ASSESSMENT OF ADVANTAGES AND LIMITATIONS OF INSTALLING PV ON ABANDONED DUMPS

OCENA ZALET I OGRANICZEŃ INSTALACJI FOTOWOLTAIKI NA OPUSZCZONYCH ZWAŁOWISKACH

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The feedback of international practice shown that the installation of photovoltaic (PV) parc on the dumps is one of the best environmental and economic solutions. However, the number of projects is still very limited comparing to the identified potential. This paper addresses site selection criteria for landfill PV installation, particularly in relation to mining hazards. For installing the PV, different environmental, technical and economic criteria should be respected. The slope of the dumps appears as the main constraint for the installation of photovoltaic panels. In addition, specific foundation systems should be considered to ensure long-terms safety and security. The paper presents several examples of installation of photovoltaic panels on coal-lignite dumps in France.

Keywords: *dumps, photovoltaic panels, criteria, post-mining hazards*

Praktyka międzynarodowa wykazała, że instalacja parku fotowoltaicznego (PV) na zwałowiskach jest jednym z najlepszych ekologicznych i ekonomicznych rozwiązań. Liczba projektów jest jednak nadal bardzo ograniczona w stosunku do zidentyfikowanego potencjału. W artykule omówiono kryteria wyboru lokalizacji dla instalacji fotowoltaicznej na zwałowisku, w szczególności w odniesieniu do zagrożeń górniczych. W przypadku instalacji fotowoltaicznej należy mieć na uwadze różne kryteria środowiskowe, techniczne i ekonomiczne. Nachylenie zboczy zwałowiska wydaje się być głównym ograniczeniem dla instalacji paneli fotowoltaicznych. Ponadto, aby zapewnić długoterminowe bezpieczeństwo i ochronę, należy rozważyć specjalne systemy fundamentów. W artykule przedstawiono kilka przykładów instalacji paneli fotowoltaicznych na zwałowiskach powstałych po eksploatacji węgla we Francji.

Słowa kluczowe: *zwałowiska, panele fotowoltaiczne, kryteria, zagrożenia pogórnicze*

Introduction and context

One of the biggest challenges in the coal mining industry is waste disposal during and after the mining operation, and associated costs (Golam, 2015). The ratio of the volume of the stripped overburden to the mass of produced coal is known as the stripping ratio, which varies between (waste material: coal or lignite) 1 to 10 throughout Europe (Ernst & Young, 2014). Mining and quarrying activities in Europe generate approximately 55% of total industrial wastes, according to a recent Eurostat report. Chmielewaka & Otto, (2014) mentioned that the Ruhr district of Germany has 104 spoil tips the large majority are from coal mining activity. 1,300 coal tailings were identified in France (Guezennec et al., 2013). In Poland, for each ton of hard coal mined the collieries obtain 0.3-0.5 t of waste, resulting in about 16-30 mt per year. As an example, the Bełchatów mine is one of the largest excavations in Europe. It annually produces 38.5 million tons of lignite and 100–120 million m^3 of excavated overburden materials (Bednarczyk, 2016). According to local authorities in Silesia region about 1.5bt of waste are stored, with coal mine waste constituting about 80% of this amount. It is estimated that there are 200 coal mine waste dumps in Poland with a total area of 4.000 ha.

The identification of sustainable reuse opportunities of dumps is certainly an attractive business for coal region in transition. This waste can under certain conditions be used for different types of engineering work including recultivation and levelling of degraded areas, highway engineering, cement production and mining (e.g. hydraulic stowing). The main revitalization and valorisation of the dumps-spoils are (Fig. 1): civil engineering project; backfilling; agriculture; sport and hobbies activities; renewable energy installation; sites for biodiversity conservation. Renewable energy production objective meets the objective of global energy transition. These new economic activities represent a potential for job creation, increased revenues, revitalization, economic development, stability for local and regional energy grids (Dias et al., 2018).

The installation of the photovoltaic panels (PV) on the dumps is one of the main reuses and is continuously increasing. The paper addresses the main selection criteria related to mining land and mining hazards. The objective is to assess the risks and the limitations of the installing the PV on dumps and spoils (coalmine).

