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CONVERSION OF LAND AREAS AFTER COAL MINE CLOSURE AND RECLAMATION

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Abstract: *Coal extraction in the form of open and underground methods is accompanied by the degradation of land, change in landscape formation and changing the flora and fauna. It is significantly vital to develop new scientifically grounded approaches to the restoration of anthropogenically disturbed landscapes based on the formation of reclamation and mining technologies. It is absolutely necessary to ensure the comprehensive quality preservation of land and water resources and to designate reclaimed land for a new purpose. This article presents an overview of the ranking most popular methods of land recultivation and possibilities of reclaimed land after the completion of reclamation and closure of the coal mine.*

Keywords: *recultivation, reclamation, revitalisation, coal mining, sustainable development*

1. INTRODUCTION

Mining activity has a large-scale impact on the environment. Coal mining has been quite pronounced considering the topographical changes of the green space that would directly affect the degradation of agricultural lands. Predictions of the effects on the environment are very important and present the concern in the sense of the loss of surface area and space for living. The study on the environment has a basic description of the effects that are expected, and it is a basic document that serves for the design of mining activities. During the operation of coal mine, a large void will be created. Filling of the areas with humus soils during coal exploitation will be parallel in time, which will enable the return of the areas to beautiful landscape based on soil analyzes and results.

Recultivation should be considered from the perspective of geoaesthetics, which implies a harmonious incorporation of the recultivated landscape into the environment [1].

Much of the terminology around mining-related land rehabilitation is used incorrectly. ‘Land capability’, ‘land use’, ‘landform’, ‘rehabilitation’, ‘landscape’ and ‘mine closure’ are used loosely and sometimes interchangeably. Although the eventual goals may be similar, each term implies a specific action or activity that requires individual planning consideration [2].

Land reclamation is a dynamic ecological restoration process, and rehabilitated vegetation requires a certain amount of time to develop, stabilize and mature. The development characteristics of rehabilitated vegetation at different land reclamation stages are significantly different, and these differences can be used to identify the key stages of land reclamation [3].

Land reclamation plays a vital role in the ecological improvement and economic development of mining regions [4].

Jackson and Hobbs, 2009 [5], defined mine rehabilitation has to compensate the ecological impact - up to date as possible and depending on the intensity/level of disturbance. In most cases it is simply impossible to restore the historical systems due to the changing environmental and habitat conditions, land use claims

and societal needs after coal mining. Following the definition of the term "restoration" describes the more ambitious aim of re-establishing ecosystem structure and function as before disturbance - replicating the reference ecosystems [6-8].

2. REQUIREMENTS OF LAND RECULTIVATION

This paper is part of research applied to the coal open pit Drmno, which has as general objectives as impact of mining in the area, as well as ecological conversion solutions for coal open pit Drmno (one of the open pits of Kostolac Basin Mining Basin), favoring significant opportunities for business development in agriculture, industry, crafts, recreation, sport, and tourism. Also, this paper presents a proposal to choose the type of re-use of the land affected by coal exploitation in the Kostolac Basin, taking the important principles of ecological planning.

2.1 Study area

The location "Drmno" is an external tailings disposal site from PK "Drmno". The maximum length is 2 km, width 1.2 km and height 50 m. The landfill slopes have been reclaimed. The thickness of bulk overburden material is 40-50 m. The area belongs to “Drmno” open pit is in the eastern part of the Kostolac coal basin, i.e., east of the Mlava River. (Figure 1)

