Research quantitative indicators of the potential of solar energy in the Carpathian region of Ukraine

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Abstract. The paper presents the results of theoretical research on the resource potential of solar energy calculated by different methods for administrative areas of the Carpathian region; the advanced methodology of the estimation of the influence of solar power plants on the natural environment is proposed, which concerns the determination of the significance of the residual effects of renewable energy on the environment and is carried out after screening and mitigation measures and is based on the three identified parameters of influence: spatial, temporal and intensity of influence. The results of statistical analysis of observational data of meteorological stations of the studied region are presented. The results of experiments that study are dependent on power generation by photovoltaic panels from meteorological elements of weather conditions; it is proved that the amount of energy received significantly depends on the cloudiness and air humidity. At the same time, it has no direct dependence on atmospheric pressure and wind speed indices. The paper presents the results of the cartographic processing of quantitative indicators of the potential of solar energy for the arrangement of the objects providing renewable energy in the Carpathian region of Ukraine.

1. Introduction
It is known that in Ukraine, as well as in many countries in the world, there is an energy due to the lack of conventional energy sources [9]. For present moment it is believed that the use of renewable energy sources is one of the ways to solve this problem. The topicality of the scientific project is apparent and related to the fact that the world community regards the use of alternative and renewable energy as one of the most promising solutions to the growing problems of energy supply [1]. One of the most promising alternative sources of energy is solar energy. Considering the dynamics of reducing the cost of electricity, generated from the sun it is strategically important for Ukraine to develop these directions of „future”, especially in such a difficult economic situation [6].

Efficiency and expediency of the use of sunny energy many works are sanctified to [1, 6, 7, 8]. Ponderable results are got in Institute of physics of semiconductors of NUN of Ukraine, in the Kyiv,
Odesa, Uzhhorod and Chernivtsi universities, on some industrial enterprises ("Pillar", "Quasar"), in other Ukrainian laboratories.

All assert simply, that application is in Ukraine of alternative energy sources, foremost, sunny energy, no doubt will give a benefit [8].

On the whole the modern state of questions of analysis and estimation of sun energy resources is in-process considered. The basic types of works are distinguished and analysed in relation to the natural resources of refurbishable energy, scientific achievements in relation to natural resources for development of alternative energy, that contain general and special description of refurbishable energy sources, methods of their use but estimations.

Analysis undertaken studies showed that today all more authors dedicate the labours to systematization and perfection of unconventional energy sources and complex calculation of options that give an opportunity on their basis to get energy (e.r. Solove, 2007).

Very often the necessary are given about sunny energy are absent and for this purpose use analytical dependences that with sufficient exactness help to decide the put tasks. Being and description of such dependences labour is sanctified (e.r. Kondratev, 1981).

Other source about the level of insolation of concrete territory are results of long-term research of NASA (cosweb.larc.nasa.gov), what is included by the satellite measuring, design of atmosphere and surface researches. In this model during the design of atmosphere such factors are used, as climatic zones, reflectance, cloudiness, precipitations and aerosols in an atmosphere.

2. Problem statement
The aim of the work - to justify the advisability of implementing facilities for using the solar energy of the Carpathian region and also to prove that for the development of solar energy in the Carpathian region there are not objective resource obstacles. At a recent time one can observe an increasing interest in the use of photovoltaic panels to produce electricity by converting solar energy. Along with other devices to generate electricity from renewable energy sources, photovoltaic panels have several advantages, including simplicity of design and construction, small weight and size, long-term life (e.r. Duffie, 1980). While the major disadvantages of its use are their low efficiency, instability of electrical energy due to weather conditions and the dependence of output power from the angle of incidence of sunlight on light-absorbing panel. In order to use solar installations, one must have data on the distribution of the intensity of solar radiation in the area. The administrative Carpathian region includes Ivano-Frankivsk, Lviv, Zakarpattya and Chernivtsi areas.

Thus, there is a need to solve the following tasks:
- Accumulation of data on solar radiation intensity in each region;
- Data processing and determination of probable characteristics of the intensity of solar radiation distribution.

3. Presentation of the fundamental material
The regional average annual values of the total solar radiation within the whole Carpathian region on the horizontal (underlying) surface are presented on the Map Info map built in GIS by us in Figures 1, 2, containing 10 colour gradations. The results indicate a gradual decrease in the quantitative indicators in the direction of the south-east-northwest.

