www.czasopisma.pan.pl PAN www.journals.pan.pl

GEODESY AND CARTOGRAPHY
Vol. 69, No. 1, 2020, pp. 97–116

DOI: https://doi.org/12.10.24425/gac.2020.131076

Research paper

Site selection for solar power plant in Zaporizhia city (Ukraine)

Liubov Yankiv-Vitkovska[1], Bohdan Peresunko[2], Ireneusz Wyczałek[3]*, Joanna Papis[4]

[1,2]Lviv Polytechnic National University, 12 Bandera st., Lviv, Ukraine, 79013
[1]e-mail: luba_y@ukr.net; [2]e-mail: bodya684@gmail.com

[3,4]Poznan University of Technology, 5 Maria Skłodowska-Curie Square, 60-965 Poznan, Poland
[3]e-mail: ireneusz.wyczalek@put.poznan.pl; ORCID: http://orcid.org/0000-0003-3963-8186
[4]e-mail: joanna.papis@put.poznan.pl

*Corresponding author: Ireneusz Wyczałek

Received: 18 November 2019 / Accepted: 21 February 2020

Abstract: Renewable energy from solar power plants is becoming more and more popular due to the depletion of raw materials and reduction of dependence on oil and gas and is also harmless to the natural environment. The management and rational use of land resources is currently a pressing problem in the world, including in Ukraine. One of the solutions is the development of technologies for the use of these areas and the establishment of environmentally friendly technologies for reducing air pollution, namely electricity facilities – solar power plants based on the use of photovoltaic panels. Choosing the right location for obtaining solar energy depends on many factors and constraints. Optimal location of solar farms is important to maximize the beneficial features of projects while minimizing the negative. A method of finding places in the vicinity of large cities that could be suitable for installing power plants was developed. The proposed method uses an analytical hierarchical process, analytical network process, Boolean logic and weighted linear combination. It has been implemented in the QGIS program. The method was successfully used for the city of Zaporizhia, but it can be directly implemented in any other region. That is why the presented works constitute a scheme that can be easily used to estimate large areas in order to optimally choose a place for a solar park in the vicinity of large cities. Such a model can be very useful for investors to find potential locations for solar energy before conducting detailed field research.

Keywords: AHP, power plants, multicriteria analysis, QGIS

1. Introduction

Solar energy currently occupies a key position among renewable energy sources and plays a significant role in implementation a delicate balance between energy development and the planet's environmental security. The natural disasters that occurred during

2019, anomalous weather events across the globe are indisputable evidence of global climate changes and clear indicators that humanity must reduce its dependence on limited energy resources. Despite the loud and utterly ridiculous statements announced at the Davos Economic Forum by some leaders of the most powerful economies in the word (for example "The United States has among the cleanest air and drinking water on Earth", source: https://www.bbc.com/news/world-51192999), ignoring the Paris Climate Agreement by some countries, the community of the whole world is now working on finding ways to solve global environmental problems.

The development of alternative energy sources is the main mechanism for reducing the burden on the planet's ecosystem. In turn, the construction of solar power plants requires a large amount of engineering research, among which the most important is the choice of their correct locations.

On the other side, management and rational use of land resources is currently a burning issue in the world, in particular in Ukraine as well as in Poland and other East-European countries. Many land plots in a number of cases are used irrationally and contrary to their intended use. The problem of rational land use requires solving a complex of practical tasks based on modern technological and technical means (Perovych and Kereush, 2017). One of the solutions is to develop the technology of using these lands and establish the environmentally friendly technologies for reducing of air pollution, namely – solar power plants (SPP), which produce electricity with the use of photovoltaic panels.

2. Definitions of project

2.1. Main problems

Atmospheric pollution in Ukraine has become a significant environmental problem, especially in the eastern part where heavy industries are located, and it is particularly severe in industrial centers such as Zaporizhia, Kryvyi Rih, Dnipro. The main emission sources are ferrous metallurgical plants and the coal industry.

According to the data of the Central Geophysical Observatory (Kyiv), the value of atmospheric pollution index for Zaporizhia is 8.4 which means a high degree of air pollution (Figure 1).

2.2. Goals and aims

The development of environmentally friendly technologies is critical for the sustainable economic development of each country. Dependence on exhaustive energy resources threatens the stable functioning of global economies, and renewable energy resources are one of the promising options for ensuring energy security (Ghazanfar et al., 2014). Therefore, the main goal of this project is to find the most suitable areas for the construction of solar power station in the city of Zaporizhia using Boolean site selection and Multi-criteria decision analysis (MCDA) implemented in QGIS software.

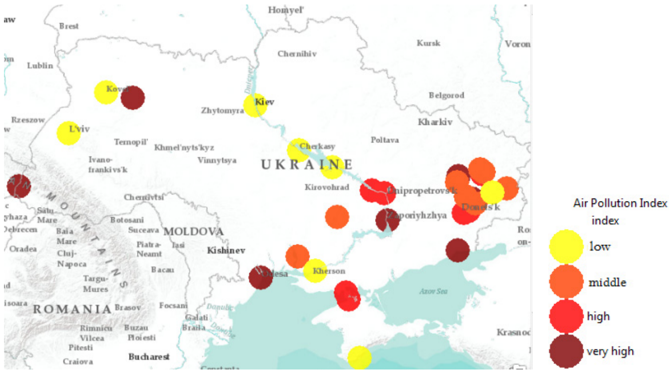


Fig. 1. Air pollution Index (Source: ArcGIS online data base, https://www.arcgis.com/home/item.html?id=61999f0185c14e7589b795d3a29a16f1)

The main goals of this project is to increase solar energy production, gradually replace environmentally hazardous power plants and reduce the amount of harmful emissions into the atmosphere and improve land use.

2.3. Study area

Zaporizhia (Ukrainian: Запоріжжя), is a city in the south-east of Ukraine, located on the banks of the Dnieper (Figure 2), with the Khortytsia island located in the River. It is the administrative center of the Zaporizhia region. The city's population is the sixth largest in Ukraine. Also, it is an important industrial center of the production of steel, aluminum, aircraft engines, automobiles, transformers for substations and other heavy goods (Wikipedia contributors. 2018. Zaporizhia).

