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Monitoring of the mining waste neutralization facility of LW Bogdanka

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Abstract
Investing in renewable energy sources bringing direct profits from unattractive areas is one of the most advantageous ways of wastelands revitalization. In the case of post-mining dumps, it is realized by using photovoltaics and wind turbines. Analyzes showed that the greatest benefits can be acquired from photovoltaic farms, mainly due to the simplicity of their design and principles of operation, as well as the quick return on investment - up to 7 years. The construction of wind turbines is more complicated. Despite the favorable conditions of the mining dumps (elevated areas, which are located mainly away from residential buildings), the construction of the turbine requires more effort in designing and installation work, mainly due to the necessity of building the foundations.
Methods for revitalizing mine dumps by installing renewable energy systems have some limitations due to periodicity of operation (time of day, season), weather conditions (wind speed, temperature), expensive energy storage, etc. For this reason, real-time monitoring of climatic conditions is required. The following parameters are monitored: the average available solar energy (important for the assessment of the efficiency of photovoltaic cells), speed and direction of the wind (which affects the efficiency of wind turbines), changes in groundwater level (risk of flooding and periodic soil softening), soil and air temperature (air – affects the choice of the method of revitalization, soil – affects the preservation of soil) and dust concentration, which affects the degree of contamination of the photovoltaic modules and thus the efficiency of the photovoltaic (PV) power plant. The presentation includes interesting data that was obtained during the tests.

Keywords
monitoring, mine dump, photovoltaics, wind turbines

Introduction

Mine dump sites, inextricably linked with the mining industry, represent an unresolved challenge that has not lost its relevance despite passing years and growing experience. Objects of such size, often contrasting with the local surroundings, are a tangible trace of human activity, for which one should take responsibility. Companies, for which the waste generated in the production process is an important element of direct interaction with nature and people, place great emphasis on its effective management.

In the case of hard coal mining plants, the mechanically separated waste rock stored at the mine waste disposal sites (mine dumps) is its basic waste. Mine dumps are mainly heterogeneous waste material (Pactwa, Woźniak and Dudek, 2021, Matusiak and Kowol, 2020, Jendrysik and Kost, 2019, Rogala-Rojek, Stankiewicz and Jendrysik, 2019), piled in a conical or irregular shape, high in relation to the local topography. Typical heights of mine dumps range from 30 m to 100 m, and slope inclination is between 20° and 40°. The specific characteristics of mine dumps make a challenge for the investment (Hajovsky, Pies, Ozana and Hajovsky, 2014). The large quantity of industrial waste and its unsatisfactory use is a big problem in Europe. There are over a thousand mine dumps in France, Germany, Poland and Belgium. Some of them were reused for various economic and social activities (Al Heib and Cherkaoui, 2021, Banaszek, Leksy and Rahmonov, 2017, Benndorf, Restrepo, Merkel, Knobloch, Kressner, Guatame-Garcia, Nolte, Möllerherm and Dalm, 2021, Hajovsky, Hajovsky, and Pies 2014, Pactwa, Woźniak and Dudek, 2020). Some dumps are used as a source of rare earth elements (Baron and Mosora, 2021, Pactwa, Woźniak and Dudek, 2020). Apart from the progressing methods for reducing the volume of waste deposited in mine dumps, such as their separation and placement directly in a mine underground or in subsidence troughs on the surface, resulting from mining activities (with the caving method), the aim is to integrate the emerging embankments with the surroundings as much as possible (Chmiela et al. 2022). During the mine dumps recultivation, some of them were adapted for various economic and social activities.

Figure 1 LW "Bogdanka" Mine Waste Neutralization Facility – under construction, partially recultivated slopes

Investing in renewable energy sources generating direct profits from less attractive areas is one of the most beneficial methods for wasteland management. In the case of post-mining dumps, the idea of using photovoltaic installations and wind turbines is natural. This subject was undertaken within the SUMAD (Sustainable Use of Mining Waste Dumps) project co-financed by the EU Coal and Steel Research Fund, where KOMAG Institute of Mining Technology is one of the consortium members (KOMAG Institute of Mining Technology website, Lutyński, 2021). The SUMAD project unites European experts who analyze the future management of mine dumps, with special attention to geotechnical, environmental and socio-economic challenges. The main assumption of the SUMAD (SUMAD project website) project is to define the methods for optimizing the use and long-term management of mine dumps, with special attention to renewable energy sources. Sustainable mine dump revitalization projects (such as SUMAD) respond to the European Coal Transformation Initiative. Identifying the possibilities of sustainable reuse of mine dumps with risk analysis (Białas, 2021) is a state-of-the-art project that can be very attractive for the European regions affected by the mining industry.

The current situation shows that there are few PV projects and installations on mine dumps in Europe and the world, although every day, more such installations are constructed, mainly in Germany and France. In Poland (Ustronie Morskie), there is a photovoltaic farm built on an ash deposit with a surface area of up to 8 hectares (Teraz Środowisko online journal website). The farm has a power of 1 MW, but it is planned to be increased to 4 MW. Installing the wind turbine farms, such as one in Pennsylvania in the USA, in the Green Mountain Wind Energy Center, located in the area reclaimed after a hard coal opencast mine (Pennsylvania Wind Working Group website) is another possibility of revitalizing the mine dumps. The main challenge of such a solution is to design and build the foundation to secure the stability of the turbine facing the loads from the ground. In Germany, a 33

MW wind farm is planned to be built at the coal storage yard (Lusatia lignite mining district in Klettwitz in Brandenburg) (&P Global website). In Poland, there is a wind farm consisting of 15 turbines of power 2.080 MW each (Kamieńsk Wind Farm website). The power plant is located on the plateau of the reclaimed external mine dump site of KWB Bełchatów mine called Góra Kamieńsk, near the city of Bełchatów, in the area of the Pole Bełchatów.

The main task of KOMAG within the SUMAD project was to monitor and record the selected environmental parameters at the LW "Bogdanka" mine's Mining Waste Disposal Facility (Figure 1). The project included only a preliminary analysis of the data and related its values to usability for the proposed sustainable revitalization measures. The analyses showed that in the case of the monitored dump of LW "Bogdanka", the greatest benefits can be obtained from the construction of photovoltaic farms, mainly due to the simplicity of their construction and operating principles, as well as the quick return on investment – up to 7 years. More complicated is the construction of wind turbines. Despite the favorable terrain conditions of mine dumps (elevated areas mainly away from residential buildings), the construction of a turbine requires more design and installation work, mainly due to the need to build foundations.