The efficiency of light-absorbing panels operation in the Carpathian has been studied on the basis of Ivano-Frankivsk National Technical University of Oil and Gas since April 2015. There are daily conducted measurements of the amount of produced electricity and meteo-indexes in Table 1.
Figure 1. Total solar radiation on a horizontal surface in the Carpathian region of Ukraine

Figure 2. Total solar radiation on a vertical surface in the Carpathian region of Ukraine
Table 1. Experimental measurements at the photoelectric station of IFNTUOG (April 2015)

| Date   | E-tot (kWh) | E-day (kWh) | Cloudiness (%) | Probability of precipitation | Air temperature (°C) | Atmospheric pressure, mmHg | Humidity (%) | Wind speed (m/s) |
|--------|-------------|-------------|----------------|-----------------------------|-----------------------|-----------------------------|--------------|-----------------|
| 01.04. | 6305        | 18,2        | 70             | 37                          | 11                    | 726                         | 30           | 10              |
| 02.04. | 6314        | 9,4         | 63             | 17                          | 7                     | 755                         | 64           | 2,2             |
| 03.04. | 6320        | 6,1         | 88             | 48                          | 3                     | 756                         | 54           | 7,7             |
| 04.04. | 6328        | 7,6         | 67             | 29                          | 4                     | 759                         | 66           | 4,2             |
| 05.04. | 6335        | 7,3         | 67             | 21                          | 6                     | 761                         | 45           | 2,4             |
| 06.04. | 6342        | 6,9         | 99             | 70                          | 4                     | 764                         | 75           | 3,6             |
| 07.04. | 6348        | 6,1         | 87             | 46                          | 7                     | 767                         | 50           | 6,3             |
| 08.04. | 6356        | 7,7         | 83             | 53                          | 7                     | 767                         | 67           | 5,2             |
| 09.04. | 6371        | 15,2        | 0              | 1                           | 10                    | 773                         | 33           | 4,4             |
| 10.04. | 6391        | 19,8        | 24             | 2                           | 16                    | 770                         | 30           | 3,6             |
| 11.04. | 6411        | 20,2        | 4              | 2                           | 19                    | 767                         | 24           | 1,5             |
| 12.04. | 6429        | 18,4        | 59             | 24                          | 18                    | 769                         | 49           | 4,7             |
| 13.04. | 6448        | 19,3        | 68             | 10                          | 18                    | 764                         | 37           | 5,8             |
| 14.04. | 6463        | 15,2        | 96             | 4                           | 10                    | 767                         | 26           | 7,1             |
| 15.04. | 6479        | 15,6        | 85             | 19                          | 13                    | 761                         | 48           | 6,9             |
| 16.04. | 6497        | 17,8        | 35             | 8                           | 21                    | 758                         | 34           | 6,5             |
| 17.04. | 6509        | 11,7        | 92             | 50                          | 14                    | 758                         | 52           | 3               |
| 18.04. | 6521        | 12,3        | 73             | 54                          | 9                     | 760                         | 43           | 6,2             |
| 19.04. | 6532        | 10,2        | 79             | 53                          | 8                     | 763                         | 45           | 6,4             |
| 20.04. | 6539        | 6,6         | 88             | 89                          | 7                     | 757                         | 68           | 7,3             |
| 21.04. | 6549        | 9,1         | 97             | 66                          | 6                     | 763                         | 58           | 5,8             |
| 22.04. | 6558        | 8,7         | 95             | 6                           | 8                     | 767                         | 47           | 3,1             |
| 23.04. | 6578        | 20,5        | 63             | 2                           | 16                    | 763                         | 41           | 4,3             |
| 24.04. | 6599        | 20,8        | 37             | 4                           | 20                    | 761                         | 32           | 3,1             |
| 25.04. | 6615        | 16,5        | 26             | 3                           | 21                    | 761                         | 30           | 2,3             |
| 26.04. | 6634        | 18,3        | 57             | 8                           | 21                    | 758                         | 33           | 2,7             |
| 27.04. | 6647        | 13,2        | 46             | 8                           | 21                    | 758                         | 37           | 2,8             |
| 28.04. | 6667        | 19,9        | 60             | 15                          | 25,1                  | 729                         | 29           | 5               |
| 29.04. | 6672        | 5,2         | 99             | 94                          | 7                     | 762                         | 67           | 6,5             |
| 30.04. | 6691        | 19,1        | 67             | 3                           | 14                    | 764                         | 44           | 1,8             |

The experimental study was conducted, the obtained results were statistically processed. The functional dependence of generating electricity on meteorological parameters was identified, namely, cloudiness, probability of precipitation, air temperature, atmospheric pressure, humidity and wind speed [4, 10].