Fig. 2. Study area (Source: Wikipedia contributors. 2018. Zaporizhia, https://en.wikipedia.org/wiki/Zaporizhia)

According to the map presented in Figure 3, Zaporizhia yearly sum of solar irradiation is over 1100 [kWh/m^2], which means that it has quite good atmospheric conditions for building solar panel stations.

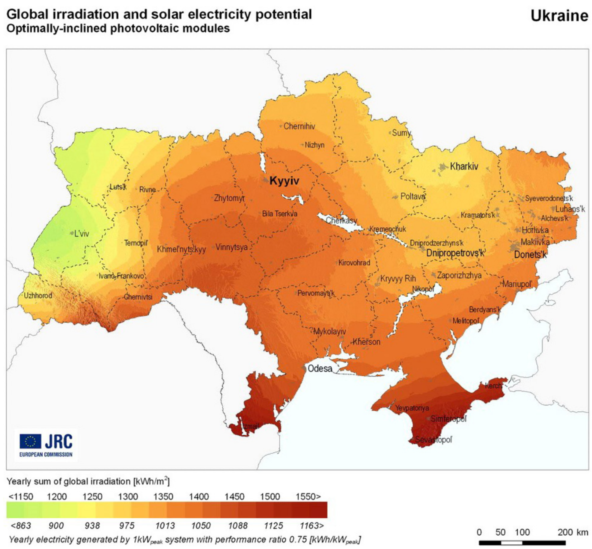


Fig. 3. Global irradiation and solar electricity potential of Ukraine
(Source: Wikipedia contributors. 2019. Solar power in Ukraine)

Zaporizhia is a large electricity generating hub. There are hydroelectric power plant known as “DniproHES” Dnieper Hydro-Electric Station, as well as the largest in Europe nuclear power plant and the biggest thermal power station in Ukraine: “Zaporizhia TEZ”. Zaporizhia plants generate about 25% of the whole Ukrainian electricity consumption (Source: Wikipedia contributors. 2019. Zaporizhia). In a view of the large number of heavy industry objects and the global trend of replacing nuclear power plants with alternative energy sources, for Zaporizhia city today is a critical issue for the development of alternative energy. Obviously, it is almost impossible to replace a nuclear power plant with the potential of solar energy, but it is possible to reduce the amount of harmful emissions from thermal power plants.

2.4. Solar power energy in Ukraine

In 2011, 90% of electricity was produced by nuclear and coal power stations. In order to improve this situation, Ukraine adopted a feed-in tariff (FIT) which is one of the highest in the world – UAH 5.0509 (EUR 0.46) per kWh (EPIA – European Photovoltaic Industry Association. 2014). The alternative energy is obtained in Ukraine from solar photovoltaic (PV), solar thermal and wind power stations. For example, one of the largest solar park in Europe, the 100 MW Perovo Solar Park which is located at Perovo (Figure 4), Simferopol Region, Crimea consists of 440,000 solar panels and in 2012 was the world’s fourth-largest solar farm. It is owned by Activ Solar, and the final 20 MW stage was completed on December 29, 2011 (EPIA – European Photovoltaic Industry Association, 2014).

Fig. 4. Perovo Solar Park (Source: Wikipedia contributors, 2018, Perovo Solar Park, https://en.wikipedia.org/wiki/Perovo_Solar_Park)

3. Methodology and Data

3.1. Introduction to site selection

Geographic Information Systems (GIS) is a powerful and effective decision-making tool for location selection, which includes detailed assessment and evaluation of various parameters. In the context of this research, decision-making process was carried out regarding the selection of the most suitable areas for the construction of solar power plants through the use of logical location selection and multi-criteria decision analysis (MCDA) through the use of social, ecological, economic intersection and physical criteria.

3.2. Methodology

Most GIS-based studies on site suitability are based on multi-criteria analysis (MCA) and designed for the solving of complex problems with several variables (Lewis et al., 2015; Mierzwiak and Calka, 2017). According to Hermann et al. 2007 the MCA is "a decision-making tool which used in environmental systems analysis to evaluate a problem by ordering multiple alternatives based on several criteria that may have different units". Some methods of multicriteria analysis include analytical hierarchical process (AHP), analytical network process (ANP), Boolean logic, weighted linear combination (WLC), and fuzzy logic. AHP is one of the most effective methods for decision making by evaluating various criteria, which was developed by Saaty (Saaty, 1980). The main aim of AHP is hierarchical representation of problems by pairwise comparison of criteria. In this case, complex problems are divided into a number of one-to-one comparisons (Yousefi et al., 2018).

In Boolean logic, all values of the criteria in the assessment are reduced to either TRUE (1) or FALSE (0), which means that each site is either suitable or not, according to the development plan for installation of solar power plant. In weighted linear combination (WLC), instead of absolute values of 0 or 1, significance weights are assigned to each criterion (Jiang et al., 2000).

In accordance with the foregoing, two methods for decisions making were used for the purpose of this work: *Boolean logic* for the immediate detection of completely unsuitable territories (Constrains analysis: 0 – unsuitable territories *or* 1 – suitable territories) and *AHP* – for analysis of factors and identification of the most suitable sites for the construction of solar power plants (SPPs) (gradation *from* 0 – unsuitable at all *to* 1 – the most suitable). Therefore, the research algorithm has the following structure (Figure 5).

