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The Analysis of the Main Geospatial Factors Using Geoinformation Programs Required for the Planning, Design and Construction of a Photovoltaic Power Plant

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ABSTRACT

The aim of the analysis was to carry out a detailed assessment of the site in Krościenko nad Dunajcem in terms of its suitability for the construction of a photovoltaic farm. Geospatial data and analysis of urban planning documents such as the Local Spatial Development Plan and the Municipality's Conditions Study were used. Factors such as insolation, topography, terrain, forestation and hydrological factors were studied in an attempt to understand their influence on the selection of the optimal location for a photovoltaic installation. The research material and methodology were based on the analysis of geospatial data of the area and the interpretation of urban planning documents. Tools were used to analyse spatial relationships and assess potential risks for a photovoltaic investment. The main conclusions of the research indicate that the terrain conditions in Krościenko nad Dunajcem are suitable for the implementation of a photovoltaic farm. The identification of optimal locations was based on the analysis of spatial factors, which confirms the potential of the area for efficient construction of photovoltaic installations. The conclusions of the analysis indicate that taking spatial factors into account is crucial when planning and selecting the location of a photovoltaic farm. However, it is necessary to continue monitoring environmental and technical aspects to ensure the sustainability of the photovoltaic project in the area.

Keywords: terrain, geoinformation programmes, geospatial factors, photovoltaic farm, GIS.

INTRODUCTION

The development of science and technology allows for a faster development of civilisation, and this entails an increasing demand for electricity – the most important type of energy, without which the development and functioning of mankind is impossible. In order to produce electricity, it is necessary to generate so-called transient energy (i.e. mechanical or thermal energy and then convert it into electrical energy. To be able to generate transitional energy, fuel is needed. Such fuel can be exhaustible fossil fuels (lignite, coal, oil, natural gas, radioactive ores) [Bordun, 2018], and natural resources, e.g. biomass [Ciuła et. al., 2023a], kinetic energy from water flow, wind energy, solar radiation and underground geothermal water, which are renewable energy sources. Excessive use of fossil fuels raises the prospect of their accelerated depletion, which generates threats to the country's energy security. Therefore, bearing in mind the aspect of dwindling reserves of fossil fuels [Nowak, 2023], there is a constant search for new energy carriers that would be able to meet energy needs while being the least harmful to the environment [Kochanek et. al, 2017]. Such energy carriers are renewable energy sources, which are defined in the Polish legal system, along with the rules of their operation, by the Act on Renewable Energy Sources [Journal of Laws 2015, item 47820], which implements the European Parliament's Directive on the Promotion of the Use of Energy from Renewable Sources [OJ L 140, 5.6.2009] into the Polish legal system. The definition of a renewable energy source contained in the aforementioned act is a closed set, starting with wind energy and ending with renewable hydrogen. Each type of renewable energy requires the use of appropriate equipment to convert one type of energy into another type, mechanical, electrical thermal, cooling [Lewandowski, 2012; Qazi et al., 2019; Ciuła et al., 2023b]. A key element when designing and selecting a site for a renewable energy investment is the type of energy source used. This mainly concerns the selection of the location of a given investment and, in particular, its inconvenience to the environment (biogas plants, landfills, wind power plants), the diversity of construction works (hydroelectric plants, high enthalpy geothermal, biomass boiler plants), the complexity of technological processes (biogas-to-biomethane conversion), or the required surface area and proper land (photovoltaic, wind farms) [Ligus, 2017; Gaska et al, 2023].With the above in mind, access to selected geospatial data for the selected location and the relationships between them are crucial [Kochanek, 2015, Litwin et al., 2022] when planning and designing a RES structure such as a photovoltaic farm [Piotrowska-Woroniak, 2015; Knutel et al., 2020; https://ieo.pl/; Messenger, 2020]. In the INSPIRE Directive [OJ L 108, 24.4.2007], spatial data is defined as any data that is directly or indirectly related to the determination of a given location in relation to another, or to a geographical area. Spatial data is any information that is directly or indirectly related to a place, or an area defined in space [Gaździcki 2012; Nowak, 2016; Bielecka et.al., 2018].

When the spatial analysis is properly performed [Wadowska 2023], the plot area can be correctly determined along with its dimensions. Through the use of dedicated geospatial data techniques [Izdebski, 2020], it is possible to detail the aspects necessary when planning a new construction project [Małysa-Sulińska, 2020] such as photovoltaic farms, sewage treatment plants, production halls or residential buildings [Nowak, 2016]. A very useful platform is the GIS (Geographical Information System) [Gotlib, 2008, Urbański, 2008], which allows data to be managed and analysed with extreme precision. A GIS consists of geographical data stored in a database, software and the computer hardware that supports it. The database contains all the data, stored in digital form. This platform has applications in land and building registration [Litwin et al., 2017], for processing environmental movement messages [Madi et. al., 2023; Yousif et. al., 2023, Mousawi et. al., 2023], pollution diagnosis [ZBenezzine et. al., 2022], and for processing information about the technical infrastructure of the area such as water, power and gas networks. The continuous development of computer science and technology has resulted in continuous upgrades to this platform.

Examples of such GIS software are: Grass [https://grass.osgeo.org/], SagaGis [https://saga-gis.sourceforge.io], QGIS [Iwańczak, 2016; Szczepanek, 2017;], ArcGIS [https://arcgis.com/index.html]. Each of the aforementioned software has corresponding applications that are adapted to the relevant industry. Most of the aforementioned software is free. Every year, spatial data analysis is becoming a more specialised branch of the industry and computer world due to its functions. The functionality of GIS systems is provided by programs such as map servers (WebMap), Database Management System (DBSM), Desktop GIS, Server GIS, WebGIS, Mobile GIS, among others [www.gisplay.pl,2023].

With these, it is also possible to create digital maps, analyse environmental conditions, plan infrastructure formation and many different spatial applications. A geospatial database makes it possible to store information about objects, as well as their exact location on a map. Therefore, it is possible to analyse the amount of area occupied by a given vegetation, conduct analyses to optimise activities, as well as calculate distances between selected points [Nowak, 2016].

MATERIAL AND METHODS

The aim of this study was to carry out a detailed spatial analysis of a site with a total area of 76 264 m^2, necessary for the design of a photovoltaic farm being a 300kW ground-mounted power plant. The object of research in the study was the land, and the legal and technical possibilities of computer analysis of this land, with the help of publicly available IT tools using geospatial data that qualify it or not, to be developed for the construction of a photovoltaic farm.

As research methods, an analysis of the Local Spatial Plan and field details made visible in various Spatial Information Systems applications and on various types of maps and orthophotos were used in this study. Investigations and conclusions were made with the help of available IT tools based on the available data and knowledge

in this area. The qualitative-quantitative analysis was performed on digitally available IT data sets:
- data obtained from the website of the Central Statistical Office [https://stat.gov.pl/],
- data made available by the Municipality Office in Krościenko nad Dunajcem,
- data from Geoportal [https://geoportal360.pl/],
- data from the Spatial Information System for the Municipality of Krościenko nad Dunajcem [https://sip.gison.pl/kroscienkonaddunajcem],
- data from the Polish Geological Institute [https://www.pgi.gov.pl/dane-geologiczne/geologiczne-bazy-danych.html],
- data from the Informatic System of Country Protection [https://isok.gov.pl/index.html],
- data from Forest Data Bank [https://www.bdl.lasy.gov.pl/portal/],
- data on the type of soils on the investment plot [https://miip.geomalopolska.pl/imap/].
- The following tools were used to perform the spatial factors analysis:
- web applications such as Geoportal and Geoserwis with the help of which it is possible to perform an examination of the spatial data contained in the database [Izdebski, 2020],
- QGIS computer software, which is used for various types of geographic data operations,
- CRFS computer software, with which it is possible to perform terrain profile analysis,
- PVsystem computer software, which can be used to determine whether a site is suitable for the construction of a photovoltaic system,
- SolarEdge software,
- eDrawings 2023 software,
- AutoCad 2020 software.

