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GIS-BASED ASSESSMENT OF THE FEASIBILITY OF SOLAR ENERGY APPLICATIONS, IN THE CASE OF ŁAZY VILLAGE

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Summary

The aim of the study was to evaluate the potential of solar plots in Łazy village, located in the municipality of Jerzmanowice-Przeginia, in terms of suitability for the construction of solar power plants of 4 different sizes: large, medium, small and micro. As a part of the study, the modelling of solar radiation and spatial analyses were performed, using the ArcMap 10.3.1 and QGIS 2.8.1. Wien software. The entire test area was divided into 4 classes, according to the insolation potential. The end result consists of maps showing the land with best prospects for solar investments. We have also presented the evaluation of the possibility for obtaining solar energy via photovoltaic panels located on the roofs. Within the village of Łazy, we have identified 63% of the parcels, of which at least 80% enjoy good or very good solar conditions, that is to say, during the year, the solar radiation for these places exceeds 960 kWh · m^{-2}.

Keywords

modelling of solar energy • GIS • photovoltaics (PV)

1. Introduction and aims of the study

Traditional methods of obtaining electricity will soon be exhausted, because the supply of minerals is limited. Furthermore, the production of energy from such raw materials is becoming increasingly expensive, and remains disadvantageous to humans, as large quantities of dust and harmful gases escape to the atmosphere during its production. Thus the growing demand for the proliferation of alternative methods of obtaining energy. Among the latter, the most common is solar energy. It is ubiquitous, inexhaustible and free. The surface of Poland is reached by approx. 1000 kWh · m^{-2} · year^{-1}. Compared to the rest of Europe, this is an average result, however it is completely sufficient for the acquisition of solar energy to be profitable [Kołodziej and Matyka 2012].

In addition, energy received from solar radiation is environmentally friendly, and its production does not emit any harmful gases. CO_2 reductions have already been imposed on the EU Member States, and by 2020, the emissions are to be reduced by about 30% [Dyrektywa… 2009]. The development of alternative sources of energy is therefore an extremely important aspect for us, as currently in Poland, the most energy is produced from coal. During the combustion of the latter, large quantities of carbon dioxide and particulate matters are emitted. This has had a heavy impact on the city of Krakow and the surrounding villages, where air pollution norms are frequently exceeded [www.radiokrakow.pl 2016]. Therefore, we should aim at the fullest possible use of alternative energy sources.

Using the solar energy, we can produce both electricity and heat. Electrical energy is obtained by means of photovoltaic panels [Chaar et al. 2011], while the heat energy is obtained from solar collectors [Rylatt et al. 2001]. The energy use of these devices, however, depends largely on the insolation, and therefore it is very important to choose a suitable location for the construction of solar energy installations [Sabo et al. 2016].

In order to determine the best places, reached by the most solar energy, we carry out the modelling of solar radiation, which can be performed for each and any area on Earth, provided that we have the right model and data set [Wong 2016, Brewer 2015].

The aim of the present study was to:

- prepare maps showing the variability of solar radiation in time, within the studied area,
- check the suitability of the plots within the village of Łazy with the view to the construction of solar power plants in 4 different sizes: large, medium, small, and micro,
- assess the possibility of obtaining solar energy through photovoltaic panels, which can be located on the roofs in the village of Łazy.

2. Methodology

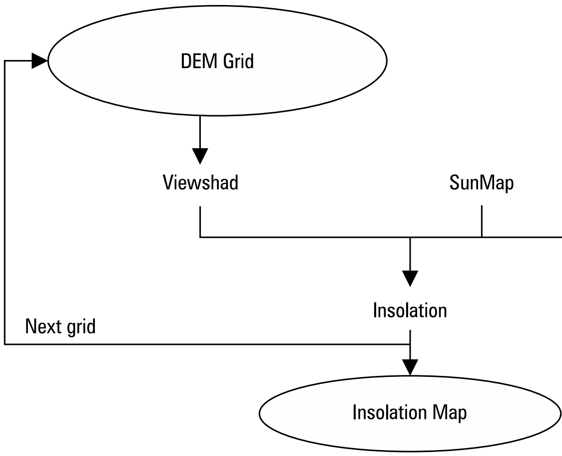
The basic primer used for the analyses was a digital terrain model (DTM) with a resolution of 30 m, that is, one pixel in the field has dimensions of 30 m × 30 m. The DTM has been downloaded from the http://earthexplorer.usgs.gov (accessed 12.2015).