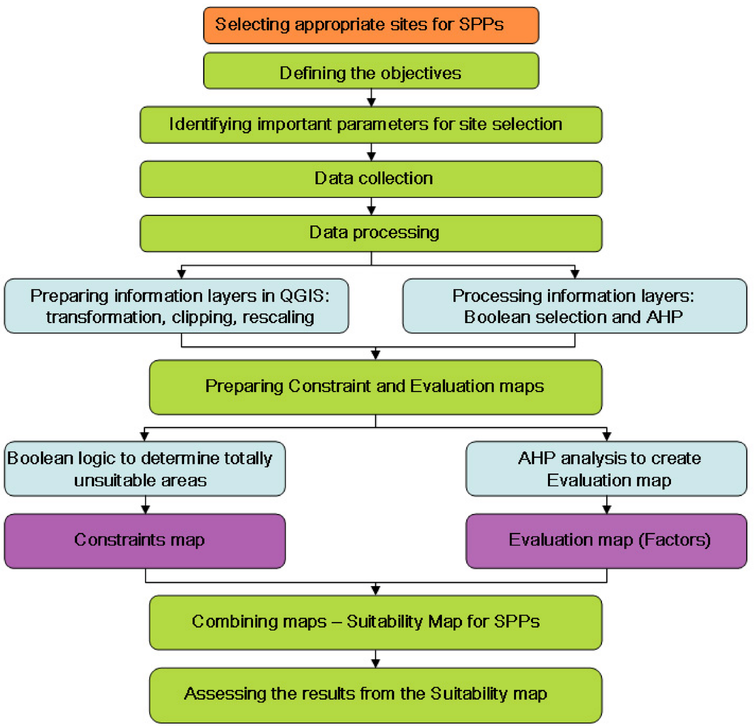


Fig. 5. Site selection algorithm (Source: Authors)

3.3. Determining criteria and data collection

In order to select suitable sites for solar power plants (SPPs) in the study area, it is required to determine effective spatial criteria and factors on the viability of SPPs. There are many approaches and ways to choose the necessary criteria for the construction of solar power plants – many of them are described in Yousefi et al. (2018). Mierzwiak and Calka (2017) took into account three groups of criteria: environmental (solar radiation, aspect), technical (proximity to roads, electrical power lines, and buildings), and economic (the size and shape of the area). Perovych and Kereush (2017) suggest analyzing the following list of criteria (Table 1).

According to the above, the criteria used in this study are classified into three groups: economic, environmental and technical (Figure 6).

Obviously, the higher amount of solar radiation, the more electricity can be generated by solar panels. In general, solar power plants are profitable with a solar radiation value of 1100 kWh$\cdot$m^{-2} per year (Perovych and Kereush, 2017). In terms of slope of the

Table 1. General criteria for Solar PV power plant siting (Source: Perovych and Kereush, 2017)

No	Criteria	Requirements
1	Abundant solar irradiation	minimum is 1100 kWh·m^{-2} per year
2	Certain slope and aspect	• slope $< 5-15°$ • aspect $= 110$–$200°$ (southeast, south, partly southwest)
3	Transmission lines adjusted to capacity located nearby	TL with equal and more than 35 kV around 600 m nearby
4	Proximity to populated area	< 2500 m
5	Proximity to enterprises	< 3500 m
6	Proximity to road network	< 500 m
7	Average air temperature in July (north hemisphere)	15–40°C
8	Proximity to multi-storey houses ($>$ 16 storeys)	> 100 m
9	Proximity to residential areas	> 500 m
10	Land cover	• free of mountains, forests, water bodies, buildings, wetlands, floodplains, • preferably low and medium grassy vegetation, shrublands, barren lands, closed landfills, abandoned mine lands
11	Protected areas	national and regional parks, areas of cultural heritage, paleontological and archaeological sites
12	Shoreline	> 1000 m
13	High altitude areas	> 1500 m

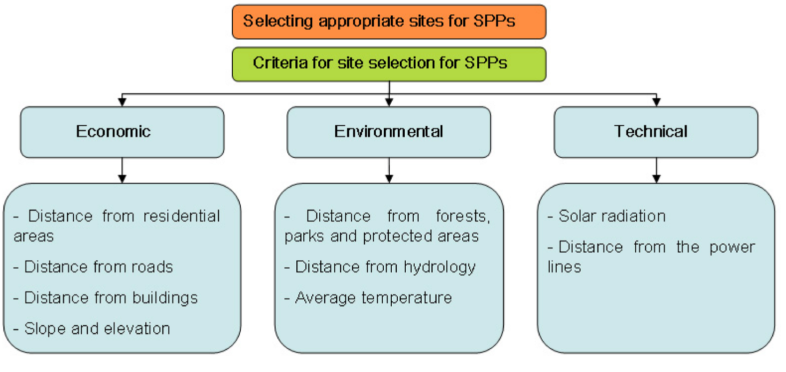


Fig. 6. Criteria for Solar PV power plant siting (Source: Authors)

terrain, in general, the flat areas are most suitable for the construction of solar panels. Increasing of the slope is accompanied by complications in the installation of panels, which leads to more expensive implementation of the project. The construction of solar power plants on slopes may require additional engineering solutions such as drainage systems, foundations, and others. Also, if the slope is more than 15%, the orientation of the panels is very important (see more in Perovych and Kereush, 2017).

The proximity of SPPs to residential areas and electricity grid, as building also plays a key role, as the construction of new power lines increases capital expenditure on SPPs development (Perovych and Kereush, 2017).

Table 1 contains all the necessary information about the requirements and restrictions for the construction of solar power plants. However, given the specificity of the study area (densely populated city with developed infrastructure and a large amount of buildings), the authors of this studies proposed the following requirements regarding the constraints and factors (Table 2).

