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Assessment of the possibility of using solar radiation in the Starachowice urban agglomeration

Abstract. *The research concerned the identification of the possibility of using solar radiation as a source of electricity, taking into account the current infrastructural capabilities of the agglomeration. To carry out this task, weather stations of the WH 2600 type with an Internet protocol allowing real-time data visualization and also data archiving and export in the desired frequency regime were selected. The weather stations were equipped with a wind vane, wind speed sensor, solar panel, temperature and humidity sensor, UV sensor, light sensor, rain sensor. Estimation of measurement uncertainty was carried out based on an in-laboratory experiment. It was noted that there was no significant variation within the mean values of solar radiation, while spatially the variation in solar radiation values within the analyzed agglomeration exceeded 50%.*

Streszczenie. *Badania dotyczyły określenia możliwości wykorzystania promieniowania słonecznego jako źródła energii elektrycznej, z uwzględnieniem aktualnych możliwości infrastrukturalnych aglomeracji. Do realizacji tego zadania wybrano stacje meteorologiczne typu WH 2600 z protokołem internetowym umożliwiającym wizualizację danych w czasie rzeczywistym, a także archiwizację i eksport danych w pożądanym reżimie częstotliwości. Stacje pogodowe zostały wyposażone w wiatrowskaz, czujnik prędkości wiatru, panel słoneczny, czujnik temperatury i wilgotności, czujnik UV, czujnik światła, czujnik deszczu. Oszacowanie niepewności pomiaru przeprowadzono na podstawie eksperymentu laboratoryjnego. Stwierdzono brak istotnego zróżnicowania w obrębie średnich wartości promieniowania słonecznego, natomiast przestrzennie zróżnicowanie wartości promieniowania słonecznego w obrębie analizowanej aglomeracji przekraczało 50% w stosunku do wartości maksymalnej. (**Ocena możliwości wykorzystania promieniowania słonecznego w starachowickiej aglomeracji miejskiej**).*

Keywords: solar radiation, energy, renewable energy sources.
Słowa kluczowe: promieniowanie słoneczne, energia, odnawialne źródła energii.

Introduction

Since around 2000, the rate of appearance of new photovoltaic installations in the world began to accelerate rapidly, and in 2015, the total capacity located in this technology was estimated at 220 GW. According to data released by the International Renewable Energy Agency (IRENA), as early as 2050 this number could exceed 4,500 GW [1]. The EU-28 countries produced 134 TWh of energy from the sun in 2020. Most in Germany (49 TWh), Italy (26 TWh), Spain (15 TWh) and France (13 TWh). In Poland, almost 2 TWh of electricity came from solar energy in 2020. However, if we consider the share of solar energy in the total electricity produced, the first place in EU countries is held by Malta (11.3%). Outside the southern European countries, Germany is in first place (10.7%). Poland obtained 1.5 percent of its electricity from photovoltaic sources in 2020, which is seven times higher than in 2018 [2]. Identifying the spatial variation of solar radiation potential is an important issue when planning photovoltaic investments in urban spaces, where there are additional technical and legal constraints. Matuszko et al. [3] presented the sunshine and insolation of Cracow in terms of the suitability of the city's solar conditions for helioenergy, identifying variations in the amount of solar energy reaching the earth's surface of the agglomeration in question. Other studies on the structure of solar energy use in cities were carried out by [4] using the SHORTWAVE-C model to estimate the level of solar radiation found the model to be correct and identified three key factors, i.e. height and density of buildings and roof construction) determining the efficiency of solar energy use in the city. In the case of a simulation of the solar energy potential of an urban development in Nagpur, India [5], six hours of sunlight were considered and it was identified that 85% of the roof area allows the installation of photovoltaic panels. Analysis of the density and geometry of buildings alone showed their significant impact on the spatial distribution of solar radiation and the surrounding space [6]. Freitas [7] reviewed the models used to generate solar maps identifying many limitations that are related to the spatial detail of the input data (atmospheric pollution, ozone, water press, optical depth of air. The analysis of the operation of solar power plants itself has been the subject of inquiry by many researchers analyzing its performance over a multi-year period [8,9]. It should be emphasized that despite many studies, there is still a need to empirically verify the structure of solar energy in a given urban area. Another element that should be taken into account for such an estimate is the formal possibilities of using the roof of a building for such an installation. Thus, the form of ownership cannot be ignored, which will determine the investment in a way that may not be economically, socially , or environmentally rational. In the case under review, all factors were taken into account and the location of the measuring stations was adequate to the investment approvals for solar energy acquisition.