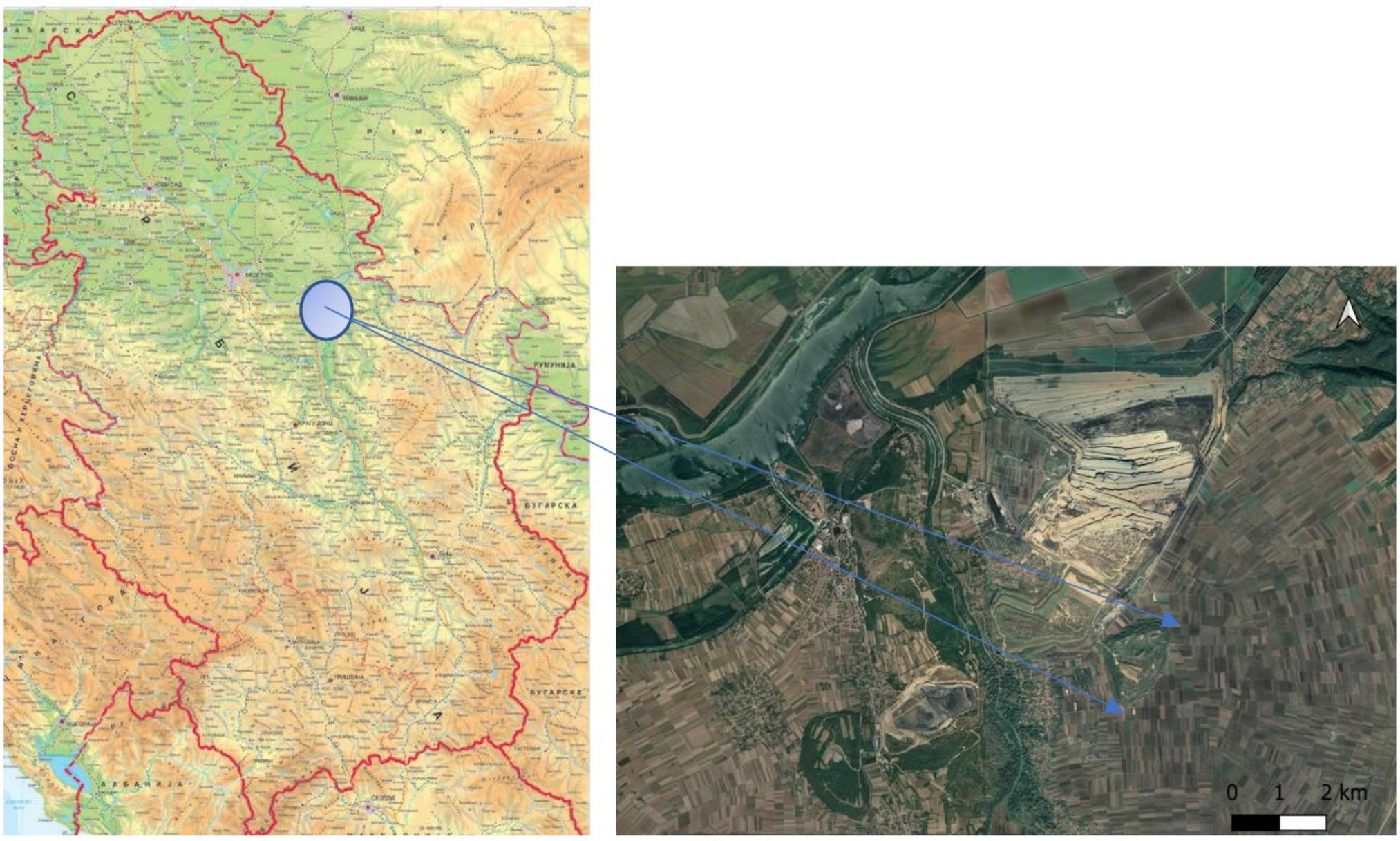

Figure 1. *Location of study area - Drmno*

The Kostolac mining and energy basin is part of the municipality of Kostolac and the Braničevo district. The Drmno deposit area, as part of the southern rim of the Pannonian basin, has a moderately continental climate, in which the steppe-continental climatic influences of the neighboring Banat are emphasized. The average annual air temperature in the wider area ranges from 10.6°C -12.3°C, the mean annual maximum air temperature is 16.0°C -18.0°C, and the mean annual minimum air temperature is from 5.9°C to 7.3°C [9].

The modern morphology of the terrain has been significantly changed. Surface mining of coal had the greatest influence on the change in terrain morphology (PK "Novi Kostolac", "Klenovnik" and "Ćirikovac", with disposal sites for overburden and ash, i.e., slag from the thermal power plant). similar of the relief changes in the originally flat Stig - south and east of Drmno (PK "Drmno", with coal overburden deposits). In choosing of the final re-use option of the lands of Drmno open pit we considered several indicators:

- geomorphological changes in the area
- Drmno ecological green rehabilitation options
- opportunities for land reuse (agricultural, forestry, recreational) compared to the regional development plan, population requirements, elements of local interest.

The importance of choosing the best option for re-use also involved an initial consultation of the local population and decision-makers on land reuse in the Drmno open pit.