One of the most important legal documents at the time of planning the construction of a PV power plant is the Energy Law [Journal of Laws 1997 no. 54 item 348]. Another legal act is the Spatial Planning and Development Act [Dz.U. 2003 No. 80 item 717] and the Agricultural and Forest Land Protection Act [Dz.U. 1995 No. 16 item 78]. In order to ensure public participation in the investment process, including for renewable energy, and the transparency of the activities of all parties, there is an Act on the provision of information on the environment and its protection, public participation in environmental protection and environmental impact assessments [Dz. U. 2008 No. 199 item 122]. At the stage of each investment process, access to and proper use of geoinformation data ensures, the efficiency of these activities and reliability of the obtained results of analyses.

RESULTS AND DISCUSSION

Geospatial analyses

Analysis of the photovoltaic farm project site using geo-information programmes

A good location is particularly important when planning an investment. During the construction process of a PV power plant [Knyps, 2014], the entrepreneur most often considers the ground, the problem of shading and the direction of the slope. When selecting a location, the distance of the entire installation from the grid is also important. The shorter the distance, the easier it is to obtain connection conditions and to draw up the associated contract. The location should be planned in advance so that no problems can arise in the course of the project with obtaining administrative permits. Before the construction of the project begins, not only the terrain, but also technical and social issues must be analysed.

Geoinformation programmes provide access to spatial data bases. Thanks to them, it is possible to analyse the site using computer software belonging to the National Spatial Infrastructure [Izdebski, 2020]. All the data that was used to prepare the site analysis for the construction of a future PV power plant in Krościenko nad Dunajcem were obtained from the National Geodetic and Cartographic Resource (GIS).

On the basis of one of the geo-information programmes, the registration numbers of the future property were determined and it was established that the future investment would be located in Poland, in the Małopolska voivodship, in the Krościenko nad Dunajcem municipality. The total area of the site for the investment is 76264 m^2. It consists of the following plots of land: 121106_2.0003.1569/18, 121106_2.0003.1569/17, 121106_2.0003.1569/16, 121106_2.0003.1569/29, 121106_2.0003.1569/28.

All the areas listed above make up one large property, which will include all infrastructure. The area on which the future development will be sited is shown on an excerpt from a topographic map (Fig. 1), and a satellite map (Fig. 2). The green line marked the boundary of the future property. It was marked in accordance with the boundaries of the GUGiK plots. Table 1 shows the exact area of each plot. A data that must be examined at the start of the construction process is the Local Development Plan (MPZP). This is a legal act adopted by the municipal council in the

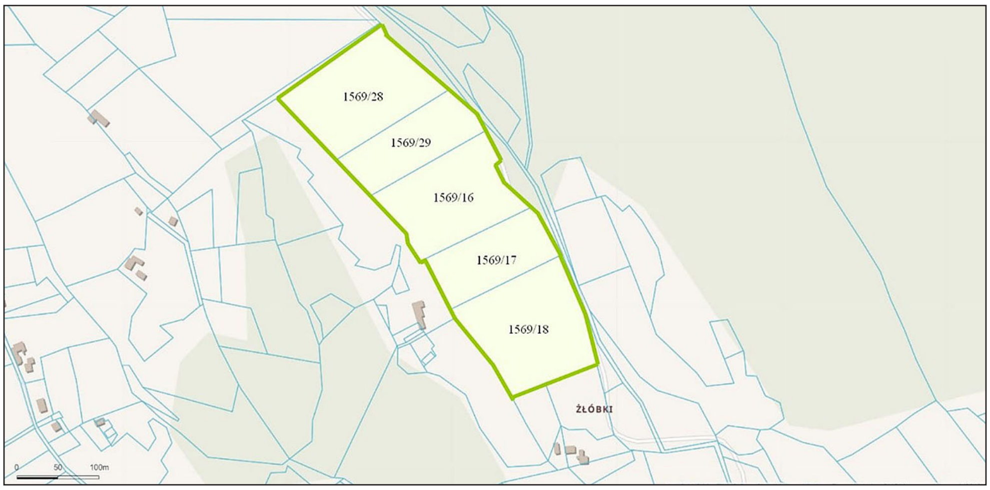

Figure 1. Investment area with delineated boundaries on a topographic map [Source: own elaboration using Geoportal360 service]

Figure 2. Investment area with delineated boundaries on a satellite map [Source: own compilation using Geoportal360]

form of a resolution. Its purpose is to describe the exact use of the land and define the conditions for development. Figure 3 shows the MPZP based on Resolution No. XXXVII/269/10 of the Commune Council Krościenko Nad Dunajcem.

When analysing the MPZP (Fig. 3), it should be noted that the future photovoltaic power plant will be located on agricultural land. Using the "measure" function in Gison, it was determined that there are agricultural areas for afforestation at a distance of 586 m. However, these do not significantly affect the future development. The closest areas to the investment are single-family and homestead development with services at a distance of 427 m. A 110 kW power line with a technical zone runs next to the investment plot. At a distance of 872 m there are areas of commercial development. The remaining area in the vicinity of the investment plot is overgrown with forests. These are located at a distance of approximately 200 m from the proposed installation.

Table 1. Area of each plot of land included in the property

Plot number	Plot area (m^2)
121106_2.0003.1569/18	17 104 m^2
121106_2.0003.1569/17	10 077 m^2
121106_2.0003.1569/16	14 916 m^2
121106_2.0003.1569/29	10 038 m^2

The future property does not interfere with the protection of the Pieniny National Park, the

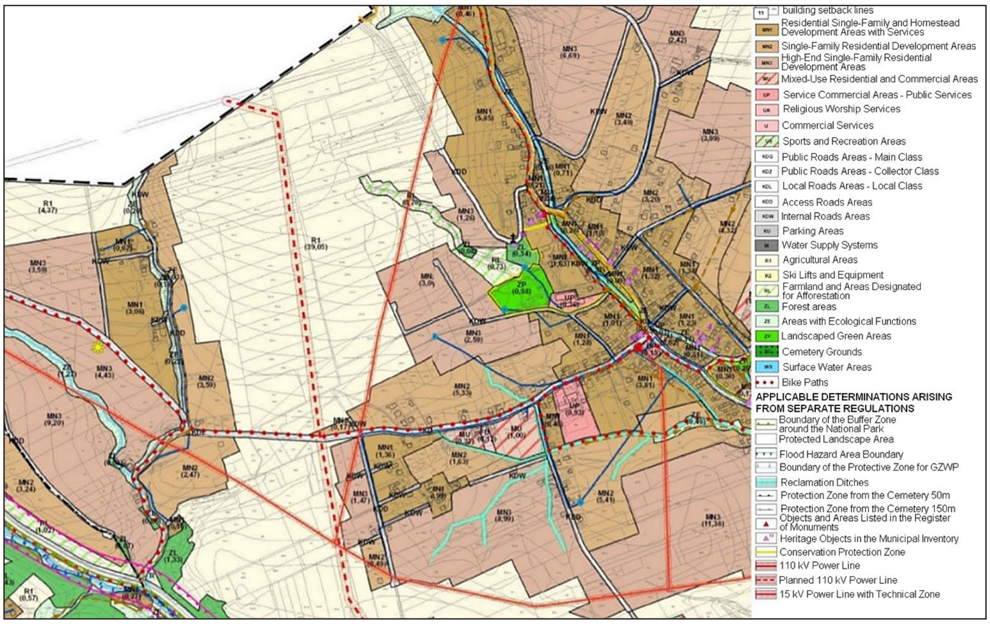

Figure 3. A fragment of the map showing the current MPZP Krościenko nad Dunajcem dated May 27, 2010. [Source: own compilation based on data from Krościenko nad Dunajcem Municipality Office]