According to the results, the amount of obtained energy substantially depends on the indexes of cloudiness and humidity. However, there is no direct relationship with the indices of atmospheric pressure and wind speed. Somewhat less dependence is observed on air temperature and probability of precipitation. Based on the gained data, the curves of dependence of power generation with the help of light-absorbing panel on weather conditions were built, the functional dependence of power generation on the cloudiness in the area conditions of Ivano-Frankivsk were obtained (figure 3) and also the functional dependence of electricity generation by photovoltaic panels on relative air humidity for the area conditions of Ivano-Frankivsk was got (figure 4).
Figure 3. The functional dependency of electricity generation by the photovoltaic panels on the level of cloudiness in Ivano-Frankivsk

Figure 4. The functional dependency of electricity generation by the photovoltaic panels from the level of humidity in Ivano-Frankivsk

4. Methodology of assessment of SPP impact upon the environment

The assessment of the magnitude and significance of the impact on the environmental components is usually carried out in three phases:

Stage 1: Determination of first-line effects (screening);
Stage 2: Development of a complex of mitigation measures;
Stage 3: Evaluation of residual effects [2, 3].

The suggested method concerns the determination of the significance of the residual effects of renewable energy, in particular solar power plants, on the environment and is carried out after screening and mitigation measures. Due to the fact that the impact of many factors influencing the natural and socio-economic environment cannot be quantified, a rating method of impact assessment is proposed, which allows comparing different types of impacts using the matrix method. The methodology is based on the three specified parameters of influence: spatial, temporal and intensity of influence. The assessment of the impact is carried out on individual components of the environment, taking into account the normal operation of the facility and the probable emergency situations.

4.1. Methodology of environmental impact assessment

Assessment of impacts upon the environment is carried out according to individual components: climate and microclimate, air environment, geological environment, aquatic environment, soils, flora and fauna, protected objects [5].

The procedure for determining the significance of impacts on the environment. The significance of the impact is estimated by such parameters as spatial scale, time scale and intensity. The comparison of the significance values for each parameter is estimated according to the developed scales suggested in Tables 2-4.

For the natural environment, no effect is taken into account, as any activity will have an impact on the natural environment. Zero effect will only be in the absence of planned activities.

Table 2. Scale for estimating the spatial scale (area) of impact on the natural environment

| Gradation       | IITK                  | Spatial boundaries of impact (km²)       | Grade |
|-----------------|-----------------------|------------------------------------------|-------|
| Spot            | Facies, tracts        | Impact area up to 1 km²                  | 1     |
| Local           | Groups of tracts, terrain | Impact area up to 10 km²               | 2     |
| Local           | Landscape             | Impact area from 10 up to до 100 km²    | 3     |
| Regional        | Landscape Districts, Provinces | Impact area more than 100 km² | 4     |
Table 3. Scale of estimation of time scale (duration) of impact on the natural environment

| Gradation       | Time scale (duration) of impact                                      | Grade |
|-----------------|---------------------------------------------------------------------|-------|
| Short-term      | less than 3 months                                                  | 1     |
| Medium-term     | from one season (more than 3 months) up to one year                 | 2     |
| Long-term       | over a long period (more than 1 year but less than 3 years) usually| 3     |
| Long-lasting    | covers the time frame of construction                               |       |
| (permanent)     | more than 3 years                                                   | 4     |

Table 4. The scale of the intensity of the impact on the natural environment

| Gradation   | Description of impact intensity                                      | Grade |
|-------------|---------------------------------------------------------------------|-------|
| Minor       | Changes in the natural environment do not exceed the existing limits| 1     |
|             | of natural variability                                               |       |
| Weak        | Changes in the natural environment go beyond the limits of natural   | 2     |
|             | variability, the natural environment is completely self-healing.     |       |
| Moderate    | Changes in the natural environment, which exceed the limits of natural| 3     |
|             | variability, violate the individual components of the natural        |       |
|             | environment. The natural environment retains the ability to self-     |       |
|             | healing                                                             |       |
| Considerable| Changes in the natural environment result in significant damage to   | 4     |
|             | the components of the environment and/or ecosystems. Separate        |       |
|             | components of the natural environment lose their ability to self-     |       |
|             | healing                                                             |       |

The significance of the impacts is an integrated (integral) estimate. Determination of significance of influence is carried out in several stages.