Table 2. Requirements regarding the constrains and factors for SPPs sites (Source: Authors)

No	Criteria	Suitability 0 or 1	
		Requirements	
		Unsuitable Areas (Value = 0)	Suitable Areas (Value = 1)
Constraints			
1	Distance from the residential areas	$x < 250$ m	$x > 250$ m
2	Distance from the hydrology objects	$x < 100$ m*	$x > 100$ m*
3	Distance from the roads	$x < 100$ m	$x > 100$ m
4	Distance from the buildings	$x < 250$ m	$x > 250$ m
5	Distance from the forests, parks and protected areas	$x < 150$ m	$x > 150$ m
Factors			
		Suitability from 0 to 1	
		Unsuitable Areas at all (Value = 0)	The most Suitable Areas (Value = 1)
1	Slope	$x > 15\%$	$x < 3\%$
2	Solar radiation	$x < 1100$ kWh·m^{-2} per year	$x > 1200$ kWh·m^{-2} per year
3	Distance from the power lines	$x > 1000$ m	$x < 100$ m
4	Average temperature, July	$x < 15$°C and $x > 40$°C	$x < 25$°C and $x > 15$°C

* according to ukrainian law

According to these requirements the following types of data were downloaded:

1. Vector data:
   – Zaporizhia boundaries data (Open Street Map, 2018);
   – Roads data (Open Street Map, 2018);
   – Electricity distribution data (Open Street Map, 2018);

- Land using data (Open Street Map, 2018);
- Buildings data (Open Street Map, 2018);
- Zaporizhia Hydrographic data (Open Street Map, 2018);
- Forests and parks data (Open Street Map, 2018);

2. Raster data:
   - Digital Elevation Model (EarthExplorer, www.earthexplorer.usgs.gov, 2018);
   - Solar radiation data (SolarGIS, https://solargis.com/, 2018).
   - Average temperature data (WorldClim, http://worldclim.org/version2, 2018)

4. Data processing

4.1. Constraints and factors of evaluation

All downloaded data have to be properly processed and prepared for AHP analysis to implement the site selection algorithm (see Figure 5). First of all it was necessary to perform the following steps:

- transformation to UTM coordinate system;
- clipping of vector and raster layers and data analysis;
- creation of buffer zones according to Table 2;
- transformation from vector data to raster data.

As a result, the following Constraint maps were obtained (see Figure 7a– 7e). Each pixel of these raster images contains the following information: value 0 – the areas are not suitable for SPPs; 1 – the areas are suitable for SPPs. Therefore, these data were used for Boolean analysis.

The next step was to prepare data for AHP analysis: creating a Slope map using DEM and clipping raster data.

It should be noted that each of all raster layers with information about solar irradiation, slope, distance from the power lines, temperature has its own units, so it must be scaled to one system for unification. The process of converting data into such numeric scales is called standardisation (Voogd, 1983). In this case, all criteria were standardized before weighting to a common numerical range using the most commonly used technique – linear scaling between the minimum and maximum values of this criterion (Eastman, 1999). The following two cases are possible to calculate suitability:

- method of standardization when suitability has a direct linear correlation with criteria (Fig. 8 – left):

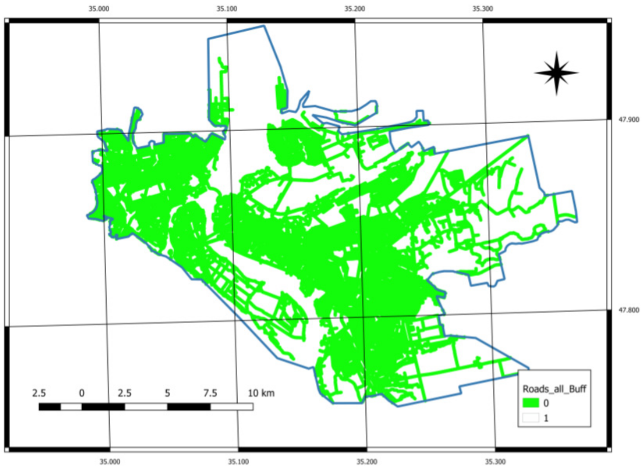
$$X_i = \frac{(x_i - \min_i)}{(\max_i - \min_i)}, \tag{1}$$

- method of standardization when suitability has an inverse correlation with criteria (Fig. 8 – right):

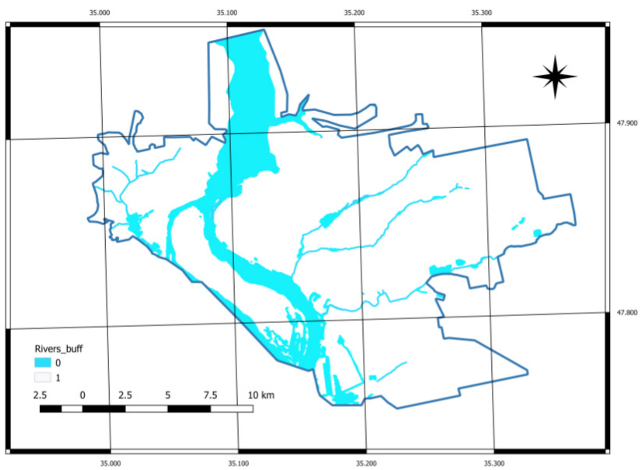
$$X_i = \frac{(\max_i - x_i)}{(\max_i - \min_i)}. \tag{2}$$

Constraints

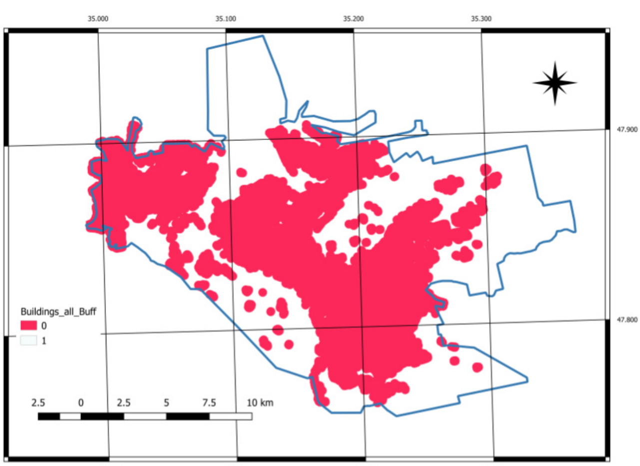
a)