Then, using the ArcMap 10.3.1 software and its available tool of "Area Solar Radiation", we have drawn maps of annual and monthly totals of solar radiation.

The modelling of solar radiation was performed using the algorithm adapted for the GIS by P. Rich [1994]. In its operation, the algorithm takes into account the exposure of the area, the relative heights, the gradients, the veiling (shadowing) of the horizon, the diffuse reflection factor and the degree of transparency, among other factors. The result is calculated based on a digital terrain model for each pixel separately (Figure 1) [Wojkowski 2007].

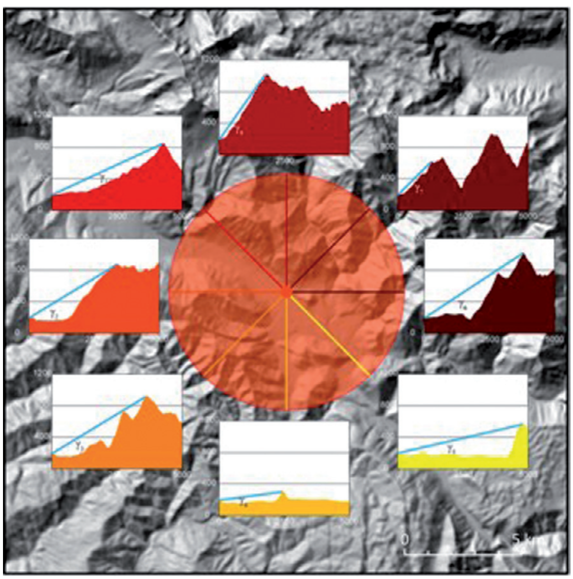
Map of the veiling of the horizon (Viewshad) was established by determining, for each point, the vertical angle in 32 geographical directions; and on that basis, by creating the lines of the veiling (shadowing) of the horizon (Figures 2, 3).

By applying astronomical formulas, a map is created showing the position of the Sun (SunMap) consisting of sectors representing the position of the Sun every half hour for the day (east-west axis in the figure), and in monthly intervals for the year (north-south axis in the figure). The map is drafted in the same system as the map of the veiling (shadowing) of the horizon, and therefore the two can be superimposed on one another, thus presenting the actual journey of the Sun across the horizon during the day, and throughout the year, at a given point. We thus obtain information about direct radiation. The colours used are only intended to illustrate the multiplicity and diversity of sectors (Figure 4).



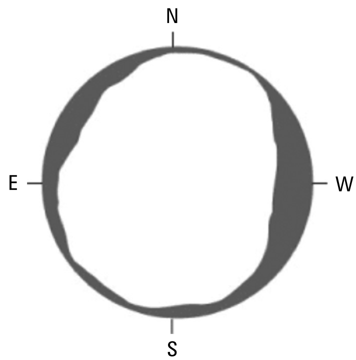
Source: [Stachura 2009]

Fig. 1. Algorithm for the calculation of solar radiation



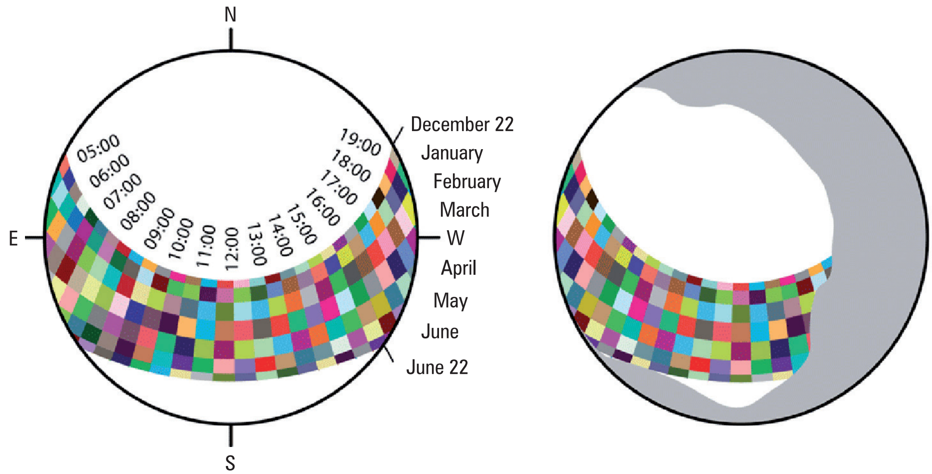
Source: http://iaps.zrc-sazu.si/en/svf#v