Material and methods

The research concerned the identification of the variation of possibilities of using solar radiation as a source of solar energy, taking into account the current infrastructural capabilities of the Starachowice metropolitan area. To carry out this task, weather stations of the WH 2600 type with an Internet protocol allowing real-time data visualization and also data archiving and export in the desired frequency regime were selected. The weather stations were equipped with a wind vane, wind speed sensor, solar panel, temperature and humidity sensor, UV sensor, light sensor, rain sensor. The technical specifications of the weather station allowed for: Open-air transmission range: 100 m, frequency: 433 MHz/868 MHz/915 MHz, temperature range -40°C - 60°C (accuracy + / - 1°C, resolution 0.1°C), relative humidity measurement range 1% ~ 99% (accuracy +/- 5%), rainfall indication 0 - 9999 mm (accuracy + / - 10%, resolution 0.3 mm (at vol. <1000 mm) and 1 mm (at vol. > 1000 mm), wind speed 0 - 50 m/s (accuracy + / - 1 m/s - wind speed<5 m/s, +/- 10 m/s - wind speed > 5 m/s), light 0 - 400 kLux (accuracy +/- 15%).

After a site visit, locations were identified where it was possible to install weather stations and the geometry of the deployment space of the stations in question allowed the use of standard methods of spatial interpolation of data. The outline of the weather stations was more than 18 km and was an irregular polygon, the sides of which had varying lengths (Fig.1).

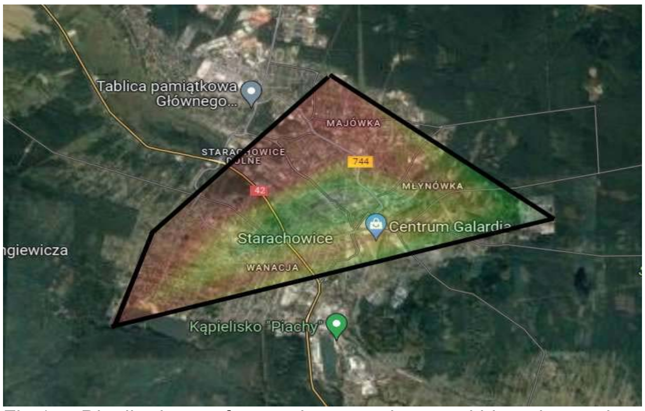

Fig.1. Distribution of weather stations within the urban agglomeration and a view of the activity status of the installed stations

The installed weather stations were integrated with the Internet, which allowed 24-hour monitoring of weather signals in the form of graphs or tables (Fig. 2).

Fig.2. Screen view of the computer application with graphics of the measured quantities

Results

The analysis included a one-year measurement cycle from which one day was selected for the article. Solar energy values were averaged for one-hour intervals. Solar energy was measured simultaneously at all installed weather stations at a frequency of 1 Hz. Figure 3 shows the values of solar intensity averaged for all measurement stations for one-hour time intervals. There was quite a large variation of possible solar energy within the urban agglomeration constituting the study area, the nature of which varied depending on the time of day. The highest average value of solar irradiance of 506 W/m^2 was recorded between 1pm and 2pm, the variation in value between measurement points expressed by the standard deviation of which was 119 W/m^2. It should be noted that the pre-monsoon and post-monsoon variation of variation within similar values of average solar irradiance was higher in the afternoon compared to the pre-monsoon hours of the measurement day.

Figure 4 shows the characteristics of solar energy potential for selected measurement points during the measurement cycle. Significant variation was found between the potential solar energy production at individual measurement points of the studied agglomeration. In the first hours of the measurement, significantly higher values of solar irradiance could be obtained in the northwestern part of the agglomeration (ISTARA 37), while in the following hours the highest values of solar irradiance exceeding even 600 W/m^2 were recorded in the southwestern (ISTARA 40) and southeastern (ISTARA 34) parts of the studied agglomeration. A similar trend of variation continued until the end of the measurement day.