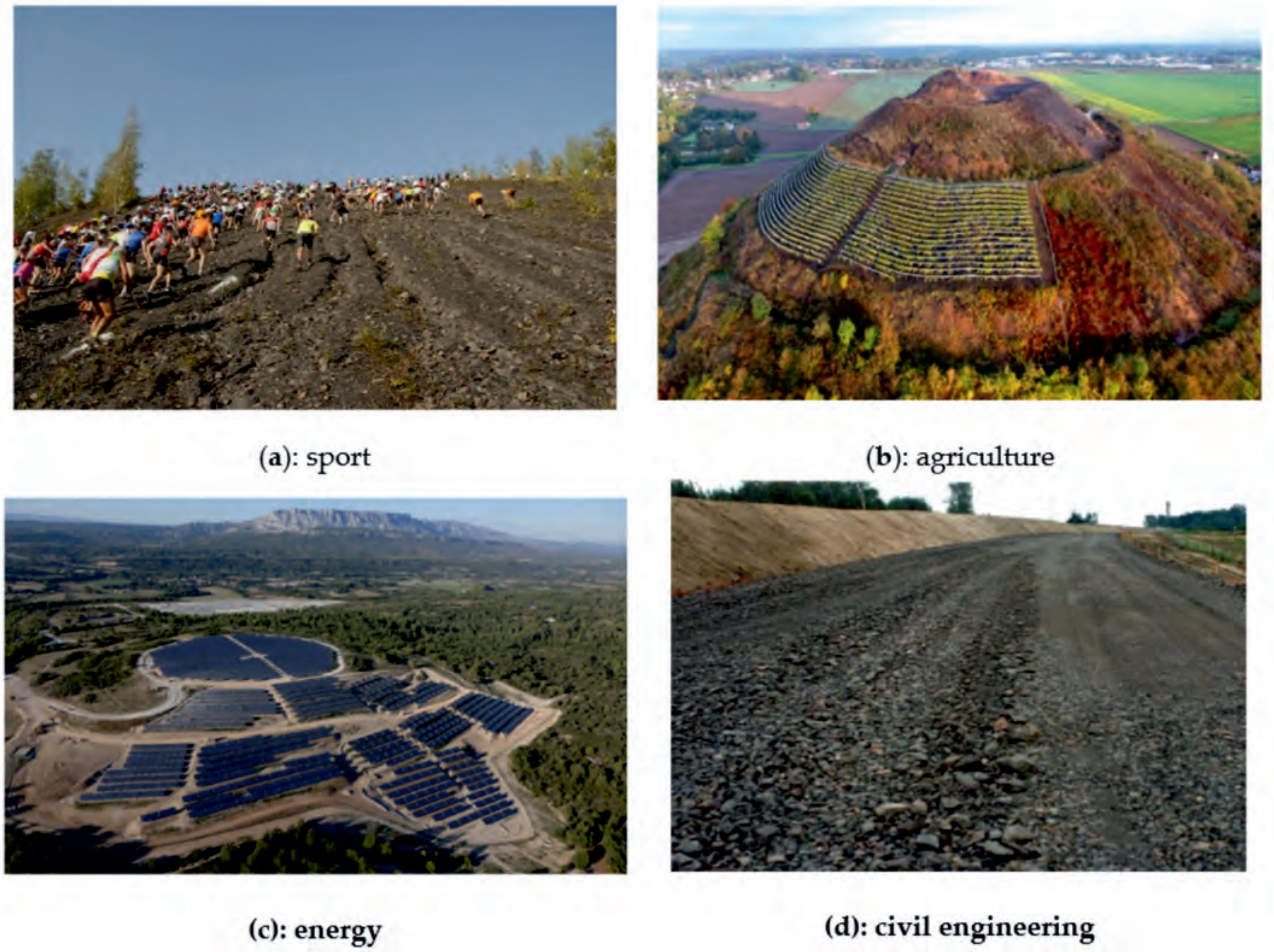

Fig. 1. Various activities can be developed on dumps of abandoned coalmines – (Mission bassin minier – France – 2007)
Rys. 1. Na hałdach opuszczonych kopalń można prowadzić działania z różnych dziedzin – (Mission bassin minier – France – 2007)
(a): sport (b): rolnictwo (c): energetyka (d) inżynieria lądowa