Fig. 2. Horizontal angles



Source: ArcGIS 10.3.1 Help

Fig. 3. Map of the veiling (shadowing) of the horizon

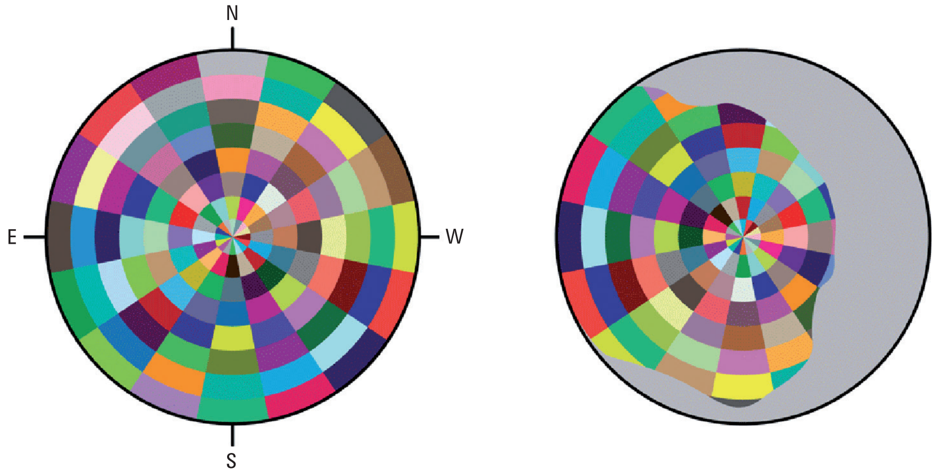


Source: http://www.esri.com/news/arcuser/0309/solar.html

Fig. 4. The map of Sun's position, featuring the veiling (shadowing) of the horizon

The map of the sky sectors (SkyMap) is obtained by dividing the hemisphere of the sky above the horizon into 16 azimuth sectors and 8 zenith districts (Figure 5). It provides us with information about the diffused radiation. Quantitative parameters of the sectors can be freely changed in the software. In the present analysis, 8 azimuth divisions and 8 zenith divisions were introduced.

Other parameters may also be subject to change. The following are the parameters used in the ArcMap for the purpose of analysing the sum of total solar radiation in 2014. These include: latitude, resolution, the period of analysis, hourly interval, Z axis multiplier, the number of geographical directions, in which the angle of the veiling of the horizon will be measured, the number of zenith and azimuth sectors, as well as diffuse reflection factor and transparency factor (Table 1).



Source: http://www.esri.com/news/arcuser/0309/solar.html

Fig. 5. Map of sectors of the sky, featuring the veiling (shadowing) of the horizon

Table 1. Parameter used for calculating solar radiation totals

Data entered into the ArcMap software	
Resolution	**200**
The period of analysis	Whole year, in monthly intervals
Data	Year 2014
Topographical parameters	
Z axis multiplier	1
The number of geographical directions	32
Radiation parameters	
The number of zenith sectors	8
The number of azimuth sectors	8
Diffuse reflection factor	0.3
Transparency factor	0.3

2.1. Classes of insolation potential

In order to assess the suitability of different areas for the construction of solar power plants most effectively, it was decided that the studied village should be subjected to a detailed valuation. The subdivision of the area into the so-called classes of insolation potential was introduced, based on the elaboration by Stachura [2009]. The method assumes that the energy obtained from photovoltaic panels would be used by the device found in every home, and working on a continuous basis – in this case, a refrigerator. The average power consumption of the latter was rated at 3.3 kW. Then, the sum of daily solar radiation was divided by the daily power demand, which produced the value of the ratio, showing the coverage of the demand for electricity. In this manner, six grades were set, from A to F (Table 2).