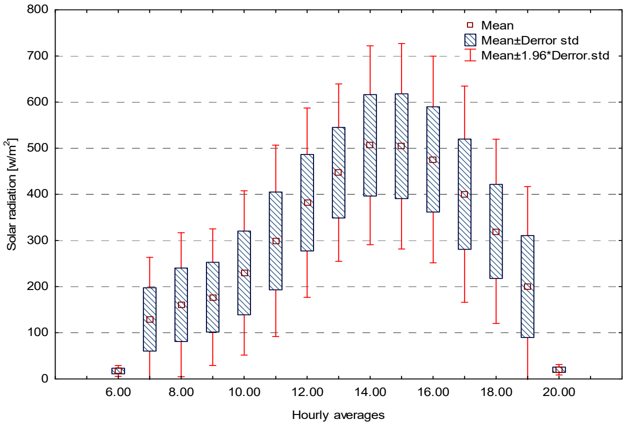

Fig.3. Variation of the intensity of solar radiation measured within the Starachowice urban agglomeration.

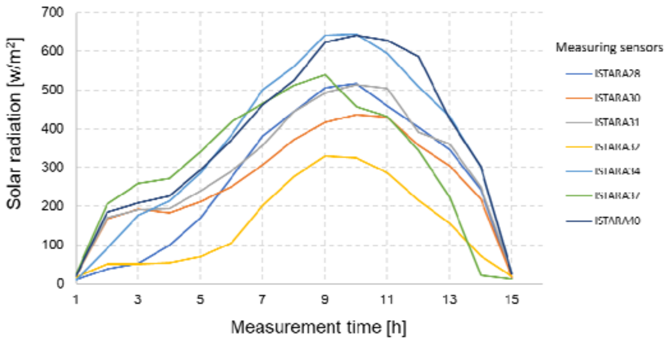

Fig.4. Characteristics of the course of solar energy heights recorded by individual measuring stations located in the analyzed agglomeration.

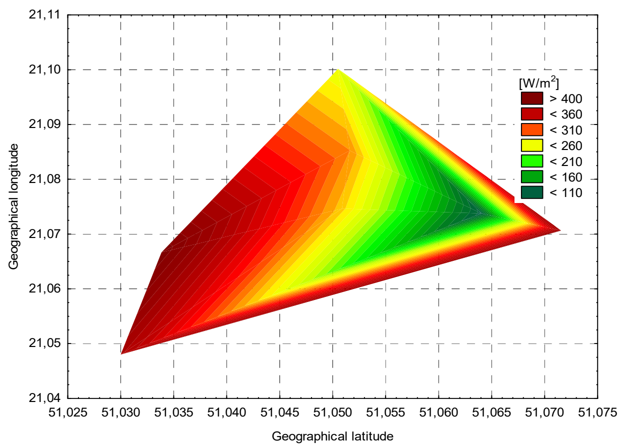

Fig.5. Spatial variation of the magnitude of solar radiation intensity within the urban agglomeration measured between 10 a.m. and 11 a.m.

Analyzing the distribution of solar irradiance, it was noted that the most unfavorable conditions in terms of solar energy production potential occurred in the central-eastern part of the agglomeration, where, at the highest insolation, the value of solar irradiance was 328 W/m^2, which was twice less than the value of solar irradiance obtained in other parts of the studied agglomeration. It was observed that the spatial variation of the intensity of solar radiation recorded as an arithmetic mean between 10 and 11 a.m. was characterized by the fact that the highest values exceeding 400 W/m^2 were found in the western part of the agglomeration, and the lowest values amounting to about 110 W/m^2 in the central and eastern parts of the studied agglomeration (Fig. 5).

A similar characteristic of the spatial variation in the intensity of solar radiation was recorded between 11 and 12 o'clock (Fig. 6). It should be noted in this case that the relative variation in solar intensity was much smaller in relation to its average value recorded over the time interval between 10 o'clock and 11 o'clock.

