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CURRENT CONDITION OF LIGNITE MINING IN OLTENIA COAL BASIN AND SOLUTIONS FOR REUSE OF MINED-OUT SPACE OF CLOSED PITS

Oltenia Coal Basin occupies the area of 4500 km^2 and encloses the most important deposits of lignite in Romania, many of which are exploited by open-pit mining. Open-pit lignite mining involves long-term occupancy of large areas and considerable negative impact on physical, chemical and structural characteristics of the lands that define the regional terrain, resulting in full degradation of previously existed landscape. The degraded lands require great efforts on their reclamation for recultivation of soils, recovering landscape and overall mitigation of mining environmental impact. Selecting post-mining use of remaining mined-out pit space is performed taking into account such criteria as climate, geomorphology, pit slope stability conditions, regional development strategy, local community requirements, financial resources, etc.

Keywords: Oltenia Coal Basin, mining, mined-out pit space, reclamation, reuse solutions.

1. Introduction

Open-pit mining activities cause severe degradation of the earth surface and generate serious environmental problems.

Oltenia Coal Basin encloses the most important lignite deposits in Romania. The basin is located within three counties, Gorj, Vâlcea and Mehedinţi, between the Danube and Olt rivers and elongates WSW-ENE for approx. 120 km.

The lignite deposits within the basin are grouped according to geographic, geological and economic criteria into 5 lignite coal fields: Rovinari, Motru, Jilţ, Mehedinţi and Berbeşti, each of which is outlined and subdivided into individual areas based on geological and mining particularities, so that a total of 19 open pits have been designed and commissioned in the basin [5].

The mining organizational structure within the Oltenia Basin was approved by Government decision No. 1024/2011, which provided establishment of the Oltenia Commercial Company S.A. The mining activity is organized by individual open pit. At present, of the available 19 open pits, there are 10 open pits operating within the Oltenia Energy Company (C.E.O.) (Fig. 1) [10].

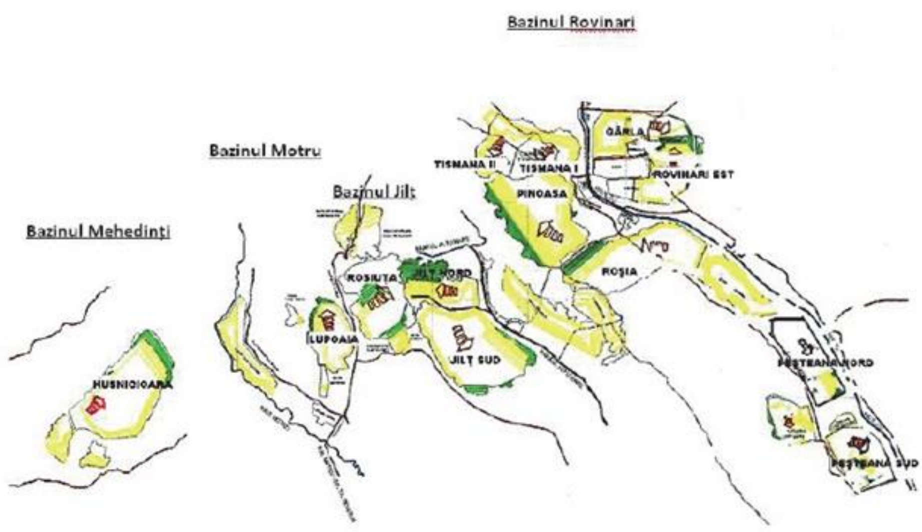

Fig. 1. Oltenia coal fields and mining areas

Table 1

Coal fields and mining areas belonging to Oltenia Energy Company

Coal field	Mining area	Surface [ha]	Date of closure
Rovinari	Tismana (I+II)	1695	2023 (I) / 2024 (II)
	Rovinari (Rovinari Est+Gârla)	1860	2024
	Pinoasa	2603	2027
	Roșia de Jiu	1738.8	2026
	Peşteana Nord	1299	2024
Motru	Lupoaia	1420	2027
	Roşiuța	1621	2027
Jilţ	Jilţ Sud	1981	2027
	Jilţ Nord	1267	2026
Mehedinți	Husnicioara	936	2019

The areas occupied by open pit mining operations consist of open pit areas, surfaces of external dumps and utilities. Of the 19 open pits put into operation, some are already closed and others are to cease operations in about a decade, according to the mining licenses expire dates and as a result of exhausting reserves or as lignite extraction is no longer efficient from technical and economical view points (Table 1).