Monitoring the site of investment in RES will allow better planning of the investment itself and its operating costs.

General information about the monitoring station

Within the SUMAD project, the KOMAG Institute of Mining Technology built a monitoring station on the LW "Bogdanka" dump site. Monitoring large areas requires using self-powered, maintenance-free measuring stations equipped with sensors to measure the necessary parameters. Batteries, charged by a photovoltaic module connected to a small wind turbine, are the power source. Data from the station was collected wirelessly and recorded on the server. The solution is based on an 8-channel recorder, to which peripheral devices are connected, recording the specified parameters. The station was built on a mast attached to concrete slabs in the centre of a 100 x 100 m site provided by LW "Bogdanka" for testing in the SUMAD project. There are traverses on the mast for the wind speed and direction sensors, solar radiation intensity and dust concentration. The station is equipped with a photovoltaic module for year-round power supply to the station and a control box with a battery, charging the controller and data recorder. Near the station, there are sensors for measuring soil temperature, a rain gauge and a probe for measuring the level of groundwater. The station was assembled and commissioned at the LW "Bogdanka" dump at the beginning of December 2020.

The monitoring station can record the following parameters:

- solar irradiance, important for the assessment of the efficiency of photovoltaic cells,
- wind speed and direction that affects the operation of wind turbines,
- amount of precipitation,
- soil temperature, influencing the soil behavior,
- dust concentration, which affects the contamination of photovoltaic modules,
- air temperature and humidity important in selecting the revitalization method,
- groundwater level (risk of flooding and periodic soil softening).

Recording the water level on the mine dump site was also planned. Therefore, piezometers with hydrostatic probes were designed. Installation of these probes required creating the geological work plan, getting permits, creating the mining plant operation plan and developing the geological documentation. Holes were drilled, and 2 piezometers were installed as part of the SUMAD project. Initially, 5 piezometers, each 10 meters deep, was planned to be made within the project. During the work, it was decided to deepen the holes for piezometers to a depth of 25 meters.

One of the piezometers (M-1) was installed near the meteorological station; therefore, the hydrostatic probe was connected with a cable directly to the recorder in the station. The second sensor was installed in the piezometer (P-1), using the eHydrolog k-2 wireless recorder, transmitting the data directly to the server. The recorder was placed inside the piezometer head, and a GSM antenna was installed on the head cover (Fig. 2).

Figure 2 View of piezometer at point P-1, with wireless data recording

The hydrostatic probes in both piezometers were lowered to the very bottom, 25 m deep. The probes were left in a mine dump site to continuously monitor the water level to see if water accumulates in the mine dump site or migrates during heavy rainfall or snowmelt after winter.

Results

The data recorded by the sensors of the monitoring stations were analyzed in terms of the suggested revitalization methods (in this case, renewable energy sources). The chapter presents the impact of each parameter on the construction of photovoltaic and wind power plants.

Solar radiation intensity (direct modules efficiency)

Investing in photovoltaic installations should start with the analysis of the potential of solar energy resources in the interesting area. Figure 3 shows a diagram of the intensity of solar radiation for 2021.

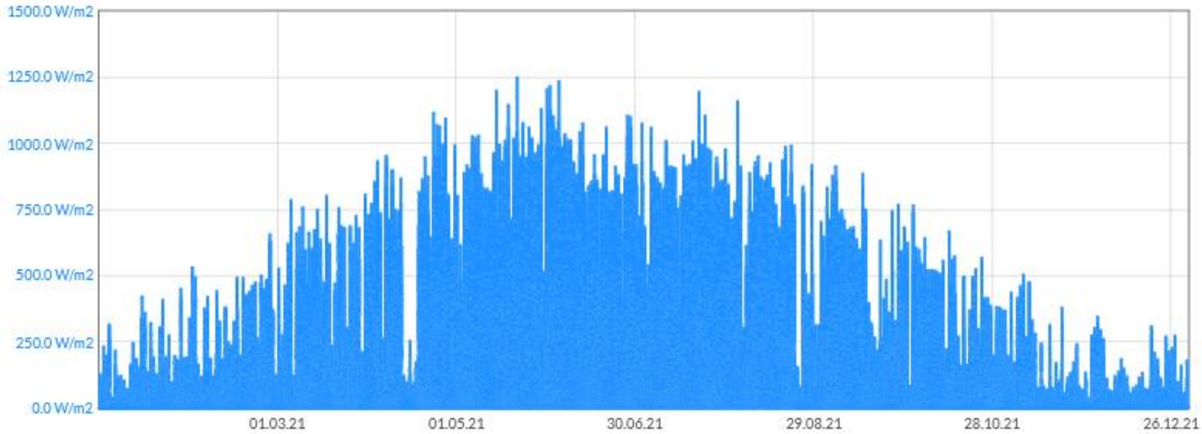

Figure 3 Solar irradiance recorded on LW "Bogdanka" dump site in 2021

Figure 4 shows the percentage of solar energy per 1 m^2 of the mine dump's surface for each month of the year in relation to the total energy produced during the year.

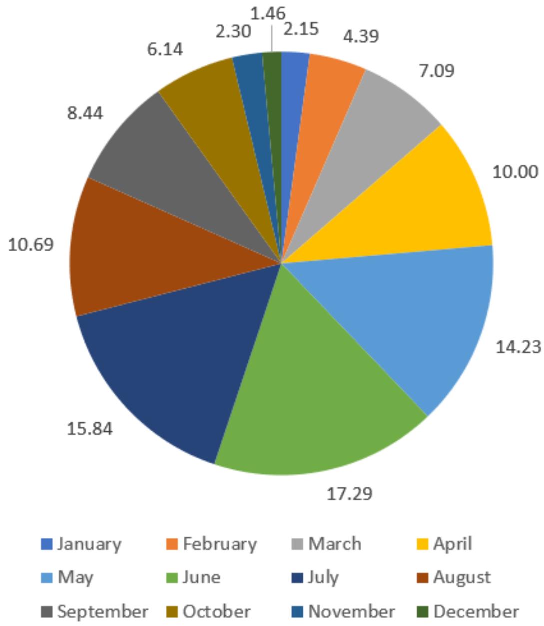

Figure 4 Percentage of energy distribution per 1 m² of a mine dump site in each month

As can be seen from the diagram, four winter months account for only (10.3%) of the annual available solar energy, which is less than one summer month. Figure 5 shows a diagram of the intensity of solar radiation in May 2021.

