of the already installed largest solar power plants within the territory of Ukraine, we calculated the distribution of the number of solar farms within the intervals of suitability of the territories.

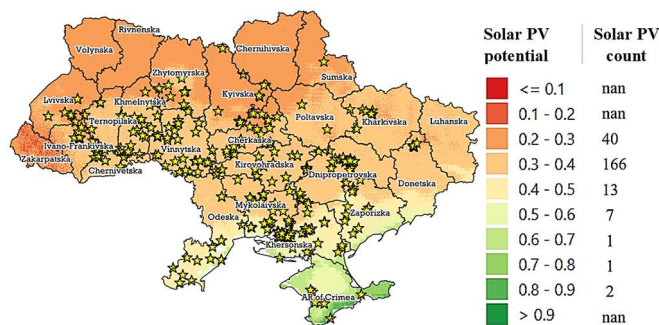


Fig. 9. Distribution of the largest solar power plants on the Map of Solar Power Plant Placement Potential in Ukraine.

From Fig. 9, it can be observed that the majority of the investigated solar power plants (166 facilities) are located in territories with a suitability coefficient in the range of 0.3-0.4. The number of plants in the intervals of 0.2-0.3 and 0.4-0.5 is slightly lower, with 40 and 13 facilities respectively. No large solar farms were found in territories that are completely unsuitable for solar power plants (coefficient less than 0.2). It is also noticeable that the potential of certain regions remains untapped. For example, in Poltava region, where the suitability of territories falls within the 0.3-0.4 range, solar power plants are virtually absent. A similar situation is observed in Donetsk, Luhansk, Kharkiv, Ternopil, and Kirovohrad regions. Donetsk and Luhansk regions have been under occupation since 2014, which could slow down or even make the development of green electricity in these regions impossible. Currently, some areas with good potential for installing solar power plants, such as Zaporizhzhya, for example, are active war zones and therefore inaccessible for installing solar panels. However, the

potential of these areas can be realized during the reconstruction of the infrastructure after the end of the war.

Therefore, in the future, it is worth paying attention to these regions and considering the possibilities of installing solar power plants there to utilize the potential of these territories for efficient solar energy generation.

V. CONCLUSION AND FUTURE WORK

During this study, based on satellite data on the climate and topographic features of Ukraine, a suitability map for the placement of efficient solar power plants was constructed. It was found that the majority of the country's area (48.36%) has a moderate suitability coefficient in the range of 0.3-0.4. The area of suitable territories (with a suitability coefficient above 0.4) exceeds the area of territories with unsuitable climate and topographic conditions.

The best conditions for efficient solar energy generation are observed in the southern zone of Ukraine (Odessa, Kherson, Mykolaiv, Zaporizhia, Donetsk regions) and the Crimean Peninsula. The least favorable conditions for solar energy production are found in western Ukraine and the Polissya region.

When analyzing the placement efficiency of the largest existing solar power plants in Ukraine, it was found that the majority (166) are located in the zone with moderate suitability (coefficient 0.3-0.4), some solar farms are situated in zones with suitability of 0.2-0.3 or above 0.4 (53 surveyed power plants), and 11 solar farms are located in zones with suitability exceeding 0.5. There are no large solar power plants in completely unsuitable areas for solar energy generation, indicating the adequacy of the chosen territories for their placement.

Certain regions of Ukraine with good suitability indicators (0.3-0.4), such as Odessa, Poltava, Kharkiv, Zaporizhia, Dnipropetrovsk, Donetsk, and Luhansk, are underutilized and have high potential for the installation of powerful and productive solar stations in the future.

Thus, our study provides valuable information on the suitability of territories in Ukraine for the installation of solar power plants, which can contribute to the development of sustainable and environmentally friendly energy in the country.

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