Over the time, 5 open pits were closed, Cicani (1974), Balta Unchiașului (1966), Beterega (1980), Urdari (2003), and Peşteana Sud (2015). The Berbeşti Open Pit Mining Division, with its 4 related open pits, was outsourced to Govora District Heating Power Plant.

2. Actual condition of Oltenia open pits.

From geological view point, the Oltenia lignite deposits belong to Pliocene formations (Dacian, Romanian and Pontian) and comprise 21 lignite seams of different thickness ranging from several centimeters to several meters and variable extensions separated by non-coal rocks (soft, cohesive and non-cohesive, predominantly clayey and sandy rocks (Fig. 2) [1].

Open-pit mining has a number of advantages compared to underground mining, such as: increased productivity as a result of complete mechanization of extraction, transportation and storage processes, lower costs, optimum working conditions and labor safety. In spite of these advantages, open pit operations also produce direct negative environmental impact. In addition, the processes of reclamation of degraded lands are much more expensive and more complicated in case of open-pit mining [9].

In the Oltenia open pits, a continuous mining process is applied, comprising three major stages: extraction, transportation, and storage.

Fig. 2. Lignite layers in Oltenia Basin

The mining methods have been selected to provide technical, economic and H&S efficiency. In most of the open pits, the combined method is used to remove wastes to inner dump.

The maximum lignite production capacity is 22 mtpa at 5 days-a-week operating program and 30.5 mtpa at 7 days-a-week operating program, depending on technical, mining, machinery provision, productivity and other conditions, and also the demand for lignite coal [10].

Table 2 presents evolution of the main indicators for the period of 2012–2016, including those from Berbeşti Open Pit Mining Division before its outsourcing to Govora District Heating Power Plant.

Mining fleet of Târgu-Jiu Branch Mining Division comprises 559 units, including 65 bucket wheel excavators, 46 dumpers, 366 high-capacity conveyors, 23 stockpiling machines, and 59 track-mounted trolleys (Table 3) [10].

The basin lignite mining history covers over 50 years, during which more than 1 billion tonnes of lignite were extracted.

Table 2

The main operation indicators for the period of 2012-2016

Item	TOTAL				
	2012	**2013**	**2014**	**2015**	**2016**
Production (kt)	29690	22596	21501	22405	23000
Overburden (kt)	176741	149412	137290	129449	153000
Overburden/coal ratio (m^3/t)	6.0	6.6	6.4	5.8	6.7
Average productivity, exc. type 2000 (m^3+tph)	1,124.0	1,140.0	1,171.0	1152	1152
Average productivity, exc. type 1400 (m^3+ tph)	1019	997	974	984	1016
Excavation capacity (m^3/hour)	186,183.0				
Stockpiling capacity (m^3/hour)	313,300.0				
Waste rock transporting capacity (m^3/hour)	253,800.0				
Coal transporting capacity (tph)	93,000.0				
Specific power consumption (kW/ m^3+t)	3.73	3.93	3.98	4.02	4
Unit cost (lei/t)	71.89	68.8	76.51	52.52	46.29

Table 3

Mining Fleet by Mining Divisions

Facility / Open pit	Bucket wheel excavator	Dumper	High-capacity conveyor	Stockpiling machine	Track-mounted trolley	Total number of facilities by mining division
Tismana	8	6	36	1	12	63
Rovinari	5	5	23	-	9	42
Pinoasa	6	4	30	2	6	48
Roșia de Jiu	9	7	43	3	6	68
Peșteana Nord	5	3	33	4	6	51
Lupoaia	5	3	27	2	3	40
Roșiuța	7	5	42	2	5	61
Jilț Sud	8	5	49	2	4	68
Jilț Nord	6	5	48	1	5	65
Husnicioara	6	3	35	6	3	53
Total by facility type	**65**	**46**	**366**	**23**	**59**	**559**