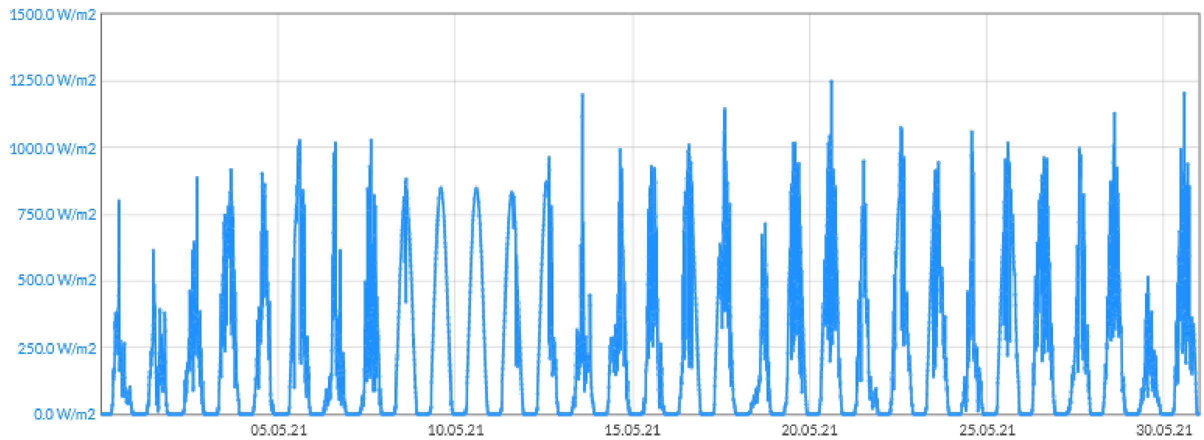

Figure 5 Solar radiation recorded in May 2021

The results show that the lighting conditions for the construction of photovoltaics were very good. The maximum intensity of solar radiation reached even 1250 W/m². From May to September, 77 days with the intensity of solar radiation exceeding 800 W/m² and 37 days with the intensity of solar radiation exceeding 1000 W/m² were recorded. Based on the recorded data, the total solar energy that reached each square meter of the mine dump was 1.12 MWh/m² per year. Assuming the 22% efficiency of solar modules currently available on the market (for example, LG380Q1C-V5 Neon R), about 0.25 MWh/m² per year of solar energy reaching the ground is recoverable. The mentioned model of a photovoltaic module in STC conditions allows for obtaining 0.22 MWh of electricity per year from each m² of the PV module surface. This means that the solar conditions on the mine dump site are very good and will allow for above-standard efficiency.

Airborne dust concentration

Manufacturers of photovoltaic modules stated that if the modules operate in normal weather conditions, washing them is not necessary due to the fact that the surface is covered with self-cleaning layers. It was also argued that cleaning the modules would cause them to fail mechanically. Practice, however, proves something else. Contamination of PV modules, such as dust, pollen, soot, leaves, moss, bird droppings, coal combustion products, etc., will greatly reduce the efficiency of the PV system. Dirt is often difficult to see with the naked eye as it first settles on edges and frames and then overlaps the entire surface of the module. Unfortunately, the rain only partially removes dirt, and more and more manufacturers recommend the need for professional cleaning of photovoltaic modules, especially to remove persistent contaminants such as bird droppings. While dirt caused by animals is difficult to predict, thus by measuring dust concentration, it is possible to estimate the amount of pollution that can affect the efficiency of photovoltaic installations. The greater or lesser contamination of the modules should be taken into account. Off gases emitted from machines in agricultural areas, rich in organic substances, which easily adhere to the surface of the modules, is a big problem. Similarly, in the case of post-mining areas, especially mine dumps, when heavy machinery is used. This type of dirt will not be removed by rain, and it will become larger and more difficult to remove with time, and in a short time, will lead to a loss of 10% and more in the efficiency of the modules. PM1, PM2.5, PM4 and PM10 dust is measured at the monitoring station. Figure 6 shows the measurement results for the entire of 2021.

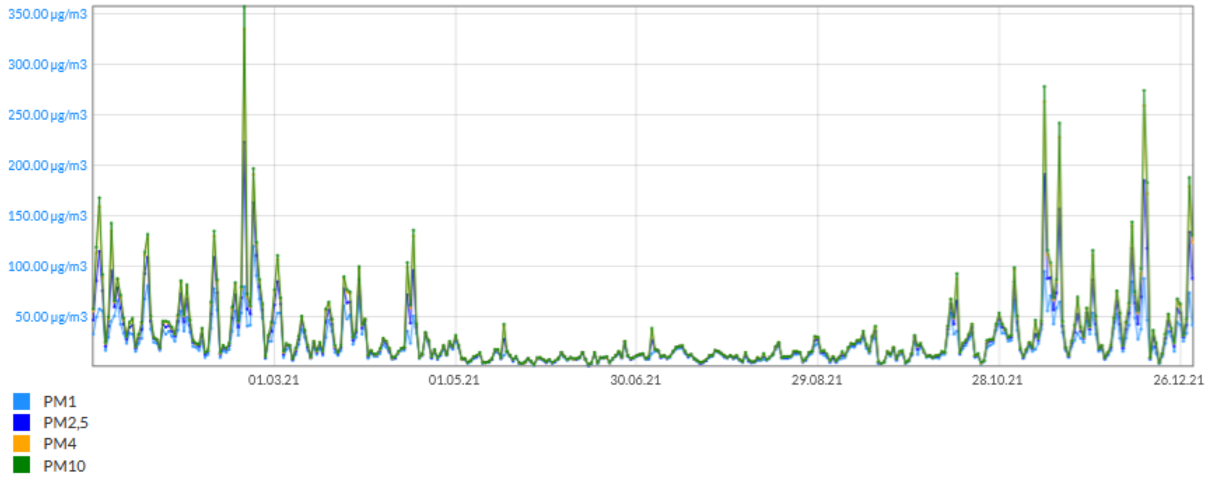

Figure 6 Dust concentration recorded at LW "Bogdanka" dump site in 2021

It is clearly visible that air pollution is much greater in autumn, winter and early spring (over 250 µg/m^3). This is naturally related to the method of heating the residential buildings in the surrounding towns. In the summertime, air pollution by each fraction is much lower (below 20 µg/m^3). There are single days with pollutants concentration up to 50 µg/m^3, which may be related to the increased intensity of ongoing work on the mine dump.