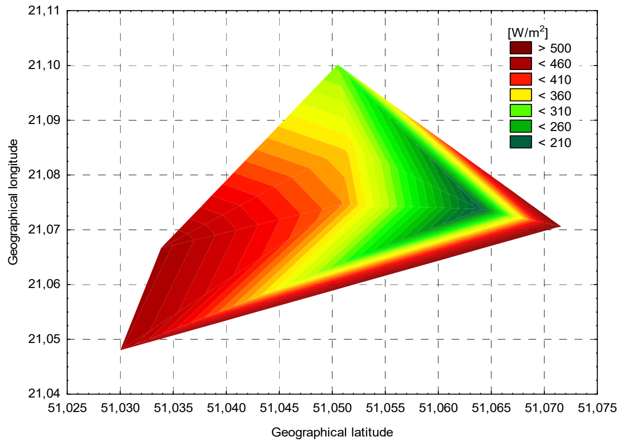

Fig.6. Spatial variation of solar irradiance within the urban agglomeration measured between 11 a.m. and 12 p.m.

At noon, the characteristics of spatial differentiation of solar irradiance began to change, and between 2 and 3 pm the highest values of solar irradiance exceeding 600 W/m^2 were recorded mainly in the southwestern part of the study area (Fig.7). The lowest values of solar irradiance not exceeding 330 W/m^2 were recorded in the central eastern and northern parts of the studied agglomeration.

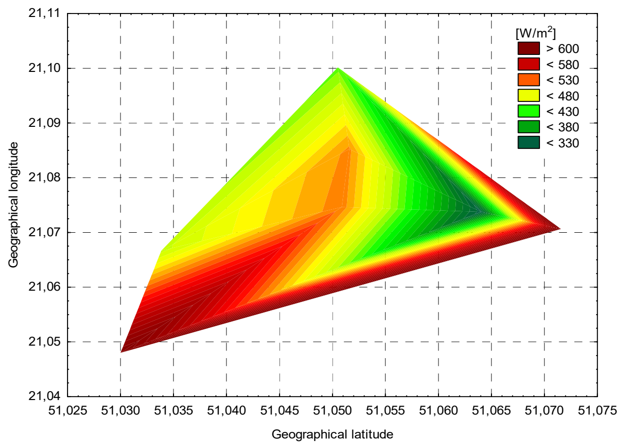

Fig.7 Spatial variation of solar irradiance within the urban agglomeration measured between 2 p.m. and 3 p.m.

In the next hour, a widening area of low solar irradiance (about 290 W/m^2) was observed toward the center of the agglomeration (Fig.8). The highest values of solar radiation intensity exceeding 600 W/m^2 continued to be recorded in the northern part of the studied agglomeration. It should be noted that the variation in the intensity of solar radiation increased and in absolute values amounted to more than 310 W/m^2.

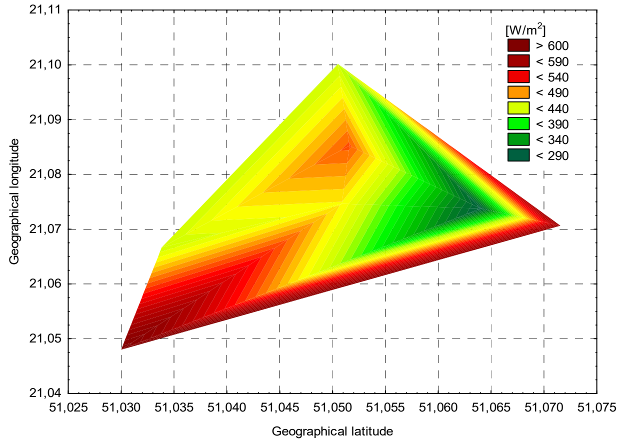

Fig.8. Przestrzenne zróżnicowanie wielkości natężenia promieniowania słonecznego w obrębie aglomeracji miejskiej mierzone między godziną 15 a godziną 16

Figure 9 shows the variation of solar irradiance between 4 pm and 5 pm, the spatial variation of which was similar to that shown in Figure 8. The highest solar irradiance of more than 550 W/m^2 was recorded in the southwestern part of the analyzed area, while the lowest solar irradiance of less than 220 W/m^2 was recorded in the southeastern part of the studied agglomeration.