Protected Landscape Area and the game area. In the MPZP, a water supply line and a sanitary sewer run along the plot, under which the future property with possible sanitary facilities may connect. An access road in the area of public roads of the main class runs next to the project. At a distance of 182 m run bicycle routes separated from the building plot by a green belt. 140 m from the investment plot there are surface waters.

The next stage is the analysis of the site in terms of environmental protection. The computer programme Geoserwis [https://geoserwis.gdos.gov.pl/mapy] supervised by the General Directorate for Environmental Protection was used for this. It is an interactive map of forms of nature protection in Poland, divided into layers. On the topographic map (BDOO, BDOT10k), monuments of nature, i.e. legally protected objects of nature exceptionally valuable for scientific, cultural or historical reasons, were marked (Fig. 4). An analysis of the map shows that the nearest natural monument is only 1.39 km away, so it does not interfere with the construction project. In the Regulation of the Minister of the Environment on the criteria for the recognition of living creatures of nature [Journal of Laws 2017, item 2300], the minimum distance to be found between a natural monument and the property must

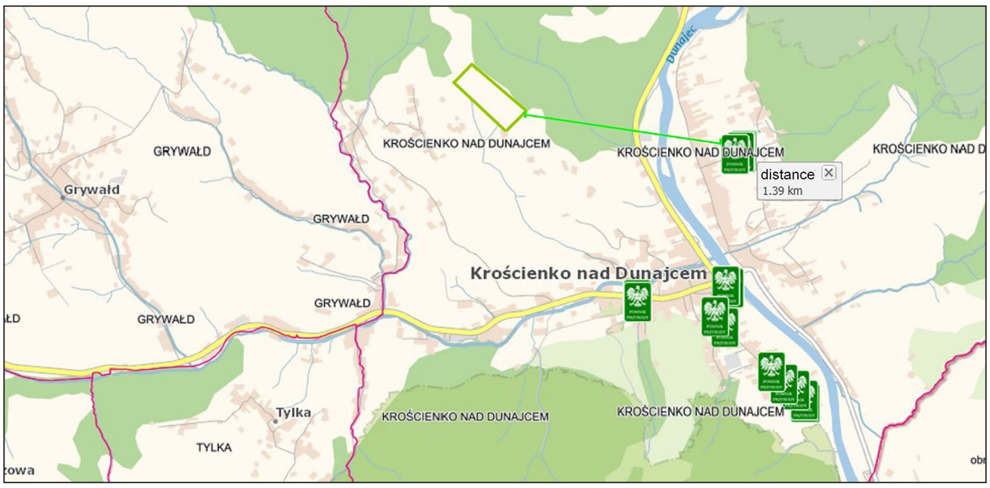

Figure 4. Topographical map of the forms of nature protection in Krościenko nad Dunajcem [Source: own elaboration based on data from the General Directorate of Environmental Protection]

be 20m. The area is then surveyed for the presence of nature reserves and landscape parks, i.e. areas protected by law due to their natural and cultural values [Nature Conservation Act, Journal of Laws 2004 No. 92 item 880]. On the topographic map, protected reserves and landscape parks are marked with layers (Fig.5). On the map in question, the investment plot is not located within any landscape park or reserve. The closest protected area is the Poprad Landscape Park – buffer zone, the border of which is located at a distance of 979.72 m in the shortest straight line from the location of the future photovoltaic power plant. The Dunajec River is the boundary of the landscape park. The nearest reserve - Kłodne nad Dunajcem - is located outside the borders of the Krościenko nad Dunajcem municipality. Legally protected areas also include National Parks and Nature and Landscape Complexes. In the National Park there is a total ban on construction of any kind of buildings except for the reconstruction of a road or power lines. The Environmental Protection Law [Journal of Laws 2001 No. 62, item 627] prohibits within the National Park the production of hazardous toxic substances by investments which may have a negative impact on the environment. When designing an investment it is necessary to obtain a decision on environmental conditions. The procedures and development rules that apply in the area are obtained from the protection plan for the individual protected area. The National Parks and Nature and Landscape Complexes are marked with layers on the topographic map below (Fig. 6). The area of the National Park is marked by a layer in

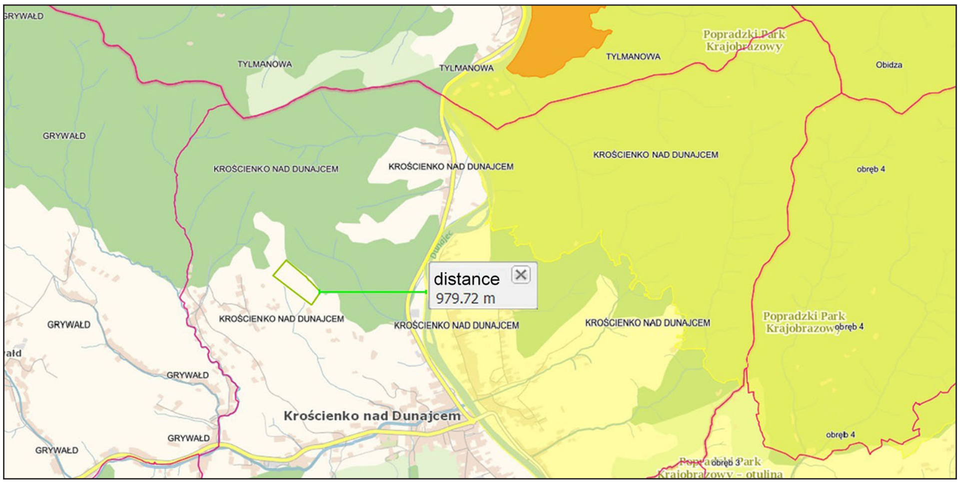

Figure 5. Topographical map of landscape parks and reserves in Krościenko nad Dunajcem [Source: own compilation based on data from the General Directorate of Environmental Protection]