Renewable energy installation: solar panels and site selection criteria

Many types of factors influence the decision to install PV in general (Fig. 2): legal, environmental, technical, financial and socio-economic (Georgiou and Skarlatos, 2016, Mierzwiak and Calka, 2017). For the environmental aspect, factors to be considered include visual impacts, land use density, wildlife impacts, reflection effects, depletion of natural resources, and waste management. The financial factors are closely related to the technical ones. The main selection criteria are land use, solar resource, network connection constraints and restrictions due to ground slope. These can include the location of the farm relative to the power lines, available sunlight hours, etc. Access to a road is also an important factor to be considered in any large-scale PV projects (Palmer et al., 2019, Noorollahi et al., 2016, Kereush and Perovych, 2017). The slope angle and the foundation type are important criteria for mountain and sloppy land.

Degraded land (Dumps)

The coal mine sites including dumps and heaps can provide economic value and contribute to the energy production of the EU states. Using abandoned open-cast coal mines and their surroundings for the installation of PV systems and wind firms is an approach with several advantages for the economy and the environment. Indeed, some abandoned mine sites may be in areas that may not be well-suited for classical commercial or industrial reuse opportunities. The following abandoned mines lands (AML) sites can be considered very suitable for the installation of PV farms:

- degraded lands (industrial wastelands, old open pit mines and dumps, etc.),
- sites with low potential in terms of agronomic value soils, fauna and flora,
- sites with development of activities (grouping with other renewable energies, such as wind),
- sites which are not exposed to natural and/or technology hazards,
- sites with limited impact on the landscape.

Additionally, to general criteria mentioned before, the potential for installing renewable energy at waste sites depends on the location, mine design and other power sourcing options near the dumps and mine sites. The social and economic criteria are generally verified for the reuse of dumps as PV farms. These sites can take advantage of the attributes of local renewable resources to generate electricity in ways that increase energy efficiency and diversity, reduce environmental impact, while enabling productive land reuse. The PV installations require relatively large areas for deployment, and dumps and spoils can offer the necessary land.