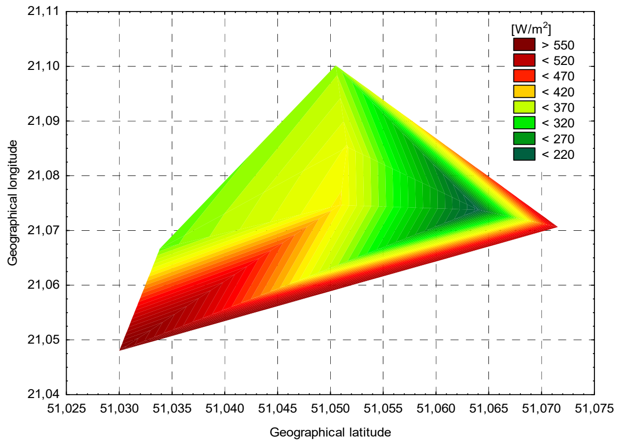

Fig.9. Spatial variation of solar irradiance within an urban area measured between 4 p.m. and 5 p.m.

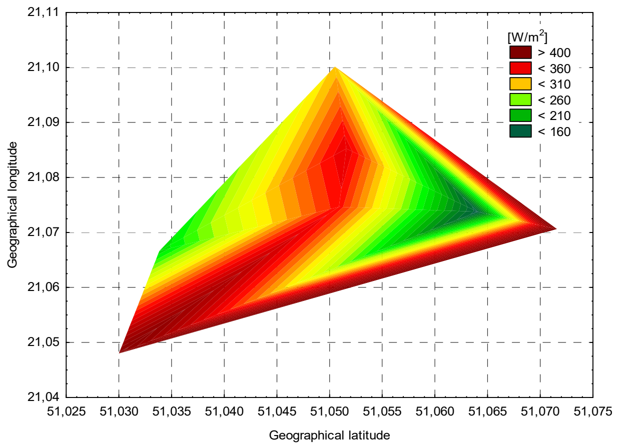

Fig.10. Spatial variation of the magnitude of solar radiation intensity within the urban area measured between 5 p.m. and 6 p.m.

In the afternoon, the variation in the spatial distribution of solar energy (Fig.10) was of a different nature from the aforementioned, where the highest values were recorded exceptionally in the central part of the area under study and in the northwestern part of the agglomeration under study.

Figure 11 shows the intensity of solar radiation as average values from the time interval from 7 pm to 8 pm.

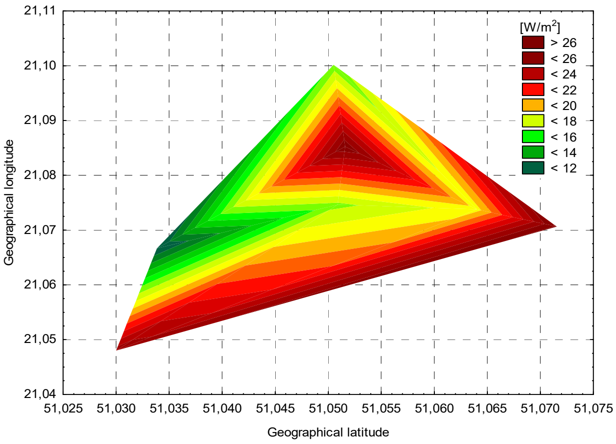

Fig.11. Spatial variation of solar energy volume within an urban area between measured between 7 p.m. and 8 p.m.

Information on the variation of solar conditions allows the use of different technical solutions [10-14], which can be adapted to the prevailing light conditions thus obtaining better efficiency. This is especially true for the time of day when light conditions are not maximal, i.e. the morning hours and evening hours of the analyzed agglomeration.

Conclusion

Significant spatial variation in the values of radiation intensity was found, which can be used in the current ownership and urbanization conditions. Differences in the average values of solar irradiance between measurement points distributed within the studied agglomeration were as high as 300 w/m2. This means that within a relatively small study area, the recorded intensity of solar radiation differed by as much as two times. Thus, there is a need to use different technologies for the selection of photovoltaic panels in urbanized space with different forms of ownership in order to make optimal use of the available potential of solar radiation energy. A helpful factor in reducing the costs of such optimization may be the creation of a dedicated numerical model based, for example on BEM (Boundary Elements Method), which has already proven its worth in several different applications [15-16].

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