Table 2. Classes of insolation potential according to Stachura [2009]

Classes of insolation potential	Description of the insolation potential class	Value of the ratio of coverage of the demand for electrical energy	The amount of solar energy [$kW \cdot m^{-2}$]
A	Very good	≥ 1.0	> 1200
B	Above good	0.9–1.0	1080–1200
C	Good	0.8–0.9	960–1080
D	Sufficient	0.7–0.8	840–960
E	Satisfactory	0.6–0.7	720–840
F	Non-satisfactory	< 0.6	< 720

Variations have been introduced to the above method, by reducing the number of classes and changing their names, while retaining the border values (Table 3).

Table 3. Classes of insolation potential applied in the studied area

Classes of insolation potential	The amount of solar energy [$kWh \cdot m^{-2}$]
Very good (A)	> 1080
Good (B)	960–1080
Average (C)	840–960
Poor (D)	< 840

2.2. Selection of plots for the construction of a solar power plant

The analysis of suitable locations for the construction of photovoltaic installations was based on the vectorized plots, located within the village of Łazy. Then the plots were divided into 4 surface (area size) classes, depending on what type of facilities could be potentially fitted there (Table 4).The installations were divided according to the law on renewable energy sources [Ustawa… 2015]. The division is as follows:

- large solar power plants, generating capacity of more than 1MW,
- medium-sized solar power plants, generating power from 200 kW to 1MW,

- small solar power plants, with a power of 40 kW to 200 kW,
- micro power plants, with a capacity of up to 40 kW,
- In addition, for the purpose of the present study, micro-installations on roofs with the capacity up to 10 kW have been distinguished.

Table 4. Subdivision of solar installations and their areas

Subdivision of solar installations	Nominal power of the plant [kW]	Required area size [m^2]
Large	> 1000	> 20000
Medium	200–1000	4000–20000
Small	40–200	1000–4000
Micro	< 40	< 1000

It has been determined that the classes of insolation potential marked as "very good" (A) and "good" (B) are suitable for solar energy investment projects, and therefore it was decided that plots located in such areas should be selected. To this end, the QGIS 2.8.1 Wien software was used, and by applying the geo-processing tool along with the "product" function, the intersection of admissible classes (i.e. "very good" and "good") and the plots the village of Łazy was obtained.

3. Results

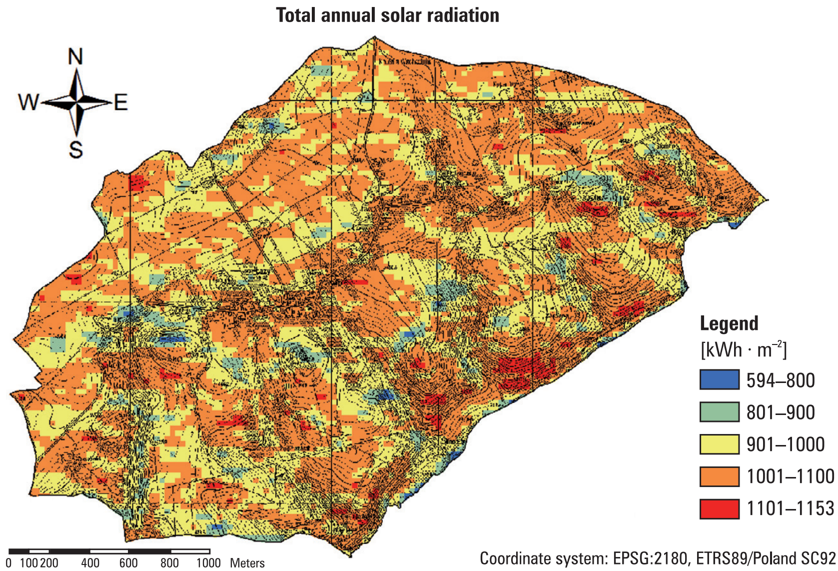
3.1. Solar radiation totals

On the basis of the solar radiation modelling, we have created a map showing spatial distribution of the annual solar radiation. In the village of Łazy, the annual amount of radiation ranges from 594 to 1153 kWh · m^{-2} (Figure 6).