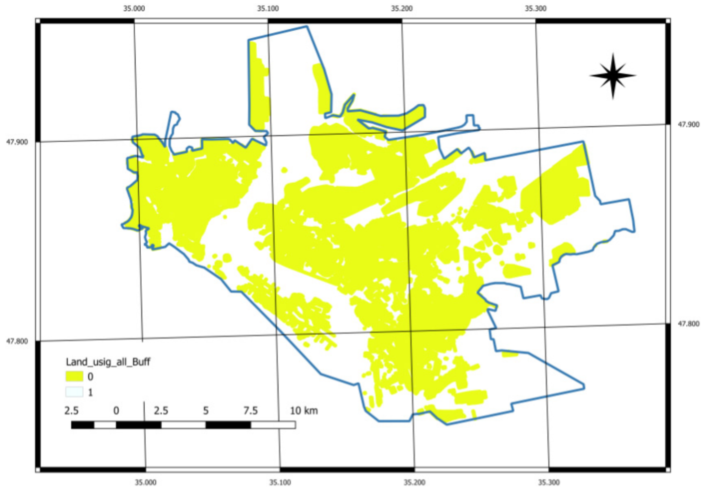
b)



c)



d)



e)

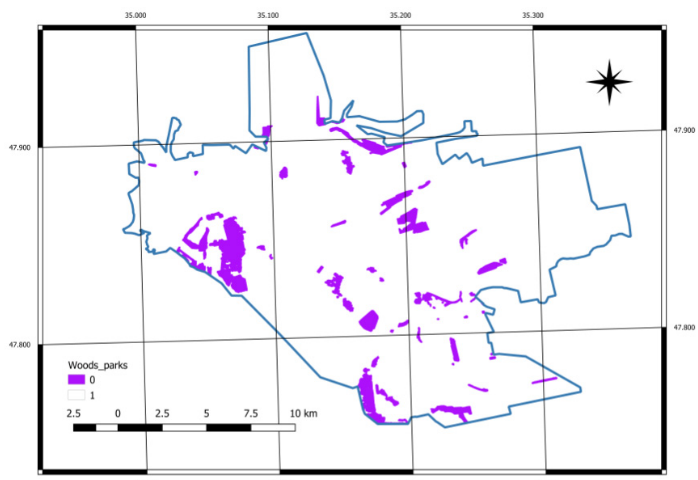


Fig. 7. a) Map of buffered roads; b) Map of buffered hydrology; c) Map of buffered buildings; d) Map of buffered residential area; e) Map of buffered forests, parks and protected areas

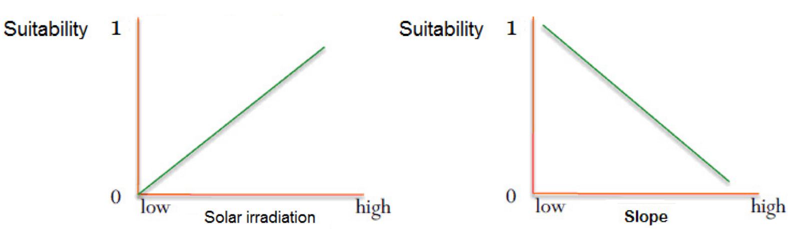
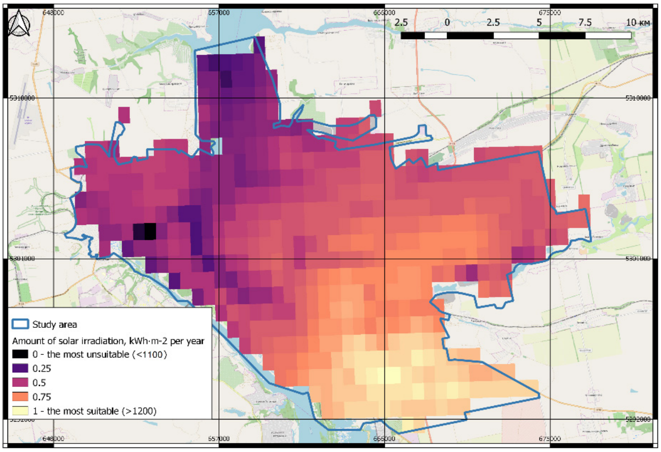


Fig. 8. Direct (left) and inverse (right) dependence of suitability on the criterion

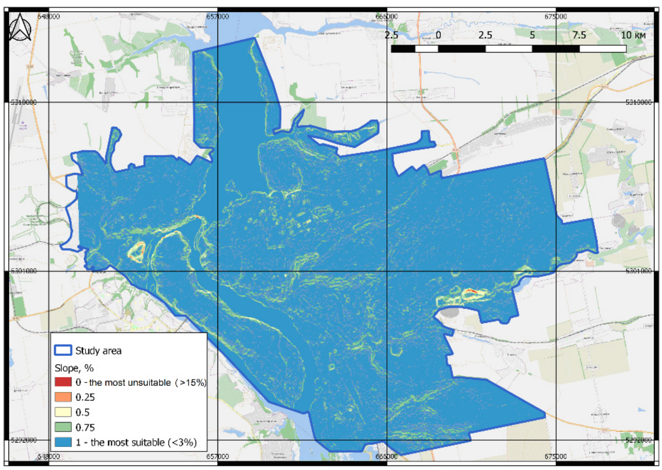
As a result, the following Evaluation maps were obtained (see Figure 9a–9d).

Evaluation Factors

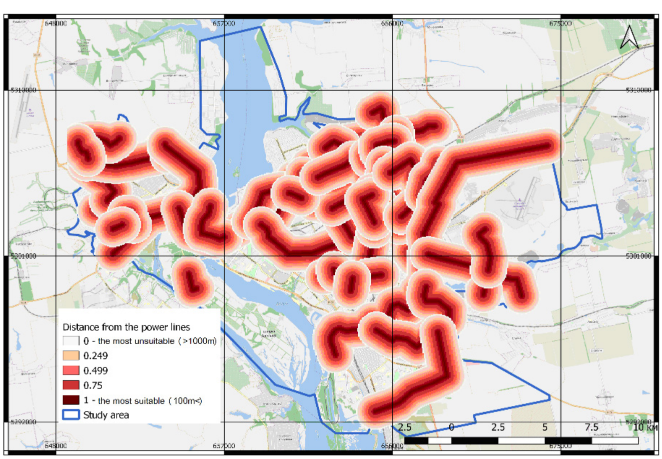
a)



b)



c)



d)