Stage 1. To determine the significance of the impact on the individual components of the environment, it is necessary to use Tables 2-4 with the criteria of impact. Significance of impact (type of activity) on the i-th component of the environment is determined as follows:

\[ Q_{i}^{nat} = Q_{i}^{tnat} \cdot Q_{i}^{snat} \cdot Q_{i}^{jnat} \]  

(1)

where:
- \( Q_{i}^{tnat} \) - A grade of time impact on the i-th component of the natural environment;
- \( Q_{i}^{snat} \) - A grade of spatial impact on the i-th component of the natural environment;
- \( Q_{i}^{jnat} \) - A grade of impact intensity on the i-th component of the natural environment.

Stage 2. The category of significance is determined by the interval of values depending on the grade, obtained in the calculation, as shown in Table 5.

| Spatial scale | Time scale    | Impact intensity | Categories of significance |
|---------------|---------------|------------------|---------------------------|
| Spot 1        | Short-term 1  | Minor 1          | 1-8                       |
| Local 2       | Medium-term 2 | Weak 2           | 9-27                      |
| Territorial 3 | Long-term 3   | Moderate 3       | 28-64                     |
| Regional 4    | Long-lasting 4| Significant 4    |                           |

Table 5. Categories of significance of impacts on the natural environment
The significance categories are the same for different components of the natural environment and can be compared with the identified component of the environment that is most affected.

Categories of significance are determined for all components of the natural environment. If the significance of the influence determined for a particular component of the natural environment (atmospheric air, animal world, etc.) is the only one, it is directly used to assess the resulting significance of the effect. However, in practice, one component of the natural environment can be influenced by different sources (activities), then the integrated (average) assessment of the significance of the impact on the i-th component of the environment will look like:

$$Q_{int}^{nat} = \frac{\sum_{k=1}^{n} Q_{ki}^{nat}}{n}$$

where: $Q_{ki}^{nat}$ - integrated grade of k-th impact (type of activity) on the i-th component of the natural environment; n - Number of influences (activities) on the i-th component of the environment.

4.2. Methodology for assessing impacts on the socio-economic environment

The assessment of the impact on the socio-economic environment as well as on the natural environment is carried out by separate components. Table 6 presents the composition of the socio-environmental components that can be considered in the process of assessment of the impact on the socio-economic environment from SPPs.

**Table 6. Components of the socio-economic environment**

| Components of the social environment | Components of the economic environment |
|--------------------------------------|----------------------------------------|
| Safety and health of the population  | Employment                              |
| Recreational resources               | Land use                                |
| Historical and cultural resources    | Saving organic fuel                     |
| Communal Infrastructure              | ...                                     |
| Transport                            |                                        |
| Waste                                |                                        |

The procedure for determining the significance of impacts on the socio-economic environment. Significance of influence is estimated by parameters of spatial, temporal scale and intensity scale. To assess the whole set of consequences of the planned activity on the social and economic conditions, a 4-level gradation with 1 to 4 points is accepted, with a negative and positive sign, both negative and positive factors of influence are ranked. Unlike the natural environment, there can be zero impact if negative effects are compensated by the same level of positive effects.

Each grading of influence on the components of the socio-economic environment is determined by the relevant criteria in Tables 7-9.

**Table 7. Scale of estimation of the spatial scale (area) of influence on the socio-economic environment**

| Gradation           | Criterion                                   | Grade |
|---------------------|---------------------------------------------|-------|
| Zero effect         | no impact                                   | 0     |
| Spot impact         | the impact is felt on the site of the object| 1     |
| Local influence     | the impact is felt on the territory of adjacent settlements | 2     |
| Territorial influence | the impact is felt on the territory of one or more administrative districts | 3     |
| Regional influence  | the impact is felt on the territory of the region | 4     |
Table 8. The scale of the intensity of the impact on the socio-economic environment

| Gradation             | Criterion                                | Grade |
|-----------------------|------------------------------------------|-------|
| Zero impact           | no impact                                | 0     |
| Short-term impact     | less than 3 months                       | 1     |
| Medium-term impact    | from one season (more than 3 months) up to one year | 2     |
| Long-term impact      | over a long period (more than 1 year but less than 3 years) | 3     |
| Long-lasting (permanent) impact | more than 3 years             | 4     |