3. Criteria for selecting post-mining use of worked-out pit space

After cessation of open-pit mining, it is important to reclaim the remaining mined-out pit space and implement its cost-effective reuse with mitigation and elimination of environmental impact. But, unfortunately, in many cases, mined-out open pits are abandoned. Such irrational practice causes a lot of economic, environmental and safety problems, first of all, for the local community.

In case of abandonment of a mined-out pit, depending on hydrological and hydrogeological conditions in the area, a lake may naturally form. This causes a risk of drowning because such lakes attract people for swimming; such lakes are very deep and have low temperature of water that can produce so-called temperature shock. Besides, the risk of water pollution arises due to the contact of water with abandoned machinery in the pit lake. On the other hand, when the mined-out pit is not flooded, it attracts off-road sportsmen that may lead to material losses and also to human live losses due to high risk of injury.

Open pit mining produces severe environmental impact. This includes negative visual impact resulting from landscape degradation, formation of deep “craters” due to pit development, generation of external waste dumps, and impact produced by mining and transporting equipment operation. Degradation of aquifer systems as a result of deep excavation causes formation of depression funnels with significant negative impact on households and agriculture in the region. These are just a few examples indicating that mining cannot be in harmony with the environment unless it implements sustainable development solutions. That is why experts all over the world look for solutions to reduce the environmental impact of mining industry [4].

Hydrogeological conditions of Oltenia mining basin vary from favorable and neutral in the Mehedinti and Jilţ coal fields to unfavorable and very unfavorable in the Motru coal field and especially in Rovinari coal field. The particularities of the lignite open pits in Oltenia Basin are shown in Table 4 [6].

Table 4

Particularities of the Oltenia basin open pits

Open pit \ Parameter	Overburden /coal ratio (m^3/t)	Mining depth (max, m)	Hydrogeological conditions (m^3water/t)
Tismana (I/II)	3.90/5.10	40/50	neutral, 1.55/2.60
Rovinari (Rovinari Est/Gârla)	5.75/6.20	75/55	neutral, 2,20/unfavorable, 5.40
Pinoasa	6.31	80	favorable, 0.70
Roșia de Jiu	5.14	120	unfavorable, 10
Peșteana Nord	5.62	80	unfavorable, 9.50
Lupoaia	4.90	40	favorable, 0.20
Roșiuța	6.80	60	favorable, 0.50
Jilț Sud	6.10	70	favorable, 0.80
Jilț Nord	6.30	65	neutral, 1.20
Husnicioara	7.60	62	favorable, 0.20

Hydrographic network in the Oltenia Coal Mining Basin is rich and includes hydrographic basins of the Jiu, Motru, Jilţ, Topolniţa and Husniţa rivers. Some work was required to regularize some rivers and their tributaries.

The overburden/coal ratio is 6:1 on the average. The average mining depth varies between 50 and 80 m in 16 of 19 designed open pits. Minimum mining depth takes place in the Peşteana Sud and Urdari open pits, and maximum one is characteristic for the Roşia de Jiu open pit, over 120 m [6].

In the Oltenia Coal Mining Basin, about 2/3 of the earth surface is represented by hilly terrain, with highly ridged hills and slopes with unstable alluvium sediments, which contributes to instability of inclined surfaces. Such hilly terrain prevails in thirteen mining areas, flat and hilly terrain in four areas, and flat terrain in two areas located in the Rovinari Coal Field [6].

The enclosing waste rocks are presented by mixes of clay and sand in varying proportions and belong to soft rock category with low resistance to compression or cutting.

4. Results and discussion

Special attention should be paid to physical stability of waste dumps (for instance, taking into account landslide hazard), and it is important also regarding to post-closure reclamation and use/reuse of these facilities/land plots [7].