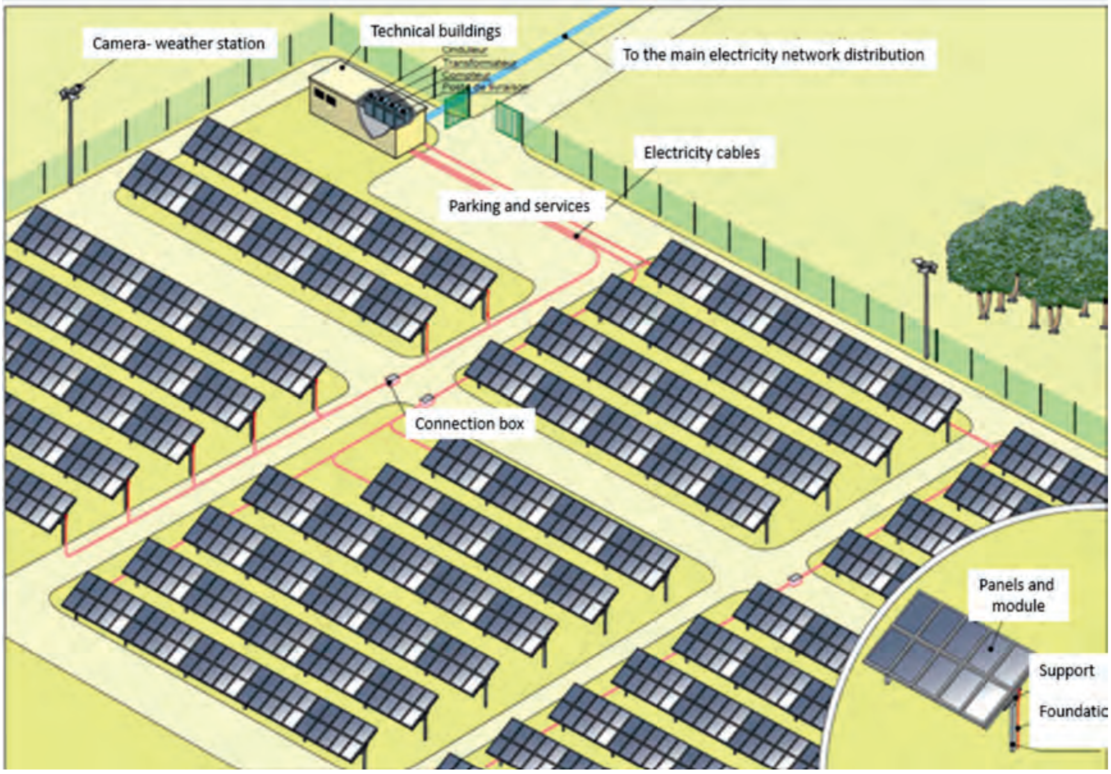

Fig. 2. Photovoltaic central, photovoltaic panel, cables, technical buildings, connection to the main energy gride, etc. MEDTL, 2011
Rys. 2. Centrala fotowoltaiczna, panel fotowoltaiczny, kable, budynki techniczne, podłączenie do głównej sieci energetycznej itp. MEDTL, 2011

Many dumps are located near existing mining infrastructure, including roads and power transmission lines, due to prior mining activities. The typical height of spoil piles ranges from 30m–100m and the slope of the spoil pile varies between 20° to 40°. The slope stability and the PV security should be assessed to predict and mitigate any potential hazard and risk. The availability of existing infrastructure can significantly reduce project costs. In addition, many landfills are located in remote areas with limited electrical infrastructure, making them well suited for the use of solar energy for on-site clean-up and reclamation activities. However, regarding local social and environmental constraints, the reuse and the valorisation of dumps for renewable energy and the installation of PV panels on the spoils can be considered as not useful project by the population mainly during closing coalmines. Because, during years, specific fauna and flora may be installed and developed in dumps areas. That can present a new challenge for the revitalization of the dumps and the installation of PV farm (Folzer et al. 2017).

Technical and economic criteria

The acceptance of PV installation on dumps should consider the following criteria related to mine conditions:

- slope stability,
- settlement and differential settlement,
- fire and internal combustion,
- emission of dust and small soil particles,
- pollution due to effluents and the chemical composition of the dumps,
- preservation of new biodiversity and natural habitats installed on the spoil and dumps during the mining and post-mining periods.

The dumps are inclined land with high slope angle, generally is more than 15°, considered as limit value for such installation. In addition, the bearing capacity of the soil may be less than the minimum value required for the PV foundation. For recent dumps, their soil may still be in processes of consolidation and induce settlement. Installation on dumps may in some cases require the use of piles to ensure the durability of the foundation. The foundation design should consider the static and the dynamic loads, the natural and induced hazards in the zone of the project. The ground movement, the differential settlement and slope stability are the main constraints of the PV constructions.

Concerning the economic criterion, the installation of the PV on the dumps has a positive economic impact. However, at short term, the cost of the project presents an important investment for small towns facing the end of coalmine activities. For this reason, PV projects are the business of private companies who have the capacity to build PV farms. The potential additional cost of setting up on sloping ground can be offset by the price of the land. Degraded land is much cheaper and can be obtained for free. The dumps and spoil can be considered between moderate to suitable for the installation of the PV, this depends on the slope and the solar criteria.

Limitation of the PV installation

The spoils can present technical limitations for the installation of PV regarding the mine hazards. The following points should be considered:

Steep slopes: the angle of the slope is a very important parameter and may be a limitation of the reuse of the dumps for photovoltaic installation. The spoil slope is generally characterized by angles >15°. This situation presents challenges for the stability of the foundation and for the anchoring system: Increasing the wind loads on the panels, the impact of stormwater and finally the effect of the erosion and the stability of the spoil. It can thus be considered that only part of the surface of the dump can be used for the installation of the PV.