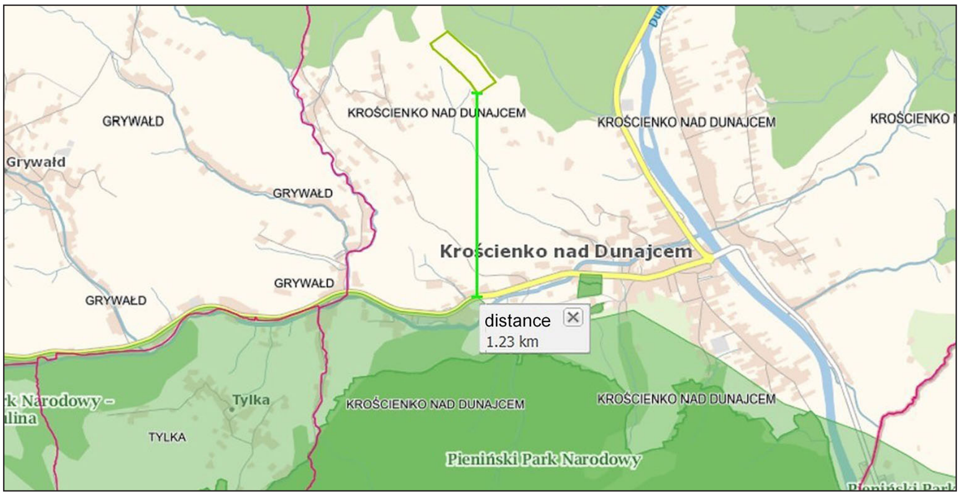

Figure 6. Topographical map of National Parks and Natural and Landscape Complexes [Source: own compilation based on data from the General Directorate of Environmental Protection]

green. The nearest National Park is located at a distance of 1.23 km in a straight line from the investment plot. This is the Pieniny National Park, whose location does not interfere with the permit for the PV power plant construction project. The project site is also not located within the Natura 2000 programme, which protects all sites, natural habitats or species considered to be extremely rare and valuable within the European Union [https://www.natura2000.gdos.gov.pl/].

The next very important aspect is to check the plot in terms of sunshine. The insolation potential in our country is between 1100 and 1250 per year. The designed power plant should be located at a suitable angle towards the south. The best angle (degree of inclination) for the installation of PV panels is such that the modules are directed perpendicular to the sun's rays. The best range is 33–37 degrees in Poland. In this range, the modules of the designed PV farm should be positioned. When the angle is large, the sum of insolation is greater in winter and autumn. If shading elements such as tall trees are present, they must be removed during construction work, as this has an undesirable effect on the efficiency of our power plant. Based on information from the Institute of Meteorology and Water Management [https://imgw.pl/], it can be concluded that the highest insolation occurs in the southern part of Poland. Krościenko nad Dunajcem is located in an area of high insolation, where the value fluctuates around 1050 per year. Therefore, it can be concluded that a plot of land in Krościenko nad Dunajcem is a very good location for a PV power plant. The ambient temperature is favourable for photovoltaic cells. If the ambient temperature is high, the cells would overheat, which would result in a decrease in the efficiency and performance of the equipment. The warmer the climate, the weaker the power output of the cell. The consequence would be a low level of energy produced.

If the installation is not directed precisely to the south and the degree of inclination is not sufficiently optimal, the designer is forced to use a statistical analysis of climate data. These are the sums of insolation which fall on the surface in all directions. Thanks to these parameters, it is possible to select such equipment and technology so that the cost-effective efficiency of the power plant can be maintained despite a slight change in the angle or direction of the installation.

Slope angle analysis and land leveling concept

A very important step in a construction project is the analysis of the angle of the land on which the investment will be built. One of the methods by which it is possible to determine the angle at which the investment plot is located is the use of a numerical terrain model (NMT) analysis. This is a point representation of the height of the analyzed area. An interpolation algorithm is used for this, thanks to which it is possible to reconstruct the shape of the entire area and determine the height at any point. The numerical terrain model is published in digital form. The aerial photo (Figure 7) shows the 3D plot that will be analyzed by NMT.

In order to carry out an NMT analysis, data must first be downloaded in ARC/INFO ASCI GRID format from the central geodetic and cartographic database. The downloaded data on our investment parcel is then read out in QGIS. These are covered by the Act, Geodetic and Cartographic

Figure 7. 3D investment plot [Source: Own compilation using QGIS software]

Law”. The second step is to produce the shading with the so-called „ShadedReliefe” option, which is shown in Figure 8. The VMTS service, a spatial data sharing standard, was used in the software at a scale of 1:500, which is a sufficient scale to generate a high-quality composite image of the data. The data was then converted via the WCS service into a raster, which was used for further analysis in QGIS software.

Once the raster was uploaded to the program’s desktop, the layer, Poland ‘C592’, was selected in the properties tab. For the vector layer added in this way, the assigned value can be read after zooming in on a small area. An area of 10×10 m when zoomed in occupies an area of one pixel.

The assigned data describes the exact height of the marked area and its coordinates. In addition, the WMS (Web Map Service) tab shows the parcel ID and the entire land register including buildings. Figure 9 shows the lowest and highest point of the slope obtained using the NMT method by determining the highest and lowest point of the investment parcel in QGIS software, the angle at which the slope is located was determined. The following formula was used for the calculation:

$$n = \frac{h}{d} \times 100\% \quad (1)$$

where: h – route elevation change, d – horizontal distance.

Slope is otherwise the ratio of the difference in height between points to the distance measured horizontally between them. Below in Figure 10 shows a graph of the slope of the slope on which the development is planned. Analysing the graph above, it can be seen that the slope angle is 5.17,

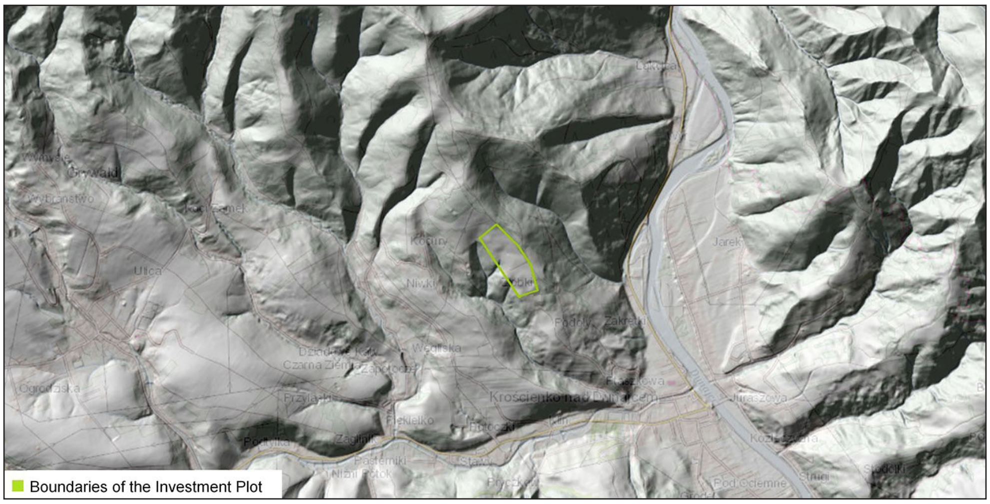

Figure 8. Visualization of NMT in the form of shading of the investment plot in Krościenko nad Dunajcem [Source: own compilation using Geoportal software]

Digital Terrain Model	
Height PL-KRON86-NH	635.5 m
Coordinates of a point	PUWG 1992
X	177109.58
Y	602000.64
Coordinates of a point WGS84 (Degrees and Tenths)	
B	49.452871 N
L	20.40779429 E
Coordinates of a point WGS84 (Degrees, Min, Sec)	
B	49° 27' 10.336" N
L	20° 24' 28.059" E