The results clearly show that there is a significant amount of dust in the vicinity of the measuring station (in all measured fractions), which may cause dirt disposition that is difficult to remove by rain. In this case, in the economic analysis before the construction of the photovoltaic installation, the OPEX should inclu de at least one cleaning of the panels in the spring.

Air temperature

It is well known that the photovoltaic module operates with lower efficiency at higher operating temperatures. The decrease in power with increasing temperature of the photovoltaic module determines the Temperature Coefficient of Power. Manufacturers of photovoltaic panels provide several parameters in their catalogue cards, and the most important ones are maximum power achieved by the PV module (P_{max}), the voltage at the maximum power point (U_{mpp}), current at the maximum power point (I_{mpp}), idle state voltage (U_{oc}), short circuit current (I_{sc}), the maximum voltage of the PV system. Knowledge of the voltage and current is necessary to select proper electrical protection for a given installation. It was assumed that the above-mentioned parameters are given for STC (Standard Test Conditions), i.e. the electric power given in the catalogue corresponds to the solar radiation intensity of 1000 W/m^2, the module operating temperature of 25°C and the radiation spectrum parameter Air Mass – AM 1.5.

Due to the fact that the STC conditions do not occur in practice, a second standard of operating parameters has been introduced, which defines the electrical parameters for the conditions of the nominal operating cell temperature (NOCT). These conditions occur much more frequently than standard STC conditions. Under NOCT conditions, insolation amounts to 800 W/m^2 at an air temperature of 20°C and wind speed of 1 m/s and AM = 1.5. Many manufacturers of photovoltaic modules provide technical data of modules for NOCT conditions in their commercial offers. However, it is worth remembering that the average annual insolation in Poland is 1000 W/m^2, not 800.

The temperature of the modules has a direct impact on the amount of electricity generated. It is assumed that for each degree above 25°C (STC conditions, under which the manufacturer specifies the parameters of PV modules), the power drops by up to 0.45%, depending on the PV technology used (Table 1).

Tab. 1. Temperature coefficients for different PV technologies (Verma and Mohapatra and Chowdhury and Dwivedi, 2021)

Technology	Temperature coefficient of power [%/°C]
Mono-c-Si	-0,40
Multi-c-Si	-0,45
a-Si	-0,20
a-Si/μc-Si	-0,26
CIGS	-0,36
CdTe	-0,25

The operating temperature of the photovoltaic module depends on ambient temperature, the intensity of solar radiation, the structure of the module itself and the speed of the wind, which is the module's natural coolant. At an air temperature of around 40°C, the modules can warm up to 70°C, which results in a loss of efficiency of up to 15% of the module's power. Due to the design of photovoltaic modules, it is not possible to continuously measure the temperature on the active surface. In monitoring systems, the temperature of the bottom surface of the PV module is measured. It is assumed that the temperature of the active surface is about 3°C higher than the temperature of the bottom surface. Figure 7a presents a diagram of the ambient temperature at the LW "Bogdanka" dump in 2021. July was the hottest month (when the air temperature on the mine dump exceeded 40°C) in 2021 (Fig. 7b).