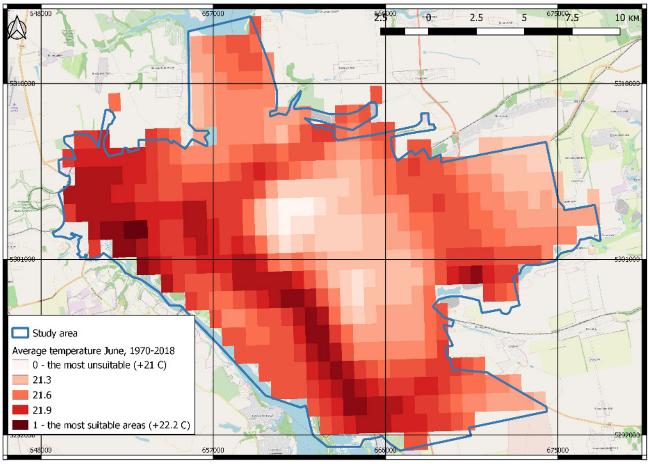


Fig. 9. a) Map of solar radiation; b) Map of slope model; c) Map "Distance from the power lines"; d) Map "Average temperature, July"

4.2. Boolean analysis

The algorithm of Boolean logic converts the input information from each raster map to binary form 0 and 1 (true or false). Therefore, the restricted areas ("not suitable at all") were assigned a value of 0 while other areas ("suitable areas") were assigned a value of 1. The resulting map is a binary map, because each location is either satisfactory or not. For example, according to Table 2, there are restrictions on the construction of SPPs closer than 100 meters to the roads. The same logic was applied for buildings: it

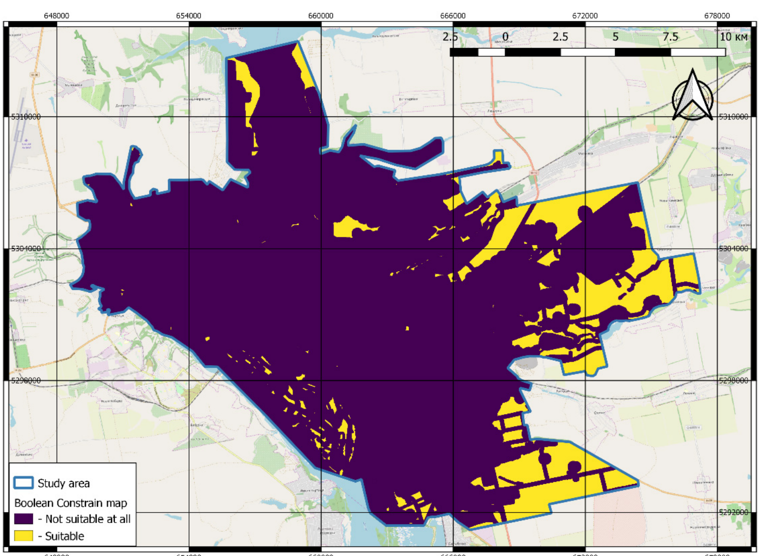


Fig. 10. Final constraint map (Boolean logic)

is impossible to construct large ground-based SPPs on the building or really close to it (unless the thing is not the type of small solar power plants on the roofs, which is not considered in this work).

Based on the criteria indicated by each layer, some areas identified as inappropriate for selection for SPP installations were excluded due to elevation restrictions. The full description of the selection criteria are shown in Table 2 and the produced maps are illustrated in Figures 7a– 7e.

As a result of multiplying these maps, it was obtained a final constrain map (Figure 10).

4.3. AHP analysis

The problem of multi-criteria analysis involves a set of alternatives that are evaluated based on conflicting and incommensurable criteria according to our decision. In order to define the strength of the factors, the weighting by pairwise comparison is used.

The Analytical Hierarchy Process (AHP) is based on pairwise comparison within a reciprocal matrix in which the number of rows and columns is defined by the number of criteria. In this case, it is necessary to specify the comparison matrix of pairwise criteria in which the importance of each pair is compared with respect to all other pairs. Therefore, it is important afterwards to calculate the priority vector with the corresponding weights (W_j). These weights are a quantitative measure of the consistency of the value judgments between pairs of criteria (Saaty, 1992). AHP Scale intensity values and definition are given in the following table.

Table 3. An AHP scale according to Saaty (1980)

Intensity of Importance	Description
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

The comparison matrix is given below. In this case F1 is Slope, F2 – Solar radiation, F3 – Distance from the power lines, F4 – Average temperature, July.

Table 4. A comparison matrix

	F1	F2	F3	F4
F1	1	5.000	3.000	7.000
F2	0.200	1	0.333	3.000
F3	0.333	3.000	1	5.000
F4	0.143	0.333	0.200	1
Sum	1.676	9.333	4.533	16.000

The next step is to calculate the auxiliary matrix – the normalized pairwise comparison matrix (Table 5), in which each cell is obtained by dividing of each judgment (the values of intensity of importance) by the sum of the corresponding column in Table 4 (Kereush et al., 2017).

Table 5. Normalized pairwise comparison matrix

	F1	F2	F3	F4	Priority vector = weight, w_i
F1	0.597	0.536	0.662	0.438	0.558
F2	0.119	0.107	0.074	0.188	0.122
F3	0.199	0.321	0.221	0.313	0.263
F4	0.085	0.036	0.044	0.063	0.057
Sum	1.000	1.000	1.000	1.000	1.000

Estimation of consistency involves the following steps (Kereush et al., 2017):

1. Determination of the weighted sum vector (by multiplying matrix of comparisons by the vector of priorities)
2. Determination of consistency vector (by dividing the weighted sum vector by the criterion weights).

Table 6. Estimation of consistency

	Weighted sum vector	Consistency vector
F1	2.356	4.222
F2	0.492	4.036
F3	1.099	4.175
F4	0.230	4.041

After calculating the consistency vector, the lambda value (λ) and the consistency index (CI) must be calculated. Lambda is the average value of the consistency vector

(Kereush et al., 2017).

$$\lambda = \frac{\sum_{i=1}^{n} C_1, C_2, \ldots, C_i}{n} = 4.118 \tag{3}$$

where: λ – average of the elements of consistency vector, C_i – consistency vector, n – number of factors.