Digital Terrain Model	
Height PL-KRON86-NH	593.1 m
Coordinates of a point	PUWG 1992
X	176741.81
Y	602283.74
Coordinates of a point WGS84 (Degrees and Tenths)	
B	49.44951532 N
L	20.41160539 E
Coordinates of a point WGS84 (Degrees, Min, Sec)	
B	49° 26' 58.255" N
L	20° 24' 41.779" E

Figure 9. Extreme points of the location of the investment plot in the town of Krościenko nad Dunajcem. [Source: own compilation using QGIS software]

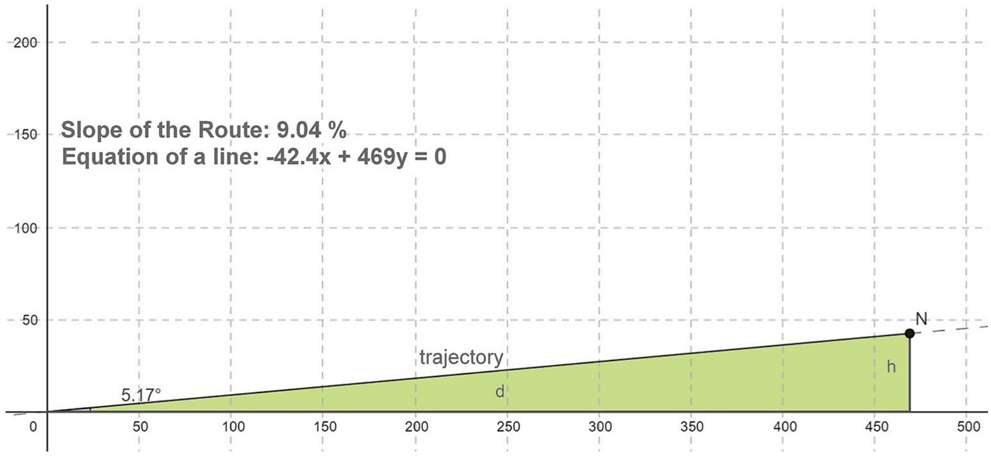

Figure 10. Diagram of the slope of an investment plot in the town of Krościenko nad Dunajcem. [Source: own elaboration using GeoGebra program]

corresponding to 9.04%. Using the measure tool in QGIS software, the horizontal distance (d) was measured and it was 469 metres, while the height difference between points (h) was 42.4 m. The difference may seem sizable, but compared to the horizontal distance, the angle does not appear to be significant. It can, therefore, be concluded that the plot meets the requirements necessary to start the construction process and the slope will not negatively affect the efficiency of the PV power plant. Next, simulations of the height surface of the site and the shading of the relief by selecting the appropriate colour scheme are drawn up below in Figure 11.

This has produced a thematic map that maps the terrain elements with different gradients. Figure 11 shows an analysis of the slope of the hill on which the plot of land is located through a build-up palette. The blue colour indicates an area that is slightly steep, while the green colour indicates an area that is not suitable for construction because the slope gradient is too steep. During the analysis, the western slope was found to be facing at the steepest angle.

Because of the slope, ground levelling is required for some of the PV plant infrastructure. This consists of selecting the appropriate ground elevation, i.e. removing or providing the desired amount of soil. The levelling is done by drawing contour lines on a map and describing the horizontal and angled surfaces. By marking out the elevation grid of our entire investment plot, it is possible to find out how the entire substructure is shaped. This will make it possible to eliminate holes and any unevenness. It should also be taken into account whether the plot is located at the correct height in relation to the roadway. Once the map and the

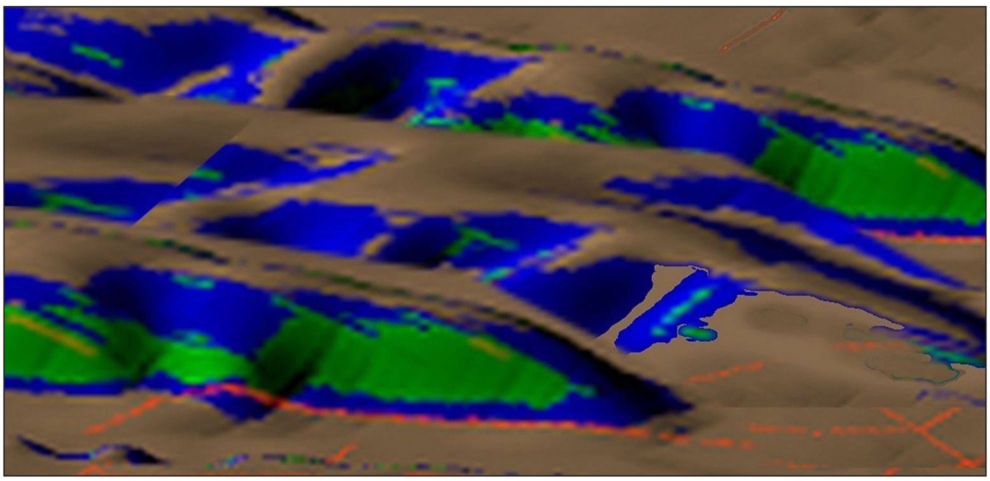

Figure 11. Simulation of the slope of the investment plot by palette build-up [Source: own development using CRFS program]

elevation grid have been refined, the profiling, i.e. the levelling of the surface, can begin. You do not need a permit for profiling, but if you are building the entire infrastructure, it is better to leave this to professionals with the right equipment.

Neighbourhood of the stand of trees with the investment

The amount of energy that will be produced by a PV plant depends mainly on the amount of sunlight that reaches the panels. It is very important to analyse the stand of trees around the installation. Any likelihood of shading around should be eliminated. It is therefore necessary to draw up precise measurements in which we determine the distance of the stand of trees in all directions from the investment plot. Shading should be foreseen and possibly prevented already during the conceptual design of the photovoltaic plant. In Figure 12 below, the existing stand of trees around the plot is marked together with the measurements. As can be seen in the figure above, the distances of the forest stand from the investment plot on the north, south and west sides are large and do not threaten the shading phenomenon. At the western edge of the plot, the woodland is only 4.55 m away, so it is necessary to keep a distance of 30 m between the PV panels and the edge of the road. In this area, there will be all kinds of utility rooms and apparatus that are not threatened by shading.

Hydrographic and hydrological analysis – flood risk map

The flood risk in Poland mainly covers valley areas and coastal regions. Different types of floods occur in each area. In addition, floods have different times of occurrence. Most often, the phenomenon was caused by precipitation. In recent years, an increase in the frequency of floods has been noted for the river Dunajec, which is the subject of this analysis. Precipitation is the most frequent cause of floods (59%). The second most frequent contributor to water surges is storminess - 13%, which does not occur in the southern part of Poland. The average gradient that occurs in the Dunajec valley is 2.14‰. This value is high, so the current velocity of the river is significant and amounts to 0.8–1.2 . When the water level rises, the velocity increases to 2.4 . The Dunajec, which flows through Podhale, is a mountain river with a high probability of frequent floods. It flows through steep slopes and narrow valleys, resulting in frequent flood and surge waves.