Recovery of degraded land from mining activities in the economic circuit comes to meet a requirement of current legislation and a requirement of the local community, thus solving several problems: eliminating the risk of sliding of positive relief forms occurring in a territory by depositing the sterile material in the external waste dumps; the elimination of the negative visual impact; the need to reintegrate the degraded areas into the productive and/or ecological area of the regions where they are located, which leads to the regeneration of their economic potential; improving the quality of the environment; reducing slopes and diminishing the intensity of erosion phenomena and accelerating the vegetation installation process.

3. LEGAL ACTS RECULTIVATION BINDING IN EU AND SERBIA

Europe-wide harmonized system and international platform for collecting, assessing and mapping the environmental data concerning coal mining activities is still missing in contrast to the socio-economic concern. The same can be applied to the quality land reclamation and follow-up use of reclaimed land. Even though there is considerable progress in recultivation practices and technologies, failures concerning landform design and post-mining land management are common.

To minimize the ecological footprint of mining, the overarching EU Extractive Waste Directive 2006/21/EC has been adopted. Article 1(a) of Directive 75/442/EEC defined the safe operation of mining, cover the management of waste (the prospecting, extraction, transport, storage and treatment of mineral resources and the working of quarries).

According to the Serbian Law on Mining, technical and biological reclamation and spatial arrangement must be performed with the purpose of environmental protection, regeneration, land reclamation and arrangement of the degraded areas. The importance of this law is the fact that it elaborates and complements the existing legal framework while at the same time further harmonizing it with the relevant EU legislation [10].

Basic decisions on the national level are sometimes contradictory and leave space for discussion about the energy strategy in Europe. On the one side, the coal phase-out gathers pace. Most EU countries have announced the national coal phase-out. On the other hand, countries in East and South Europe like the Czech Republic, Poland, Croatia, Slovenia, Serbia, Romania, Bulgaria or Greece still depend on their economic development from coal production.

4. PLANNING OF RECULTIVATION

The reclamation planning process is crucial for the overall effectiveness and efficiency of the implementation of open pit reclamation. In the process of planning, i.e. selection of the reclamation model on which all further planning activities depend, can be used various multi-criteria decision-making methods such as Promethee, AHP, TOPSIS. Decision support models consider several criteria to determine the optimum solution, also used to support decision makers in solving complex problems through simple procedures.

It is important to point out that the defined model can be used in all planning and exploitation phases of an open pit mine, regardless of whether it is a new mine or an open mine where exploitation is carried out. The iterative nature of the model enables corrective measures during the implementation of reclamation plans and, in this connection, optimal decision-making on the final plan of reclamation and rehabilitation of the area in the phase of closing the surface mine.

Table 1 shows comparison of the methods that can be applied to select the purpose of the terrain after reclamation, their feature, advantages and disadvantages.

Table 1. *Comparison of methods which can be used for choosing a recultivation solution*

Method	**Feature**	**Advantage**	**Disadvantage**
Promethee	Partial ranking of the actions, based on the positive and negative flows	User-friendly outranking method, completeness of ranking, partial and complete ranking of alternatives, respectively.	Does not provide a clear method to assign weights and it requires the random assignment of values
Analytic hierarchy process (AHP)	Combination of qualitative and quantitative analysis.	Make decisions in a comprehensive way of thinking and systematically treat research objects as a system.	Cannot provide new options for decision-making.
TOPSIS	Chosen alternative should have the shortest geometric distance from the positive ideal solution	Simplicity, comprehensibility, ability to measure the relative performance for each alternative in a simple mathematical form.	Can cause the phenomenon known as rank reversal, when alternatives order of preference changes when an alternative is added to or removed from the decision problem.
Logical Framework Approach (LPA)	Use simple diagrams to analyze complex relations.	Clarify the cause and effect in the project.	Greatly affected by important assumptions.

Figure 2 shows what conditions and problems should be considered by the decision maker, as well as thoughts on purpose after reclamation.