We noted that the highest solar radiation in the village of Łazy was recorded in July, remaining in the range of 126.7–171.9 kWh · m^{-2}, while the smallest radiation was received in December, and ranged from 2.7 to 12.7 kWh · m^{-2} (Figure 7).

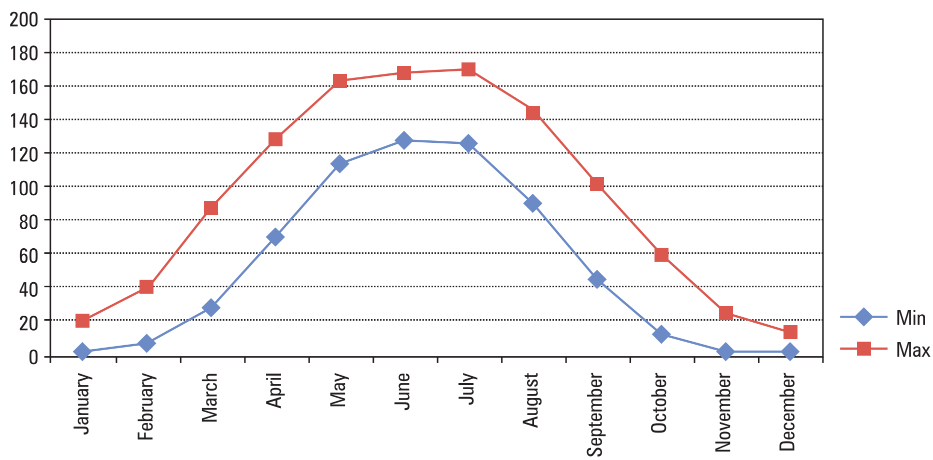
Within the Łazy village, the biggest surface is occupied by areas with "good" insolation potential class – namely, 441 ha; then, the "average" class occupies 111 ha; followed by "very good" class – occupying 33 ha; with the remaining class of "poor" only at 6 ha (Figure 8).

Overall, in the village of Łazy, there are 17 plots with area size greater than 2 hectares, which is suitable for the construction of large power plants. Also, there are 463 medium-sized plots, 579 small plots, and 152 micro plots (Figure 9, Table 5).



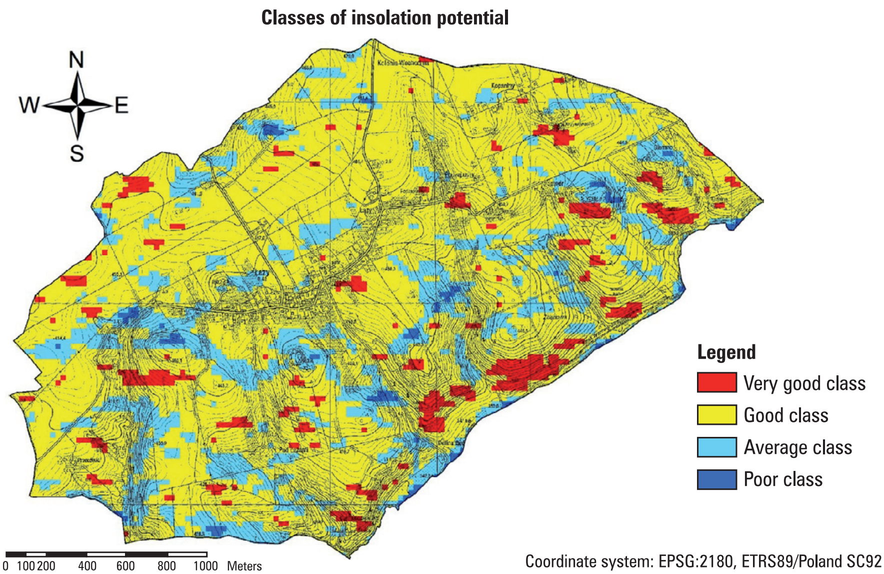
Source: author's study (M. Krzyś)