Studies conducted by IMGW indicate that the most vulnerable section before flooding in Krościenko nad Dunajcem, where the future investment will be built, is the Middle Dunajec with its tributaries. This is mainly due to the phenomenon of anthropopression occurring in heavily urbanised areas where natural retention is lacking. To check whether an investment plot is in a safe location away from the risk of flooding, flood hazard maps (MZP) are analysed. These make it possible to determine the risk of flooding. In addition, with these documents it is possible to take measures to ensure protection for people, the infrastructure of the locality and the environment.One of the software tools for analysing flood risk is QGIS. Figure 13 and Figure 14 below simulate the flood risk.

After simulation in both cases, a clear change in the size of the river Dunajec can be seen. In the

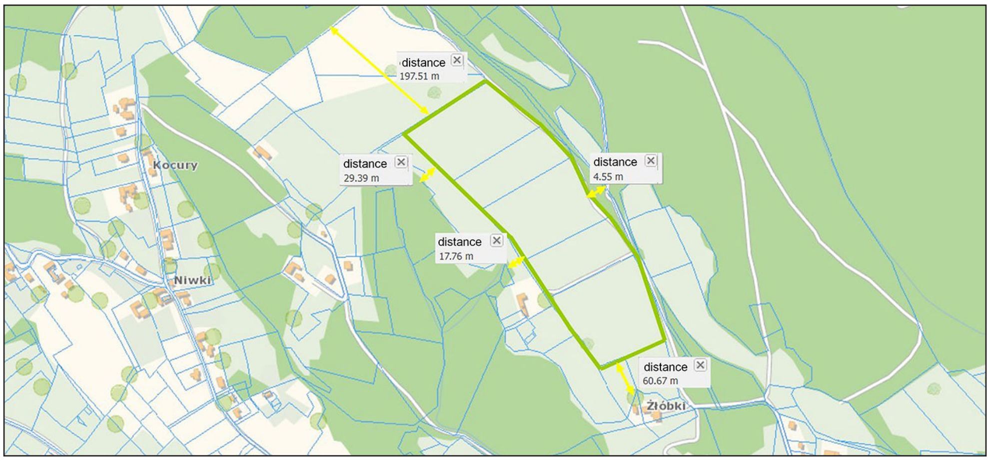

Figure 12. Stand distances from the investment plot [Source: Own compilation using CRFS program]

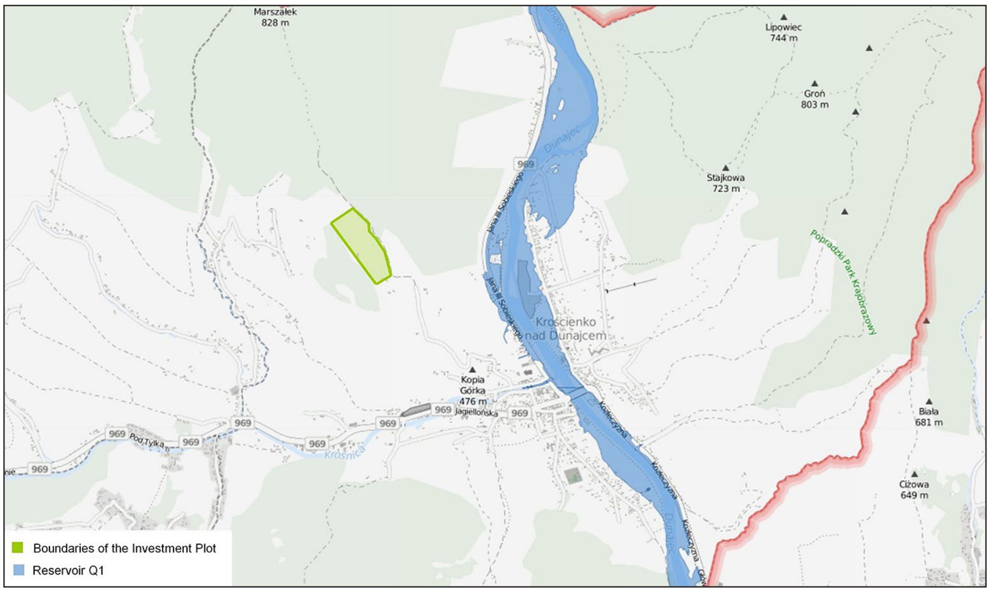

Figure 13. Simulation of flood risk Q1
[Source: own development using QGIS software]

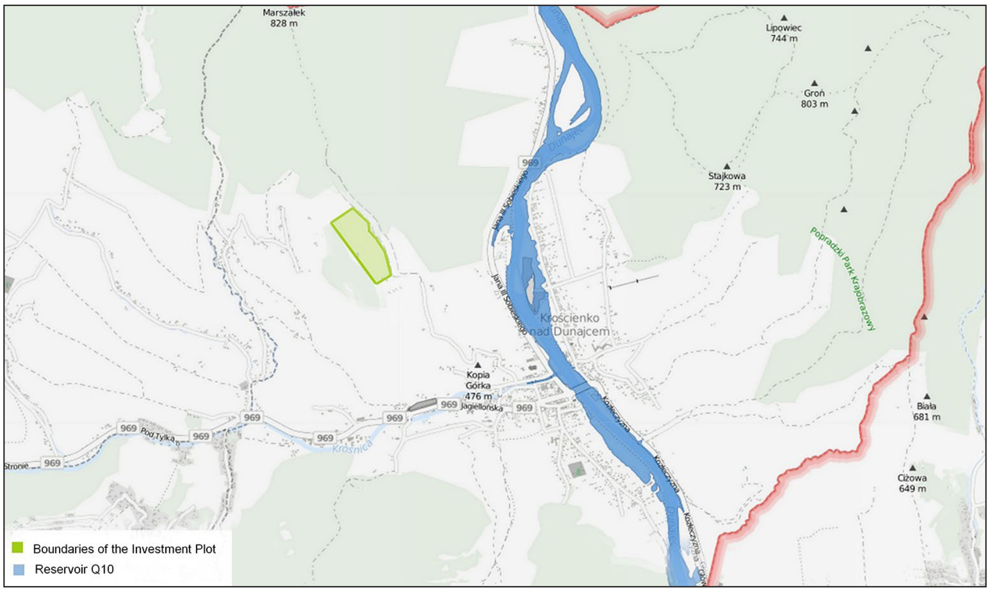

Figure 14. Simulation of flood risk Q10
[Source: own development using QGIS software]

case of Q1 (Fig. 13), i.e. areas where the chance of flooding is medium and once in 100 years, the regions of Wądoły near the middle Dunajec with its tributaries and Flisaków Pienińskich Street are the most prone to flooding. In the case of Q10, i.e. areas where flooding occurs once every 10 years, the scale of flooding is much smaller, but the regions listed in Q1 are still prone to flooding. Thanks to the simulations carried out, it can be concluded that the Dunajec is not at any risk of flooding for the project.