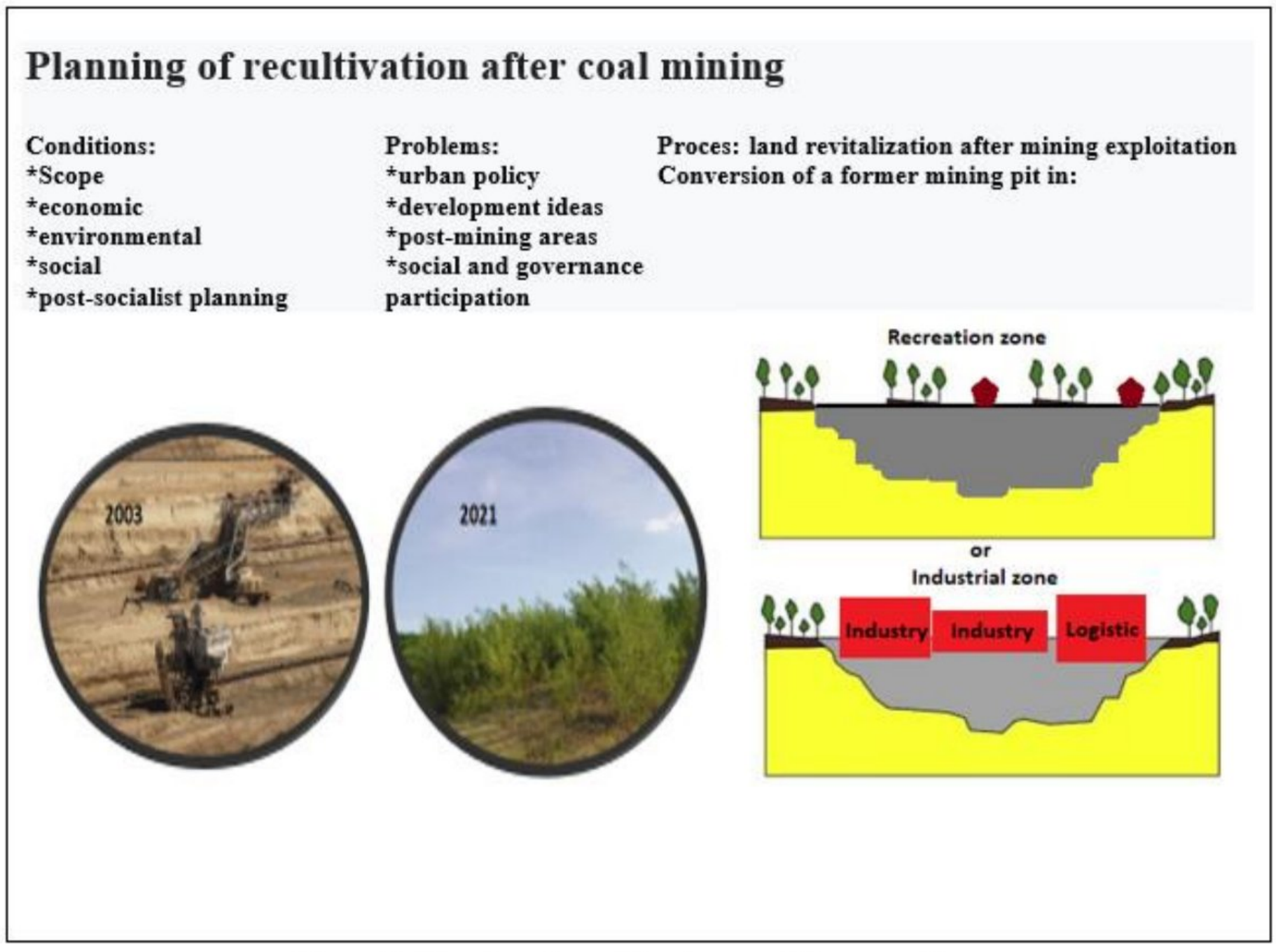

Figure 2. *Planning of recultivation, conditions, problems*

This paper presents a tabular presentation of possible, assumed variants or alternatives of recultivation solutions, as well as their combinations, which can be used in the analysis of the choice of arrangement of post-exploitation landscapes (Table 2). The subject of our research is the surface mine Drmno viewed as a training ground for experimental analysis of the choice of the type of reclamation and the appropriate arrangement of the landscape.

Such process modeling of the unified reclamation system foresees a total of 10 alternative possibilities for designing reclamation contents and arranging the post-exploitation landscape of landfills.

Table 2 *Alternative solutions for the purpose of the terrain*

Ordinal number	**Variants or alternative solutions for the purpose of the terrain**
A1	Forestry
A2	Agriculture - farming
A3	Agriculture - pomiculture
A4	Agriculture - viticulture
A5	Forestry and agriculture (combination A1/A/2, A4)
A6	Park and horticulture
A7	Zone for industrial construction - wind generators
A8	Zone for industrial construction – solar panels
A9	Agricultural settlements and restitution for rural settlements +A11/A1-A5
A10	Surrendering to spontaneous succession and self-cultivation

For each alternative, criteria can be determined, as shown in the table 3. According to these criteria, it is possible to choose different reclamation solutions that combine technical and biological recultivation.