The calculation of CI is based on the observation that λ is always greater than or equal to the number of criteria considered (n) for positive, reciprocal matrices and $\lambda = n$, if the pairwise comparison matrix is consistent matrix. Accordingly, $\lambda - n$ can be considered as a measure of the degree of inconsistency. This measure can be normalized as follows (Perovych and Kereush, 2017):

$$CI = \frac{(\lambda - n)}{(n-1)} = 0.039, \tag{4}$$

where: CI – consistency index, λ – average of consistency vectors, n – number of factors.

The term CI, called the Consistency Index, provides a measure of departure from consistency. To estimate the CI, AHP compares it by a random index (RI), and the result of this comparison – consistency ratio (CR) – can be defined as (Perovych and Kereush, 2017):

$$CR = \frac{CI}{RI}, \tag{5}$$

where: CI – consistency index, RI – random index.

Random index is the CI of a randomly generated pairwise comparison matrix of order 1 to 10 obtained by approximating random indices. Table 7 shows the value of RI according to the order of comparison matrix (Saaty, 1997).

Table 7. Random index (RI)

Order matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In this case order of the comparison matrix is 4 and $RI = 0.9$, so consistency ratio (CR):

$$CR = \frac{0.039}{0.9} = 0.044 < 0.10. \tag{6}$$

The consistency ratio (CR) is designed in such a way that if $CR < 0.10$, the ratio indicates a reasonable level of consistency in the pairwise comparisons. If $CR > 0.10$, then the value of the ratio indicates an inconsistent assessment. In such cases, the initial values in the comparison matrix should be reconsidered. In this case $CR < 0.10$ therefore results indicates a reasonable level of consistency.

4.4. The integration of Boolean analysis and AHP

The suitable areas obtained by the multiplying of corresponding Boolean maps should be estimated using raster layers of AHP evaluated maps. The final map can be calculated by the following formula:

$$S = \left(\sum_{i=1}^{n} w_i \cdot x_i \right) \cdot \prod c_j , \tag{7}$$

where: S – suitability, x_i – evaluation factors, w_i – weights of the factors, c_j – constraints.

As result, it was calculated one raster, which is scaled from 0 (not suitable at all) to 1 (the most suitable areas) and contains information of all evaluation factors and constrains together (Figure 11).

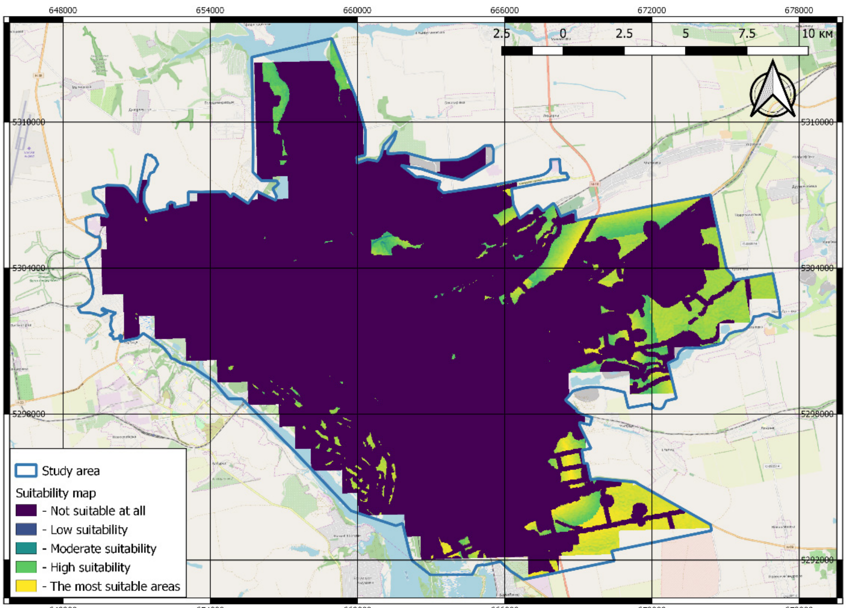


Fig. 11. Suitability map – the result of AHP and Boolean analysis

5. Results and analysis

The next step in this study is to analyze the results obtained. Using suitability scale it is possible to determine where are the best areas for solar power plant construction. In addition The Public Cadastre Map of Ukraine was used in order to choose from those result areas that have no specific purpose and are not privately owned (Figure 12).

Figure 13 shows the most suitable areas regarding the availability of access to power lines.

These areas have the description as in Table 8.

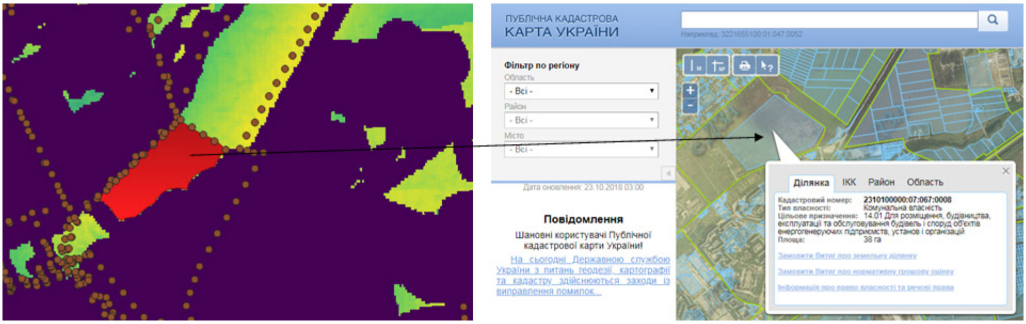


Fig. 12. Using Public Cadastre Map of Ukraine (Source: http://map.land.gov.ua/kadastrova-karta)