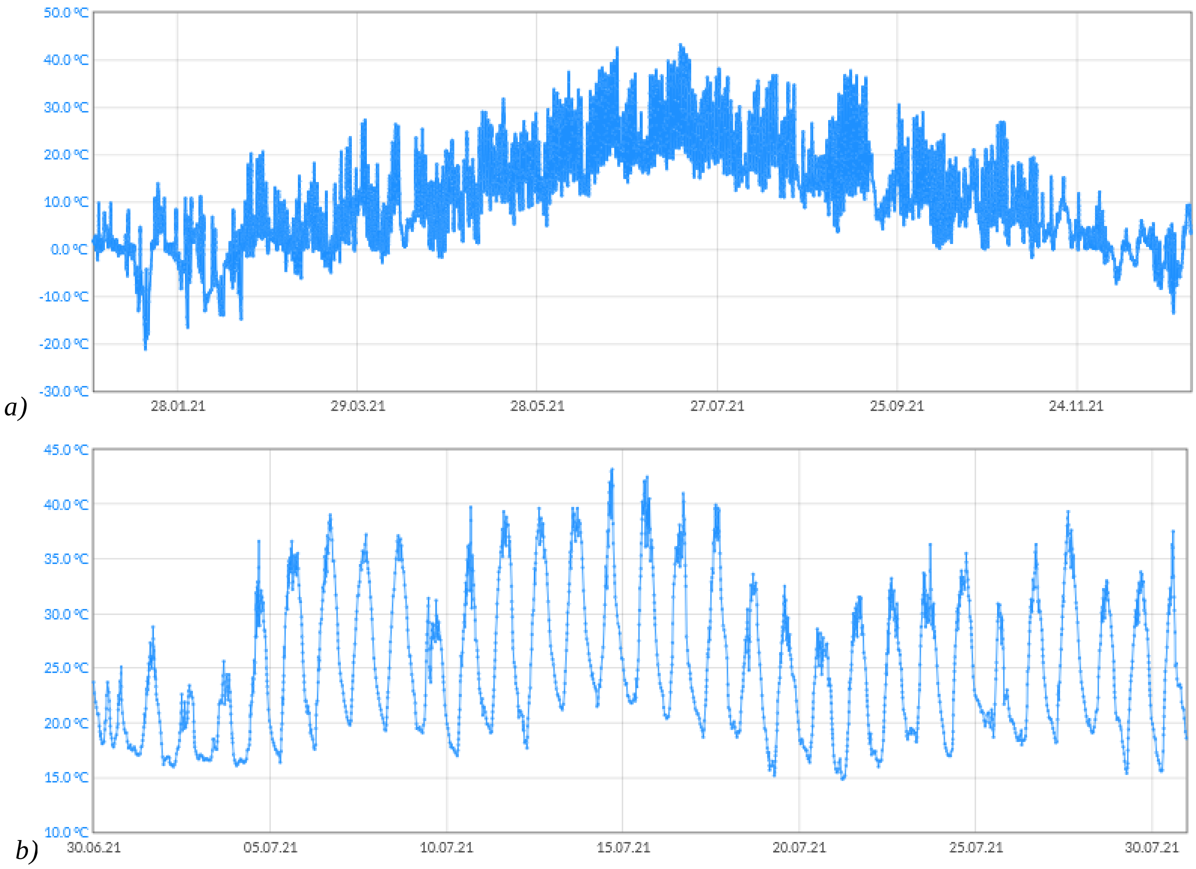

Figure 7 Air temperature recorded on LW "Bogdanka" dump: a) in all of 2021, b) in July 2021

Table 2 shows the minimum, maximum and average temperatures throughout 2021.

Tab. 2. Temperature in each month of 2021

Month	Temp min [°C]	Temp avg. [°C]	Temp max [°C]
January	-21.4	-1.3	14.1
February	-16.8	-1.8	21.4
March	-6.8	3.8	26.4

April	-3.8	7.8	28.3
May	1.3	14.2	32.2
June	4.5	22.7	43.7
July	14.9	24.9	43.3
August	8.5	18.7	37.5
September	3.6	14.8	38.9
October	0	10.3	29.7
November	-1.9	5.4	23.1
December	-14	-1.1	12

Temperature measurement allows for assessing if the power drops are caused by high temperatures or a system malfunction or failure. Knowing the relationship between the decrease in efficiency of the installation and temperature (above 25°C), it is possible to estimate more accurately the expected energy recovery, which is very important in the case of revenue planning.

Wind speed and its direction in the aspect of building the wind turbines

It is possible to estimate the potential of a site for recovery of wind energy on the basis of the "wind atlas". Due to the fact that the data contained in such atlases are averaged in a given area, they may not take into account local terrain conditions such as artificial hills (mine dumps). Such elevations change wind pressure and allow access to higher atmosphere layers. In this case, it is advisable to estimate the local windiness through in-situ surveys. Such measurements are taken by using wind speed and direction sensors located on the measuring mast. In addition to these basic values, air humidity, temperature and pressure, which are needed to determine the air density and the sensitivity to icing, are also recorded. On the basis of measurements, it is possible to determine the wind speed distribution in the given part of the year and also to forecast energy production in a wind farm. The dominant wind direction is another information from the wind measurements. It is important for planning the location of wind turbines in the area of a future wind farm (in the case of mine dumps, it is the flattened top of the dump).

The vertical wind speed profile (Green Power Development website) or the speed gradient in the boundary layer defines wind speed as a function of height above the ground. It is of key importance in wind energy, and its knowledge allows to determine the energy efficiency of a wind turbine. In practice, it is determined using the interpolation function on the basis of wind measurements or, less precisely, on the basis of the roughness class of the terrain.

Measurement of wind speed and direction at the monitoring station is taken at the height of 2.5 m. Approximate wind speed at higher altitudes should be calculated. Function (1) is one of the most popular functions that interpolate the vertical wind speed distribution (Radziewicz, 2009):

$$V = V_{known}\left(\frac{h}{h_{known}}\right)^{\alpha} \qquad (1)$$

where:
α – power factor of a terrain roughness
V – wind speed
h – height

In Poland, for the purposes of wind energy recovery, a 6-class of terrain roughness is proposed, and the corresponding power factors α are given (Table 3).

Tab. 3. Terrain roughness classes in Poland (Radziewicz, 2009)

Roughness class	Gradient wind height H_G [m]	Power factor α	Site description
0	300	0.150	Flat open land on which the height of irregularities is less than 0.5 m
1	330	0.165	Flat open or slightly waved terrain. There may be single buildings or trees at large distances from each other.
2	360	0.190	Flat or wavy terrain with large open spaces. There may be groups of trees or low-rise buildings considerably apart from each other.
3	400	0.220	Terrain with obstacles, i.e. forested areas, suburbs of larger cities and small towns, loosely built-up industrial areas.
4	440	0.270	Terrain with numerous obstacles in close proximity, i.e. clusters of trees, buildings at a distance of min. 300 m from the place of observation.
5	500	0.350	Terrain with numerous large obstacles close together, forested areas, centers of large cities.

Figure 8 shows the wind rose recorded at the LW "Bogdanka" mine dump in 2021.

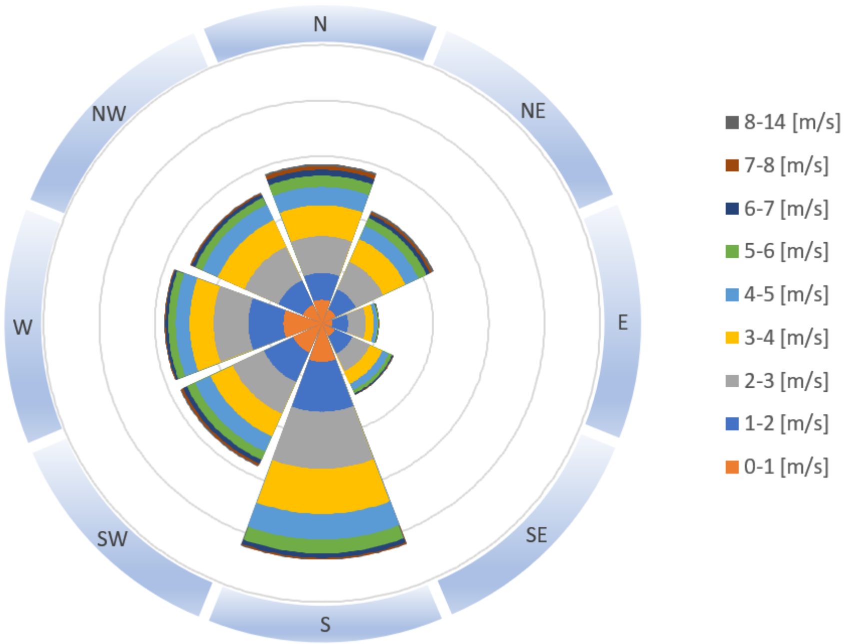

Figure 8 Wind rose recorded on LWB dump in 2021

On the basis of measurements, it is possible to develop the wind rose during the year and, as a result, also to forecast electric energy production in a wind farm. The dominant wind direction (in this case, it is the southern direction) is additional information from windiness measurements. It is important for planning the deployment of wind turbines on the site of a future wind farm.