Combustion and fire risk: Like any electrical system, a PV system can release large amounts of heat in spots in case of a malfunction, and thereby become a fire source. PV modules are combustible irrespective of their technology and design. The PV module can independently continue burning in the event of a full-scale fire. The installation of the PV on coal or lignite can increase the fire hazard of the dump. The risk assessment should be carried out to mitigate such hazard (Sepanski et al., 2015). In the case of intervention on „cold" heaps containing combustible materials, the risk of overheating must be considered. Earthworks must avoid, particularly, any entry of air and water into the deposit (risk of self-heating).

Settlements: the installation of the PV on loose and/or unconsolidated material can produce differential settlement. Uncompacted soils or soils that have been subjected to combustion phenomena can produce important deferential settlements causing the instability of the installation.

Gas production: the gas production due to the existing of residual quantities of coal and lignite may can affect the PV installation.

Dust emission: dust is defined as solid particles less than 500 µm in diameter. Dust deposition on the panels during windy days can affect the efficiency of PV. This particle absorbs 15% of shortwave energy of the sun. For very small particles, during dry period, the dust can cover the panel and reduce the productivity of the installation. Dust can thus decrease the efficiency of energy production and increase the cost of the maintenance. Additionally, the Transmission access, high up-font cost, cost of storage, permission, responsibility, energy market, funding for the preparation of the site and the installation of the PV on the spoils should be considered. Flooding: A review of flood risk should be undertaken to determine if there are any areas of high flood risk associated with the site. Existing and new drainage should also be considered to ensure run-off is controlled to minimize erosion.

PV installation in France

The French energy strategy is to increase the renewable energy production. Furthermore, the national strategy in France guides the development of photovoltaic energy on degraded sites: industrial or military wastelands, old mines or landfill sites, industrial or artisanal areas. To encourage the installation of the PV on abandoned mines, the specifications of the CRE (Commission de Régularisation de l'Energie) tender offer a bonus of nine points (out of a total of 100) for projects targeting the use of degraded sites such as industrial wastelands, polluted sites or old mines. Different PV installation projects were developed in abandoned coalmine lands (Provence, Lorraine, etc.). 15 installations of PV are currently effectives in France. The following section will illustrate examples from coalmine basins in France.

The Provence colliery is situated in southern of France, between the cities of Marseille and Aix-en-Provence. 37 spoils were identified, their surface varying between 1000 m^2 and 32 ha. Three spoils were revitalized for the installation of the PV panels to produce green electricity and supply the city of Gardanne (Fig. 3).

The municipality of Gardanne, located in the heart of the coalmines installed PV on two of existing spoils: Sauvaire and Bramefan (France). The solar park is part of the site's restoration and offers the opportunity to produce renewable energy on a degraded site. The ambition of Gardanne is to be an energy positive town with no greenhouse gas emissions. With its sunny location, Gardanne has climatic capital that allows it to fully participate in the energy transition. The installation was to use the waste spoils of the former mines to install a ground mounted photovoltaic power plant. The surface of the Bramefan spoil is 75 ha (Fig. 3). The installation of PV concerned mainly the horizontal part of the dump. The second spoil is Sauvaire, located near Gardanne (Fig. 3). The photovoltaic plant does not generate any pollution and produces electricity that guarantees supply for nearly 5,000 households. The surface of the spoil is 35 ha, it occupies a valley; 38,200 modules for a power of 9.36 MWp were installed. The water flows were collected under the deposit. Before the installation of the PV panels, the pipeline was partially obstructed, and pumping was therefore placed to evacuate water accumulating upstream. The solar power plant produces the equivalent of the electricity consumption of 50% of the city of Gardanne each year.