Fig. 6. Annual solar radiation



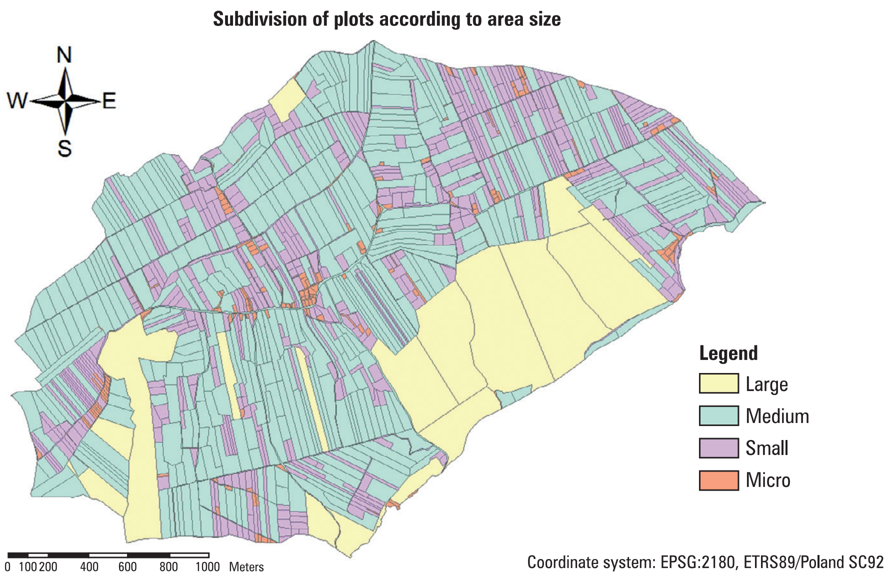
Source: author's study (M. Krzyś)

Fig. 7. Maximum and minimum monthly intervals of solar radiation



Source: author's study (M. Krzyś)

Fig. 8. Classes of insolation potential. "Very good" class when insolation exceeds 1080 kWh · m^{-2}, "good" class (960–1080 kWh · m^{-2}), "average" class (840–960 kWh · m^{-2}), "poor" class (less than 840 kWh · m^{-2})



Source: author's study (M. Krzyś)

Fig. 9. Subdivision of plots according to area size

Table 5. Subdivision of plots according to the size of the planned power plant.

	Overall	
	Number	Area size [ha]
Large	17	128.24
Medium	463	328.85
Small	579	124.57
Micro	152	9.62
Total	**1211**	**591.28**

Having performed the analysis, the plots were designated, which are located in their entirety within the areas of classes A and B, and those where at least 80% of the surface of the plot overlaps with the aforementioned classes. The construction of power plants on those parcels is the most profitable. Table 6 summarizes the quantity and the surface area of plots belonging to particular classes. Also included is the information on the annual total radiation, reaching the area of these plots. The biggest amount of radiation, that is as much as 190.07 MWh $\cdot$ year^{-1}, reaches the area of medium-sized plots, due to the fact that they occupy the largest area. The least radiation reaches the area of micro plots, and is equal to 7.56 MWh $\cdot$ year^{-1}.