Flat the non-overgrown mine dump (or a hill) area, if required, is classified as roughness classes 0 or 1, which will improve the economic analysis results in the construction of wind farms. In addition, the mine dump slope angle, causing laminar or turbulent airflow, impacts the efficiency of wind turbines on dumps. The artificial elevation (a dump) creates an area of increased air flow rate.

Ground temperature

In below-zero temperatures, the water in the ground freezes, causing the so-called frost heaves. These can damage foundations, drain pipes, geothermal heat exchanger pipes, etc. The depth of ground freezing is the distance from the surface to the end of below-zero temperature. The ground is usually moist and also freezes. Poland is located in a warm, temperate transition zone. Every winter, there are severe frosts. This is a typical phenomenon. If the frosts are severe and of long duration, the ground may freeze to a great depth. The area of Poland has been divided into four zones depending on the depth at which the ground freezes (Inżynier Budownictwa website). For each of the zones, the depth of freezing was also indicated (Table 4).

Tab. 4. Ground frost zones in Poland

Zone	**I**	**II**	**III**	**IV**
Frost depth [m]	0.8	1	1.2	1.4

The depth at which the building will be located depends on the depth of the ground freezing, its type and the groundwater level. Most ready-made designs include an average foundation depth of 1-1.2 m. The final level of the foundation is determined by the architect, who adapts the design to a building's specificity and location. If there are any doubts as to the ground quality, it is worth ordering the geotechnical survey. After taking samples and analyzing them, a geo-technician can give detailed recommendations. Designing the foundation of wind turbines is one of the most difficult engineering tasks. The biggest problem is the complexity of the loads transmitted by the foundation onto the subsoil. In addition to static effects, there are also dynamic effects related to the operation of a wind farm. During the preliminary work, field tests to a depth equal to about 1.5 of the foundation diameter are recommended before constructing a wind turbine. It is important that at the stage of planning the ground tests, the people who decide on their scope and foundation method should be aware of the complexity of the issues of cooperation between the structure and the soil. On the basis of field and laboratory tests, the following geotechnical parameters necessary for the correct designing of the foundation of the structure should be determined:

- type of soil divided into lithological layers,
- maximum level of the groundwater table,
- parameters describing physical properties,
- effective strength parameters of the soil,
- shear strength of the soil without drainage,
- static and dynamic soil deformation modules,
- Poisson's ratio with drainage and without drainage.

In the project, which aims to investigate the possibility of revitalizing the mine dumps by the installation of renewable energy sources, for example, wind turbines, the ground temperature at a depth of 0.5 m and the groundwater level in piezometers were monitored. According to the map of soil freezing zones in Poland, the LW "Bogdanka" mine dump, on which the measurements were taken, is located in zone II, i.e. the freezing depth for this area is 1 m. According to the measurements throughout 2021 (Figure 9a), the soil temperature in the dump at a depth of 0.5 m approached 0°C but did not drop below zero, even in the coldest month – February (Figure 9b).

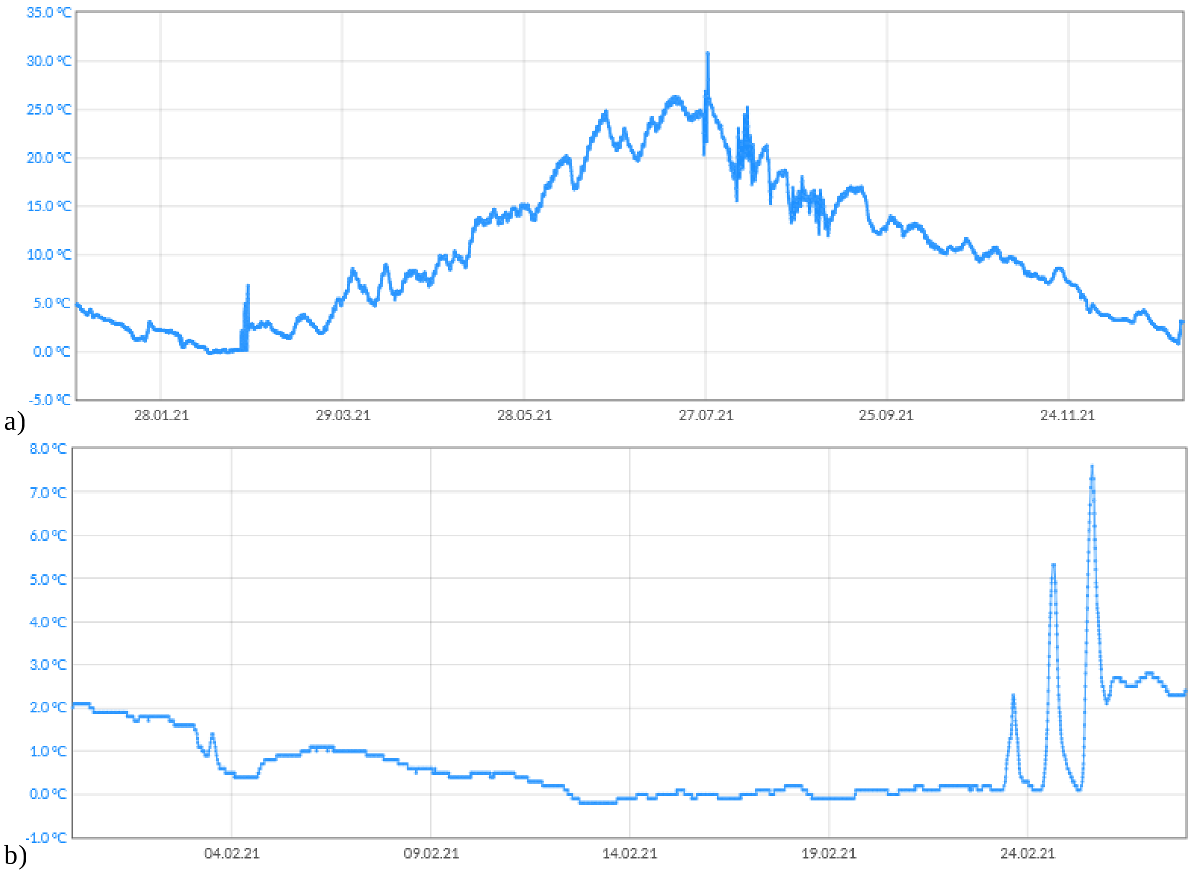

Figure 9 Ground temperature (-50cm) recorded on LW "Bogdanka" dump: a) in 2021, b)in February 2021