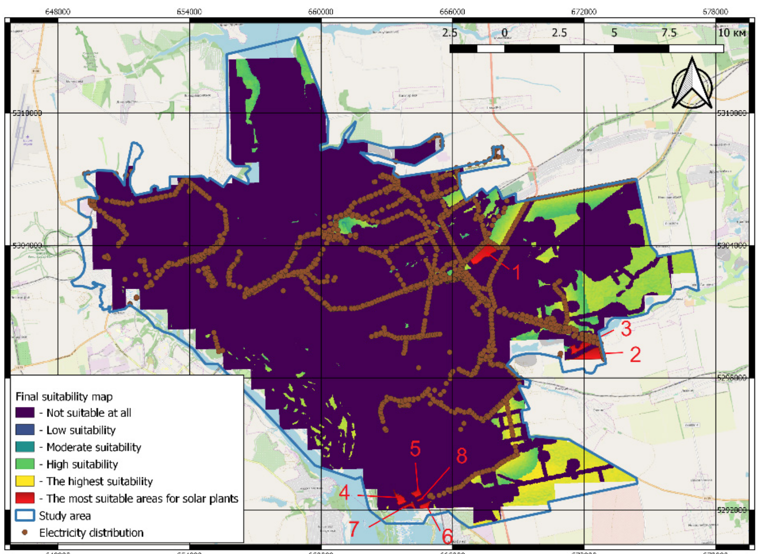


Fig. 13. The most suitable areas (red ones) to build solar power plants in Zaporizhia city

Table 8. Parameters of the most suitable areas (Source: Authors)

No	Area in km^2
1	0.633
2	0.435
3	0.286
4	0.154
5	0.088
6	0.094
7	0.026
8	0.073

6. Conclusions

In recent decades, the use of ground-based solar photovoltaic (PV) power plants is increasing worldwide. The rapid rate of such growth is driven by tax breaks (feed-in tariffs) to produce green electricity, as well as from the low cost and high productivity of solar panels.

In general, the selection and analysis of parameters for the optimal location of solar power plants is a decisive factor that can significantly improve all the benefits of the project and minimize the negative sides. Optimally positioned solar panels will reduce the costs associated with developing an appropriate infrastructure for transporting electricity or certain equipment. Therefore, this work represents a model that can be easily used to estimate large areas for the optimal choice of space for a solar park location in large cities. Such a model can be very useful for investors to find potential locations for solar energy sites before conducting detailed field research.

As a result of implementing this methodology, 8 locations were selected within the city of Zaporizhia, which due to the features of this area are most suitable for the construction of solar power plants. The low consistency ratio (CR) value indicates the reliability of the result. Apart from the issue of optimal placement of solar energy plant, the technique used in this study allows to improve land management in urban areas (development of non-purpose areas for solar power plants).

It should be noted that multi-criteria decision analysis (MCDA) is fairly reliable technique for analyzing various factors and making decision. However, the reliability and quality of the result of this analysis depends significantly on the selection of constraints and evaluation criteria, as well as on the calculation of the intensity of importance of each of these factors. Therefore, the results of such analysis must be confirmed by appropriate field research before direct implementation of the project.

Acknowledgments

The study was carried out in 2019 as part of the statutory research financed at the Lviv Polytechnic National University and Poznan University of Technology (project No. 504101/0413/SBAD/5439).

References

Eastman, J.R. (1999). Multi-criteria evaluation and GIS. *Geographical information systems*, 1(1), 493–502.

EPIA – European Photovoltaic Industry Association. p. 24. Archived from the original (PDF) on 12 June 2014. Retrieved 12 June 2014.

Hermann, B.G., Kroeze, C. and Jawjit, W. (2007). Assessing environmental performance by combining life cycle assessment, multi-criteria analysis and environmental performance indicators. *J. Clean. Prod.*, 15, 1787–1796.

Jiang, H. and Eastman, J.R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *Int. J. Geogr. Inf. Sci.*, 14, 173–184.

Kereush, D. and Perovych, I. (2017). Determining criteria for optimal site selection for solar power plants. *Geomatics, Landmanagement and Landscape*, 4, 39–54.

Lewis, S.M., Gross, S., Visel, A., Kelly, M. and Morrow, W. (2015). Fuzzy GIS-based multi-criteria evaluation for us agave production as a bioenergy feedstock. *GCB Bioenergy*, 7, 84–99.

Mierzwiak, M. and Calka, B. (2017). Multi-criteria analysis for solar farm location suitability. *Reports on Geodesy and Geoinformatics*, 104/2017, 20–32. DOI: 10.1515/rgg-2017-0012.

Perovych, L. and Kereush, D. (2017). Technology of optimal site selection for solar photovoltaic power plants using GIS and remote sensing techniques. *Geodesy, Cartography and Aerial Photography*, 86, 73–79.

Saaty, T.A. (1992). *Decision-Making for Leaders*. 2nd Ed. RWS Publications, Pittsburgh, USA.

Saaty, T.A. (1997). A scaling method for priorities in hierarchical structures. *J. Mathem. Psychol.*, 234–281.

Saaty, T.L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill International: New York, NY, USA.

SolarGIS. (2018) https://solargis.com/.

The Central Geophysical Observatory (Kyiv), wdc.org.ua/en/partners/central-geophysical-observatory.

U.S. Geological Survey. (2018). EarthExplorer, www.earthexplorer.usgs.gov.

Voogd, H. (1983). *Multi-criteria evaluation for urban and regional planning*. London, Pion.

Wikipedia contributors (2018). Perovo Solar Park. In: Wikipedia, The Free Encyclopedia. Retrieved January 19, 2019, from https://en.wikipedia.org/wiki/Perovo_Solar_Park.

Wikipedia contributors. (2018). Zaporizhia. In: Wikipedia, The Free Encyclopedia. Retrieved January 19, 2019, from https://en.wikipedia.org/wiki/Zaporizhia.

WorldClim (2018) http://worldclim.org/version2.

Yousefi, H., Hafeznia, H. and Yousefi-Sahzabi, A. (2018). Spatial Site Selection for Solar Power Plants Using a GIS-Based Boolean-Fuzzy Logic Model: A Case Study of Markazi Province, Iran. *Energies*, 11, 1648.