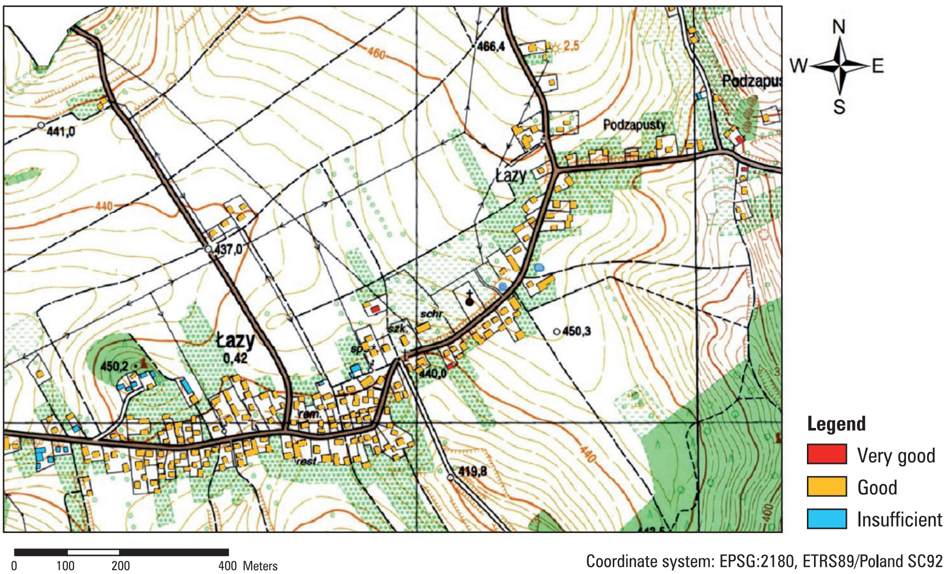
Table 6. Quantitative and area size Summary of plots, post-analysis.

	Number of plots					
	Located in their entirety within the area of insolation potential classes A and B			At least 80% located within the area of insolation potential classes A and B		
	Number	Area size [ha]	Total radiation [MWh $\cdot$ year^{-1}]	Number	Area size [ha]	Total radiation [MWh $\cdot$ year^{-1}]
Large	0	0.00	0.00	3	11.2	11.17
Medium	140	96.20	99.37	111	89.16	90.70
Small	257	56.84	58.33	85	21.37	21.51
Micro	91	6.31	6.44	16	1.13	1.12
Total	**488**	**159.35**	**164.14**	**215**	**122.86**	**124.50**

In addition, analysis was also performed of the roofs of the buildings, with the view of mounting photovoltaic panels thereon. 351 roofs in the village of Łazy have been vectorized. Then, similarly as this was done with the plots, the layer of roofs was compared to the layer of the insolation classes, thus obtaining the sets of roofs belonging in the classes described as “very good”, “good” and “unsuitable for investment.” Because, against the background of the whole village, the roofs shown on the map are poorly visible due to their small size, we decided to present only a fragment of the area, occupied by the largest number of these (Figure 10). Below we present a quantitative list (Table 7), and the percentage of roofs in each class of insolation potential (Figure 5). The vast majority, that is 88% of the roofs, lie within the area of "good" or "very good" conditions for the installation of photovoltaic panels. In 12% of roofs, micro installations would not be justified.

Table 7. Quantitative list of roofs in respective insolation potential classes

Insolation potential class of roofs	Number
Very good	19
Good	290
Insufficient	42
All	**351**



Source: author's study (M. Krzyś)

Fig. 10. Analysis of roofs with the view to the installation of photovoltaic panels

4. Conclusions

The analyses we have carried out lead us to the conclusion that, in the village of Łazy, we can find a lot of favourable sites, suitable for the construction of solar power plants of different sizes, that is, large, medium and small or micro-installations. The results we obtained may be useful for future investors.

According to the analyses we have performed, the construction of large power plants would be reasonable (i.e. with at least 80% of the area located within class A and B of the insolation potential) in 3 plots; the average-sized power plants could be installed in 251 plots; while the small ones could be fitted in 342 plots, and micro power plants in 107 plots. Micro photovoltaic installations could be justified on as many as 309 roofs.

Installations using the energy produced from solar radiation in the period between April and September present a good alternative compared to fossil fuels. Using the example of the Łazy village, we have demonstrated that there exist many attractive and indeed optimum locations for that purpose.

Inventories of solar energy are inexhaustible, and after bearing the cost of the investment, we can profit from relatively cheap energy. It is necessary, however, to bear that initial investment cost of the construction, in order to be able to enjoy the cheap – and above all – "green" energy. If funds were to be found for the construction of such power plants, we could significantly improve the quality of air, and reduce the cost of energy production in the future.

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