The above results do not give a complete view of the ground temperature because the observation period was too short. Air temperature indicates that 2021 was relatively warm. There were no long periods with temperatures below 0°C. Measurement of temperature with a thermal imaging camera showed that the mine dump did not show thermal activity in the investigated area.

Groundwater level

The presence or absence of groundwater is an extremely important parameter for designing the foundations. Foundations can be heaved even by about 30%. Taking into account the significant impact that this has on the investment costs, it is always advisable to carefully investigate the water situation, for example, with piezometers. In addition, reference can be made to archival measurements in the area. The variability in the water level over a 20-year may be quite large. In this context, the water level analysis of the given investment area as well as the identification of watercourses or the risk of water accumulation, are also helpful.

Groundwater level sensors were installed at the beginning of July 2021. From then, the water level in both piezometers was recorded. Within a period of data analysis, several rapid increases in water levels were observed (Figure 10). The first increase took place on August 1, 2021 (in the M-1 piezometer), and then on August 24 (P-1) and August 30 (M-1).

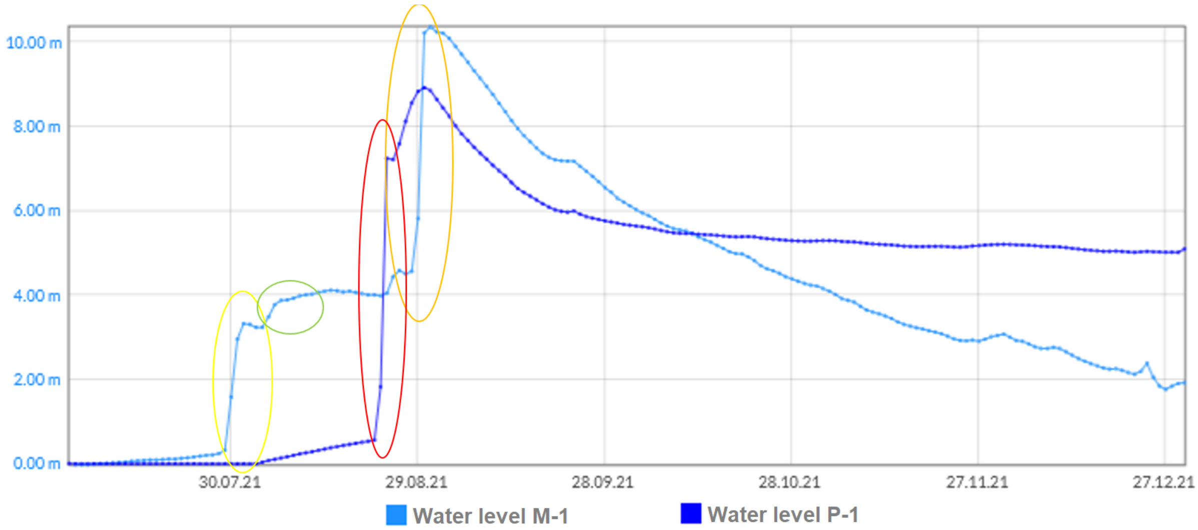

Figure 10 Water level at weather station M-1 (blue) and at point P-1 (dark blue)

To analyze the above picks in water level, they were compared with the recorded rainfall. Due to the failure of the rainfall sensor at the weather station, data from a nearby weather station located in the vicinity of Lublin were used for comparison (Figure 11).

	Temperature				Rainfall		
Date	t	tx	tn	tng	RRR		
2021-08-01	21.0	25.8	15.6	[illegible]	14.8	0.0	14.8
2021-08-02	16.8	22.7	14.7	14.7	0.6	0.6	0.0
2021-08-03	17.0	22.4	11.3	9.6	1.7	0.7	1.0
2021-08-04	17.1	21.3	11.7	9.4	0.0	0.0	0.0
2021-08-05	15.0	17.8	12.3	9.4	30.2	6.6	23.6
2021-08-06	15.4	18.2	13.3	13.3	2.1	1.7	0.4
2021-08-07	18.1	24.5	12.5	12.3	0.0	0.0	0.0
2021-08-08	19.2	23.3	14.6	12.2	7.9	0.2	7.7
2021-08-09	19.5	25.2	15.4	14.6	0.0	0.0	0.0
2021-08-10	19.7	26.1	13.8	11.3	5.4	0.0	5.4
2021-08-11	17.4	23.4	13.4	11.1	0.0	0.0	0.0
2021-08-12	17.3	22.8	12.0	10.0	0.0	0.0	0.0
2021-08-13	18.7	25.6	10.7	7.4	0.0	0.0	0.0
2021-08-14	21.9	28.9	14.6	11.9	0.0	0.0	0.0
2021-08-15	22.6	30.0	15.9	13.3	0.0	0.0	0.0
2021-08-16	22.2	28.0	16.4	13.8	14.9	0.1	14.8
2021-08-17	16.2	23.3	14.6	13.2	0.0	0.0	0.0
2021-08-18	14.3	19.2	10.6	8.3	0.0	0.0	0.0
2021-08-19	16.4	21.7	10.4	6.9	0.0	0.0	0.0
2021-08-20	18.7	23.3	13.1	10.2	0.3	0.0	0.3
2021-08-21	16.4	21.3	13.5	11.4	0.0	0.0	0.0
2021-08-22	17.2	23.5	9.3	5.9	0.0	0.0	0.0
2021-08-23	15.4	18.6	14.7	12.6	43.6	36.0	7.6
2021-08-24	12.4	15.6	11.3	[illegible]	51.3	48.3	3.0
2021-08-25	12.0	16.7	8.6	8.9	0.1	0.0	0.1
2021-08-26	11.2	13.9	8.0	4.6	7.7	7.6	0.1
2021-08-27	13.0	17.2	10.7	10.3	2.3	1.8	0.5
2021-08-28	14.1	19.1	11.5	10.8	0.0	0.0	0.0
2021-08-29	13.2	16.3	8.5	6.6	1.4	0.2	1.2
2021-08-30	12.9	14.6	11.8	[illegible]	16.7	9.5	7.2
2021-08-31	13.4	16.9	12.0	9.8	[illegible]	1.2	0.0