Table 9. The magnitude of the intensity of impact on the socio-economic environment

| Gradation             | Criterion                                | Grade |
|-----------------------|------------------------------------------|-------|
| Zero effect           | no impact                                | 0     |
| Insignificant influence | positive and negative deviations in the socioeconomic environment correspond to existing fluctuations of the variability of this indicator before the implementation of the project | 1     |
| Weak influence        | positive and negative deviations in the socio-economic environment outweigh the existing trends in changing living conditions in settlements | 2     |
| Moderate influence    | positive and negative deviations in the socio-economic environment exceed the existing conditions of the middle-level level | 3     |
| Significant influence | positive and negative deviations in the socio-economic environment outweigh the existing conditions of the medium-regional or inter-regional level | 4     |

Integral assessment of the impact on the socio-economic environment consists of three stages.

Stage 1. To determine the significance of the impact on the individual components of the socio-economic environment, it is necessary to use the tables of the criteria for the effects of Tables 7 - 9.

Significance of influence (type of activity) on the i-th component of the socio-economic environment is determined as follows:

$$Q_i^{se} = Q_i^{tse} \cdot Q_i^{sse} \cdot Q_i^{jse}$$

(3)

where:

- $Q_i^{tse}$ - A grade of time influence on the i-th component of the socio-economic environment;
- $Q_i^{sse}$ - A grade of spatial influence on the i-th component of the socio-economic environment;
- $Q_i^{jse}$ - A grade of intensity influence on the i-th component of the socio-economic environment.

Valuation points of significance are determined separately for negative and separately for positive spatial, temporal influences and intensity influences.

Stage 2. In the second stage, for each component under consideration, the integral grade is determined by summing up the complex assessment points of the significance of negative or positive influences.

Stage 3. The category of significance is determined by the interval of values depending on the score obtained during the calculation, as shown in table 10.
Categories of significance are the same for different components of the socio-economic environment and can be compared with the identified component of the socio-economic environment that is most affected.

The score obtained allows you to determine the level of influence (Insignificant, Moderate and Significant) on a specific component of the socio-economic environment.

**Table 10. Categories of significance of impacts on the socio-economic environment**

| Final grade | The final impact          |
|-------------|---------------------------|
| from +1 to +8 | Slight positive impact    |
| from +9 to +27 | Moderate positive impact |
| from +28 to +64 | Significant positive impact |
| 0           | Impact is absent          |
| from -1 to -8 | Minor negative impact    |
| from -9 to -27 | Moderate negative impact |
| from -28 to -64 | Significant negative impact |

Similarly, with an assessment of the impact on the natural environment, if the significance of the effect determined for a specific component of the socio-economic environment is the only one, it is directly used to assess the resulting significance of the impact. When acting on one component of the natural environment of various sources (types of activities), an integrated (average) assessment of the significance of the impact on the i-th component of the socio-economic environment will look like:

\[
Q_{\text{integ}}^\text{se} = \frac{\sum_{k=1}^{n} Q_{ki}^\text{se}}{n}
\]

where: \( Q_{ki}^\text{se} \) - Integrated point of k-th impact (type of activity) on the i-th component of the socio-economic environment; n - Number of influences (activities) on the i-th component of the socio-economic environment.

It is expedient to analyse the effects on certain components of both natural and socio-economic environments from different sources with the help of estimating matrices based on the matrix of Leopold. Integral (average) estimates for a particular component of the environment are used to determine the significance of the impact.

5. Conclusions
The results of experiments showed the dependence of the generation of energy by photovoltaic panels on meteorological elements of weather conditions, in particular cloudiness and humidity. At the same time, it has no direct dependence on atmospheric pressure and wind speed. The constructed maps of quantitative indicators of solar energy potential for located facilities providing renewable energy in the Carpathian region of Ukraine indicate the feasibility of introducing opportunities for using solar energy in the Carpathian region.

The method of determining the significance of the residual impacts of solar power plants on the environment and the socio-economic environment is proposed. It is performed after screening and mitigation measures. Due to the fact that the influence of many factors influencing the natural and socio-economic environment cannot be quantified, a ball method of impact assessment is proposed, which allows comparing different types of impacts using the matrix method. The methodology is based on the three specified parameters of influence: spatial, temporal and intensity of influence. The impact assessment is carried out on selected components of the environment, taking into account the
normal operation of the facility and probable emergencies: climate and microclimate, air environment, geological environment, water environment, soils, flora and fauna, protected objects.

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