Table 3 *Determination of criteria*

Ordinal number	**Eligibility criteria**	**Category**	
		D	**E**
K1	The amount of investments per unit of area	**x**	
K2	Investment period - investment time	**x**	
K3	Time of return of invested funds	**x**	
K4	Annual maintenance costs per unit surface	**x**	
K5	Adaptability of the recultivation solution to the environment		X
K6	Local needs (local community interest)		X
K7	Social and economic importance of reclamation for the local community		X
K8	The percentage share of the recultivation form (variant) in the total recultivation operation	x	
K9	Technological complexity of carrying out reclamation works		X
K10	Organizational complexity of the execution recultivation		X
K11	Post reclamation continuous maintenance time	**x**	

Interpretation: D - Deterministic, E - Expositive, x – no alternative, ***x*** *– alternatively (preferably), X – alternatively (necessarily)*

One of the possible uses of the reclaimed terrain is the option of building photovoltaic panels or wind generators. Photovoltaic panels represent a workable solution to the question of how to restore areas degraded by years of coal mining in a way that balances ecological health with economic needs. One of the solutions was to combine ecological restoration with a solar-power generation base, thereby creating a situation with ongoing economic viability.

Using reclaimed mine land for solar energy projects is very attractive for the mine's post-closure phase. Coal mining concession areas are generally larger than the mined area. Mining operations expand progressively during the operation lifecycle of the coal mine and portions of the site can be used for renewable power production. The application of solar PV systems provides an opportunity for an alternative revenue source. Equally important is that obtaining licenses to operate in the coal mine rehabilitated land may get easier and faster because generally there is no public opposition and no competition with agricultural activities. Figure 3 shows Photovoltaic panels in Boortai Coal Mine in China (left) [11], solar plant in Klettwitz former open pit mine, Brandenburg, Germany (right) [12].

Figure 3. *Using solar and wind energy on recultivated site - Photovoltaic panels in Boortai Coal Mine in China (2022) on left side, solar plant in Klettwitz, Germany on right side*

One of the most prominent environmental engineering issues facing Drmno in recent years is the need to rehabilitate and reallocate a former coal open pit mine. Fortunately, new technologies act as a facilitator for the conversion of this type of land. Rehabilitation and reallocation of these sites often prove to be a difficult enterprise. Costs usually become excessive and offer few options for repurposing. These projects tend to prove quite costly in terms of the project itself and preliminary soil investigation and recultivation.

The demand for alternate usage of these areas is often low, making it somewhat difficult to justify such a long-term project financially. In some cases, the total length and costs of the overall project are unclear at the outset.

Furthermore, building the new solar plant on this site is a huge step in the right direction compared to its previous usage. This rehabilitation allows for the sustainable repurposing of a large area, but it will allow for the reintroduction of an ecosystem previously destroyed by mining contamination. When it comes to reallocating and rehabilitating land after coal extraction, solar plants on conversion sites provide a win-win solution for all participants. The energy efficiency and construction capabilities of solar modules allow for the successful and cost-effective reallocation of environmentally hazardous mining sites that would otherwise stop using. These recultivated lands now have a new, environmentally sustainable purpose, significantly decreasing the area's environmental footprint.

5. CONCLUSION

Surface mining of coal is increasingly determined by many issues related to environmental and sociological values. With constant economic development, corporate social responsibility, and public awareness advance further. More and more attention has been paid to land reclamation areas after coal exploitation. Remediation of degraded areas will still be one of the most important parts of the coal industry in the future, which requires more resources and effort.

Further significant progress in the reclamation is related to several factors:

- basic research, application of the sands, which would be the reclamation friendly and neutral for the natural environment,
- application of the proper material management – soil, leguminous mixtures, seedlings, etc.
- optimization of the existing reclamation methods by introduction of improvements and new solutions to the process, in order to increase quality and yield of the reclaimed land.

This paper and the presented examples aim to show the comprehensiveness and applicability of multi-criteria methods for choosing the purpose of recultivated terrain after the closure of an open-pit coal mine. The crucial point seems to be the know-how transfer into reclamation practice - implementing concrete solutions and site-adapted decision.

Land recultivation and revitalization of damaged lands offers good ecological, economic, and social benefits. This process is highly crucial for sustainable and healthy development of industrial mining

companies. In fact, land reclamation plays a vital role in improving the environment for residents and the ecological landscape, as well as contributing to the economic grow of the mining region.

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