Geological analysis – landslide hazard with map of active landslides in the vicinity of the power station

The ground analysis consists of a number of steps such as measuring the depth of groundwater occurrence, investigating the chemical composition of the ground and measuring PH levels in soils. It is also very important to prepare an analysis for the occurrence of active landslides in Poland, i.e. translocation of earth and rock masses caused by human intervention or forces of nature. This phenomenon involves the movement of masses in a sliding motion together with rotation. In order to eliminate the potential risk of building investments in landslide-prone areas, maps are used. These are drawn up at a scale of 1: 10000 and we can find in it all the data on the extent to which there is a landslide hazard and the extent of the landslide. Below in Figure 15 is a map of landslides

As can be seen on the map above, there are a large number of active landslides in the vicinity of the investment plot. However, they are located at a great distance without threatening the future PV power plant. The nearest landslide-prone area is only at a distance of 232.69 m. In order to carry out the analysis of active landslides, the terrain profile, which is a chart showing absolute heights, is also verified. This is done by plotting the intersection line of the plot surface on the image plane. In Figure 16 below, a profile analysis of the development plot is drawn up.

The analysis shows that the area of the site is not significantly different. The total length of the upward sections was 438.5 m, while the downward sections were only 36.5 m. In the sampling option you will find all the height deviations listed in the form of coordinates. Based on these, you can search for the section to be leveled. The next step was to make an analysis of the volume of earth masses from the plane, which is shown in Figure 17. Through this process, we are able to determine the smallest and largest height of the entire area of the investment plot. The software

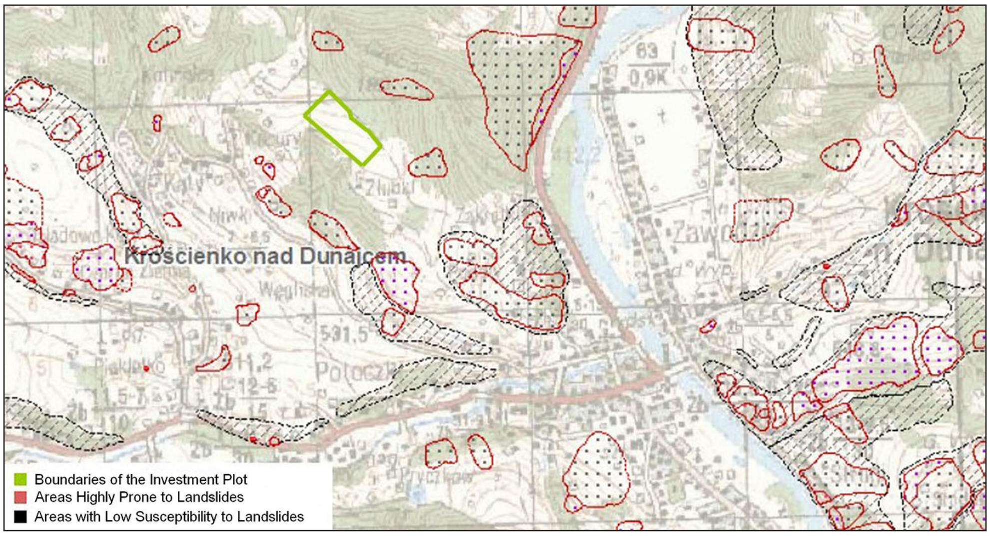

Figure 15. Map of active landslides with marked investment plot [Source: own compilation using SOPO program]

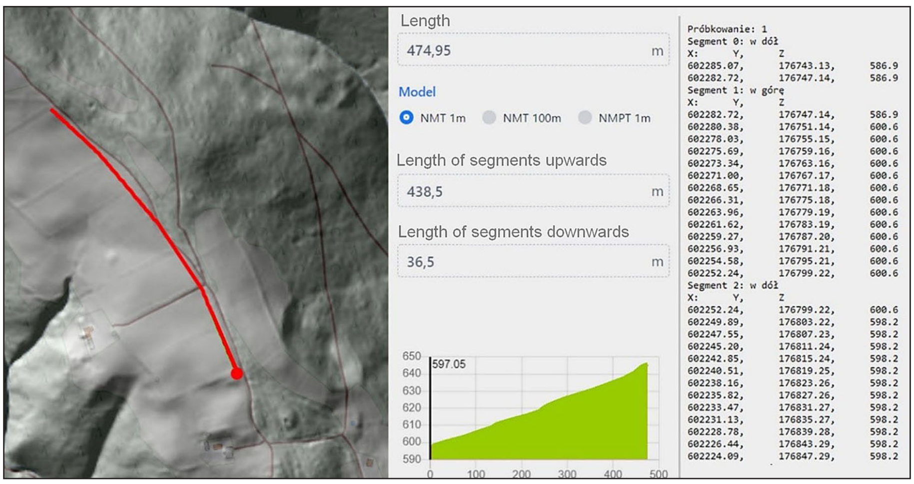

Figure 16. Site profile analysis. [Source: Own compilation using SOPO software]

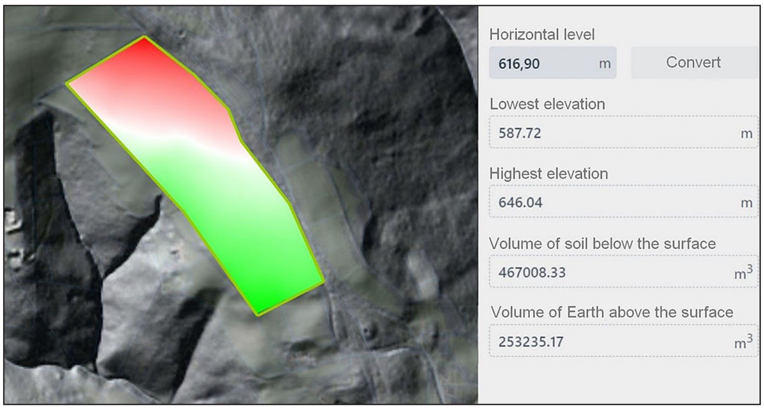

Figure 17. Analysis of the volume of land masses from the plane [Source: Own compilation using Geoportal software]

additionally recalculates the volume of earth that is below and above the level expressed in m^3.

As shown in the figure above, the lowest point, which was recorded along the entire plane of the plot, is 587.72 m, while the highest is 646.04 m. The greatest changes in elevation were recorded at a distance of 287.4 m from the lowest edge of the property, which is marked in red.

Location of the photovoltaic farm site from main national roads

Providing access to a public road when planning an investment is strictly defined in the Regulation of the Minister of Infrastructure [Journal of Laws 2002 No. 75 item 690] In a situation where there is no direct access to the roadway, which would be located next to the investment plot, it is necessary to establish an easement. It is very important that the access road is sufficiently paved and its width is about 5 m. In Figure 18. the access road to the investment plot is marked with a red line, along with its dimensions. Its length is 700.92 m. It is a properly paved dirt road with a width of 4.47 m and it connects to the Angles community road. The nearest county road 969 is located from the plot at a distance of 2.58 km. The road has been paved by using natural and broken aggregate. At the very edge of the project, a 136.77 m section of the road will be further reinforced with geotextile, on which concrete slabs will be placed.

Determination of soil quality based on the land registry

During the course of the investment process, an important step is to determine the bonitification of the land on which the infrastructure will appear.