The Lorraine coal basin is located in North-Est of France. The mining activity ceased there definitively in 2004. Several spoils exist (Ste Fontaine, Wendel, Creutzwald, La Houve, etc.). On the most important site, Wendel dump, a photovoltaic park of 12 megawatts was installed (Fig. 4). The creation of a photovoltaic farm on Wendel dump meets the recommendations of the State who wants to develop solar power plants on post-industrial ground, rather than on agricultural parcels. The Wendel heap covers an area of 117 ha and the summit platforms are at an altitude of approximately 300 m NGF. Deposits consist of waste rock. The central platform consists of black shales more or less fine, covered by a rather dense but young vegetation, dominated by verrucose birch showing some areas of fallow land. The dump also served as a landfill of materials from the demolition of various mining facilities. The heap is in the form of a vast plateau with the

Fig. 3. Provence coalmine – Gardanne – France – installation of PV on existing coal dumps (A: Sauvaires, B: Bramefan, C: Madame d'Andrée (URBASOLAR et Google Maps)

Rys. 3. Kopalnia węgla w Prowansji – Gardanne – Francja – instalacja PV na hałdach powstałych po eksploatacji węgla (A: Sauvaires, B. Bramefan, C: Madame d'Andree (URBASOLAR at Google Maps) shape of a crescent. All the deposits of the central heap are 15 to 60 meters thick. The site of the photovoltaic power station corresponds to this central platform (also called central heap). The main hazard linked to this site is the combustion of shale. The Wendel spoil is being monitored by the Mining Police for an old area kept fenced. Beyond this zone, there are 2 hot spots of combustion in the south-west and south-east of the slag, which are being monitored. The main challenges of the project are the production of renewable energy and the preservation of biodiversity and natural habitats. The annual production of the plant (18,600 MWh) represents the equivalent of the annual electricity consumption of approximately 5,600 households (excluding heating) and the saving of 9,700 tons of CO_2 equivalent.

Another example concerns the installation of four PV on an abandoned open mine (Sanvignes-les-Mines - France). In 2021 were installed 28000 PV on more than 14 ha. The energy production is about 14 MWh/year. The site began in 2020 and was commissioned in July 2021 for a total budget of 10 million euros. This energy can fulfil the need of 10 000 habitants. The study demonstrates that the revitalization of the spoil/dump zones is profitable for the communities and corresponding of the main objective for coal regions in transition.

The Nord-Pas-de Calais Mining Basin corresponds to the French part of the northwest European coal layers. Heaps and mine waste lands occupied a surface of 3500ha, for a total weight of 700 million tons of materials stored for 2.3 billion tons of coal extracted (Conservatory of Natural Sites of Nord and Pas-de-Calais, 2005, O'Miel, 2008). More than 339 spoils are localized in the region. Different revitalization projects were developed covering geotourism, museums, agriculture and sport activities. Even the large number of dumps in the basin, non-real renewable energy installation on the abandoned coalmines. On the Loos-en-Gohelle site, as demonstration project, in addition of wind turbines, 136 experimental photovoltaic panels were installed at the foot of the 11/19 pit and twin slag heaps at the former coal mine site in Loos-en-Gohelle, in 2015.

Conclusion

The installation of PV on abandoned coal mines (degraded land) and specifically on dumps make sense and is supported by the European commission. The strategic approaches for reusing and revitalizing dumps are that, once geotechnically stable and environmentally remediated, they could be repurposed for investments into new low-carbon industries including the installation of the PV on dumps land. However, the current situation shown few PV installation projects and installations in Europe and in the world.

The spoils/dumps, of coal mine is overburden waste material, heterogenic and unconsolidated comparing to natural lands. The spoil geometry is generally built as conical or irregular in shape with a high profile in relation to the local topography. The typical height of spoil piles ranges from 30m–100m and the slope of the spoil pile varies between 20° to 40°. The slope stability and the PV security, are the main hazards, should be assessed to predict and mitigate any potential hazard and risk.

The technical progress and adopted solutions can overcome the limitations related to the dump specifications and residual mining hazards. The mitigation solutions to increase the potential for installing the PV on abandoned coal mines must, in addition to the associated economic and social criteria, ensure environmental preservation.

Funding and Acknowledgments: This work has received funding from the European Union's Research Fund for Coal and Steel. under the project „ Sustainable Use of Mining Waste Dumps (SUMAD)". No 847227. Financial assistance by the European Commission is much appreciated.

Fig. 4. Lorraine Basin — France – installation of PV on existing coal dump- Wendel (Source: Luxel)
Rys. 4. Lorraine Basin – Francja - instalacja PV na hałdzie powstałej po eksploatacji węgla - Wendel (źródło: Luxel)

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