Figure 11 Data from a weather station near Lublin (August 2021)

A clear correlation can be seen here – a rise in the water level in one piezometer causes a slow rise in the other. Precipitation on August 1 (yellow) and August 5 (green) resulted in an increase in the water level at point M-1 (at the weather station) and a slight increase in P-1. Heavy rainfall on August 24-25 (red) caused a sharp increase in the level at P-1 and a slight increase at point M-1. After the pick in P-2, further growth was stable, while the next rainfall on August 30 (orange) caused a sharp increase in point M-1 (by 6 meters).
It is difficult to explain such fluctuations in the water level in the mine dump because, despite heavy rainfall, these changes should not be so sudden. The graph, however, is not a form of a pick which does not indicate a human factor or a sensor error. The increase in water levels was significant but spread over a (short) time. Presumably, as a result of the terrain next to these piezometers, the rainwater that collected on the surface found its wa y to the piezometer holes (where there are plastic pipes covered with gravel) and caused the level in the piezometer to rise. In the following months (September-October), piezometers are "drying". Since August 2021, there has been no such rapid rise in water levels. The results indicate that after these leaks, the piezometers were sealed by the siltation of the gravel bed.

The hydrostatic probes indicate the water level above the sensor (converted from pressure). In both piezometers, the probes were lowered to a depth of 25 m; therefore, in order to obtain the water level below the ground surface, the results of the sensors should be recalculated. Even in the case of a sudden pick in the water level in piezometers, recorded in August 2021, in relation to the mine dump surface, the highest level was -15 m. At the end of 2021, the water in the piezometers remained at -21 m and -23 m. These are the values safe for all foundations, including the construction of wind turbines.

Conclusions

Mining activities (in particular open pit and underground mines) produce waste deposited in mine dumps. There are over 1000 mine dumps in Europe, and only some of them were revitalized to bring profits. Mine areas, including dumps, may be profitable and can contribute to electric energy production in the European Union countries.

The SUMAD project verified the possible future use of the mine dumps. Dumps occupy a large area and have a high volume. They differ in shape, material content and terrain potential. Investing in renewable energy sources that bring benefits from wastelands for the economy and environment is one of the most beneficial ways of managing mine dumps or abandoned mines.

A method for assessing the location for potential investments in renewable energy sources was suggested in the project. The method consisted of recording the selected parameters and analysis of their impact on the legitimacy of building photovoltaic and wind power plants. The results can be used in the decision-making process on the optimal use of the mine dump revitalization method. Only the selected environmental parameters on the LW "Bogdanka" mine dump were monitored and analyzed for the usefulness of proposed sustainable revitalization activities.

The recorded intensity of solar radiation, important for assessing the efficiency of photovoltaic cells, showed that conditions for constructing a photovoltaic power plant on the LW "Bogdanka" mine dump are very good – photovoltaic panels should work with efficiency higher than the nominal one. Significant dust concentration related to the mine dump development and agricultural areas in the vicinity of the mine dump makes it necessary to take into account the cleaning of photovoltaic panels in the operating costs. In the summer months, the air temperature at the measuring site (on the flattened part of the mine dump) exceeded 40°C. This may be related to the direct exposure of the measuring station to sunlight. Installing the photovoltaic panels in such a location is beneficial due to the lack of buildings and vegetation that can cause shading, but then again, the panels are exposed to heating up to a temperature of over 70°C, which will reduce their efficiency by 15%. In 2021, there were not many hot days with temperatures above 40°C, but such periods should be anticipated in the planning of profits from the photovoltaic power plant.

Other recorded parameters, i.e. wind speed and direction, affect the efficiency of wind turbines. South wind direction dominates, and the wind conditions at the monitoring site are good. Ultimately, before investing in wind turbines, it is recommended to take wind measurements at a height not lower than 75% of the turbine rotor axis height. The construction of wind turbines depends on the ground parameters, mainly due to the complexity of loads transmitted by the foundation onto the ground. In-situ tests during the preliminary work before building a wind turbine are recommended. Ground temperature, the volume of precipitation and the water level on the mine dump was recorded. It was found that the frosting depth in 2021 did not exceed the normative values for eastern Poland. Intensive rainfall in several short periods of the year caused an increase in the aquifer horizon recorded by piezometers. The highest recorded water level was 15m below the surface where the monitoring station was built. The landform of the mine dump causes its systematic drying – at the end of 2021, water levels in piezometers were over 20 m below the surface. The results show that there should be no problem with losing the stability caused by precipitation and high aquifer horizon.

The land on which the mine dumps are located are mostly non-public areas; therefore, the owners are responsible for their management. Recently, mining companies have included waste management as one of their strategic objectives. Due to the potential hazards resulting from the mine dumps revitalization, a thorough risk assessment is a major aspect that should be considered before commencing any project.

The monitoring data, once scientifically analyzed, can be used in the decision-making process on the optimal use of the mine dump revitalization method. Detailed analysis of some parameters requires extended knowledge, for example, in geology or foundation design. Therefore, it is important to take advantage of relevant specialists' knowledge when analyzing the results of tests before investing in RES. The presented data show good potential for the Bogdanka mine dump in terms of its revitalization by the installation of RES. Thanks to the SUMAD project, the authorities of Bogdanka can use the measurement results for further analyzing the viability of the investment. It is worth mentioning that the Bogdanka Mine undertakes many initiatives to minimise the amount of waste transferred to the mine dump. In the context of revitalization solutions applied at the facility itself, it strives to respect the expectations of many stakeholders.

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