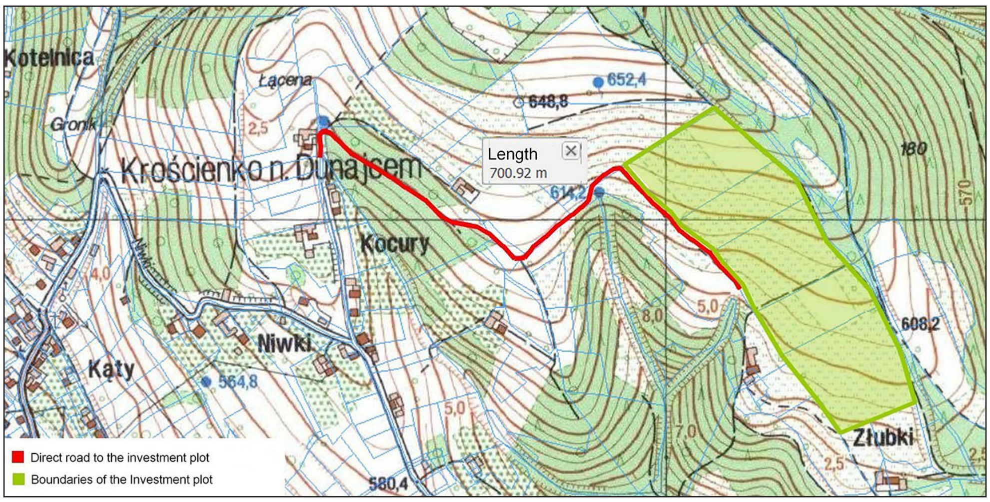

Figure 18. Designation of the access road to the property [Source: Own compilation using Geoportal software]

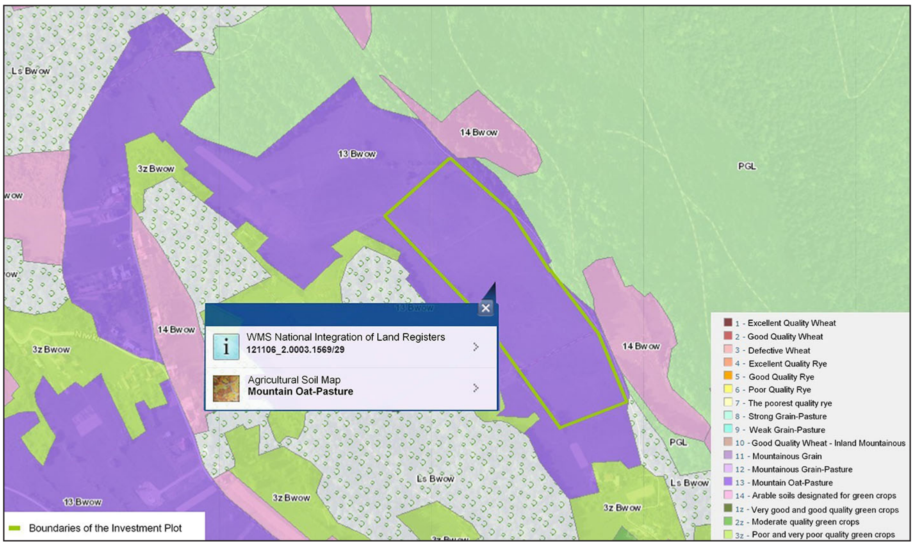

Figure 19. Soil type on the investment plot with boundaries
[Source: own compilation using GeoMalopolska software]

This process will determine, the quality of the soil in terms of its fertility occurrence of water relations and the degree that determines the complications of cultivation. By confirming low, soil quality, it will be possible to obtain permits for the construction of investments. In Poland, there are 9 classes of arable soil and 6 classes of green land, which are described in detail by regulations. Data on the land class of the investment plot was checked in the extract of the land register, which was obtained from the municipality office in electronic version. In addition, the bonitation was determined based on the GeoMalopolska computer program [https://miip.geomalopolska.pl/] on the soil-agricultural map. Figure 19 shows the type of soil on the investment plot along with its boundaries.

On the basis of agricultural soil suitability complexes, it was determined that land 121106_2.0003.1569/29 belongs to the oat-pasture mountain group. These are soils whose mineral origin is derived from brown soils leached from carbonate-bonded sedimentary rocks. The mechanical composition includes heavy silty clay-weakly skeletal. The type of soil found on the investment plot is most often used for growing legume or grass mixtures. The species of oat-pasture soils is found at an altitude of 550–800 meters above sea level. Yields on this land are small, so it is possible to obtain official permits to begin the construction process.

When considering flood-prone areas in Poland, they are mainly concentrated in valleys and coastal regions. Different types of floods occur in these areas and have varying times of occurrence, often caused by precipitation. Floods appear sudden and uncontrolled, difficult to stop excess precipitation. Recently, an increase in the frequency of floods has been found on the Dunajec River, the subject of the study. The area, as a mountain river, is prone to frequent flooding due to its steep slopes and narrow valleys. Studies indicate that the area of Krościenko nad Dunajcem, where the project is to be built, is particularly vulnerable to flooding, mainly due to anthropopressure, accelerating surface runoff. Flood hazard analysis (MZP) makes it possible to determine the risk of flooding in the area. Simulations using QGIS software have shown that the Dunajec River poses no threat to the project. It is also important to survey the land for landslides, retention, and analyze the site profile to identify possible risks. Access to a public road, as a key element of infrastructure, is also studied and analyzed in accordance with legal regulations. Soil fertility and its suitability for a particular type of crop is also verified to obtain the necessary construction permits.

CONCLUSIONS

Entrepreneurs involved in photovoltaic investments are looking for suitable plots of land with high insolation to fully exploit the potential of the designed installation. The use of energy generated from renewable sources is safe for the climate, although it cannot fully constitute the basis of the States' energy industry. The reason for this is energy generation is highly dependent on weather conditions. Weather conditions are sometimes unfavorable, making it impossible to fully exploit the potential of an installed photovoltaic system. Typically, photovoltaic installations bring tangible benefits to the individual benefiting from energy generated in an environmentally friendly way,using the latest technology, increasingly contributing to a complete shift away from fossil sources to renewable ones. The main objective was to analyze the site located in Krościenko nad Dunajcem in Malopolska province in terms of the possibility of building a photovoltaic farm. The analysis looked at spatial factors directly affecting the relief of the site. The first aspect considered was the current Local Spatial Development Plan, as well as the Study of Conditions and Directions of Spatial Development of the municipality in which the location was selected.

It was concluded that the investment site is suitable for the construction of a PV farm. Undertaking the construction of the described project will not affect the functioning of the world of fauna and flora, especially in targeting protected species. The project will also not interfere with groundwater and groundwater, as no industrial wastewater will be generated from the PV installation. Also, there will be no degradation of biocenoses, all natural values will remain intact. In addition, the farm can be fenced keeping an elevation of 0.2 m from the ground to ensure safe migration of reptiles and amphibians. The study of the site for the construction of the photovoltaic farm was carried out thoroughly, clearly indicating the validity of the choice of the site for the investment.

The use of GIS (Geographic Information System) played a key role in the preparatory process for the construction of the photovoltaic plant by enabling the analysis of a wide range of relevant spatial data. GIS tools allowed detailed analysis of the site, taking into account terrain, accessibility to power grids and road infrastructure, among other things. Thanks to GIS, it was possible to meticulously examine insolation, geological aspects, potential landslide risk, forest cover and hydrological hazards, which helped assess the suitability of the site for the construction of a photovoltaic farm. In addition, GIS allowed the identification and analysis of data on nature conservation, protected animal species, and natural values of the site, which was crucial for minimizing the environmental impact of the investment. As a result, the use of GIS enabled a comprehensive evaluation of the site for the construction of a photovoltaic plant, taking into account many important spatial factors.

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