Currently, the pit slopes and inner dump slopes within the Basin demonstrates relatively good stability, with a series of superficial landslides with no serious technical and economic impacts. Regardless of whether geometry of the ultimate pit slopes residual and mined-out space was initially designed to provide their stability, further studies and work to increase the stability are required prior to flooding or other reclamation measures.

Knowledge of physical and mechanical characteristics of the enclosing rocks is required for slope designing, to prevent landslides implement relevant measures for increasing stability [6].

There are numerous ways of reuse of the mined-out pits (Fig. 3), therefore determination of appropriate reuse type depends on specific factors, such as climate regime, the area terrain, configuration of the mined-out pit, hydrogeology and hydrology of the area, stability conditions, local community requirements, financial resources, regional development trends.

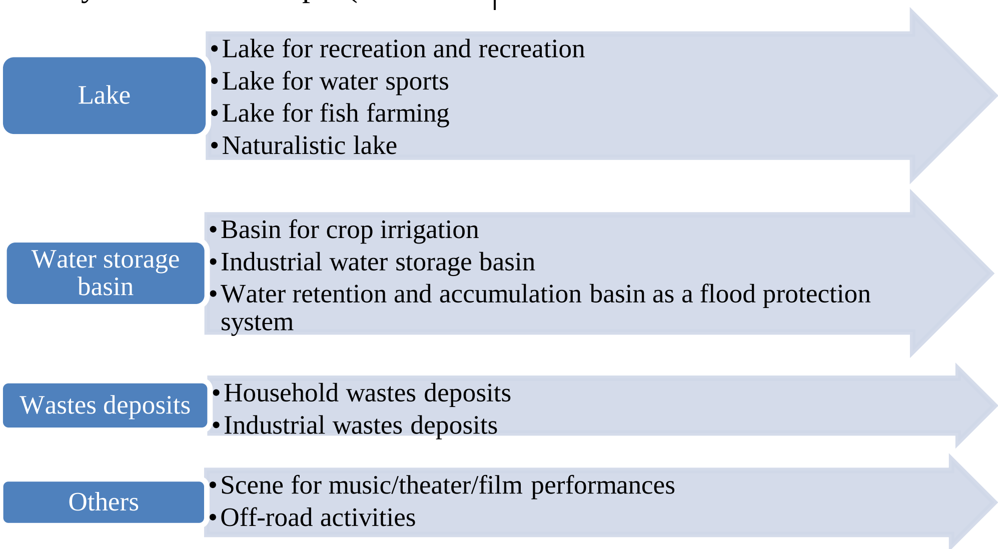

Fig. 3. Ways of reuse of mined-out pits

Mined-out pits present an example of heavy environmental impact of mining activities.

Mined-out pits can find various reuses, including stockpiling of wastes or forming a lake for industrial of recreational purposes [8].

Stage of closure and monitoring of mined-out open pit must be planned before starting the project implementation, with ensuring corresponding funding. The common practice, unfortunately, is to abandon the mined-out pit at the end of the production cycle, thus producing heavy impact on natural environment and life conditions of local communities up to future generations [3].

Besides work on stabilizing ultimate slopes of mined-out pits, shaping and revegetation of surrounding lands for integrating them in the landscape should be performed.

Due to the location of Oltenia Mining Basin, local hydrological and hydrogeological conditions, stability conditions, geomorphology and orography, the use of the surrounding lands, the distance to residential areas, regional development strategy, and local community requirements, two types of reuse of the Oltenia's mined-out pits were selected, which present the greatest advantages, namely:

1. Forming open pit lake for various purposes;

2. Waste disposal.

Since starting mining, much attention should be paid to soil protection. Soil is a vital and extremely valuable resource that contains mineral and organic elements capable to provide sustainable vegetation development, but it is very hard to regenerate it. Soil may be immediately relocated to new site for use, or stockpiled and conserved for later use on degraded surface after mine closure [8].

Besides, at the mining stage, many measures can be implemented to ensure sustainable development of mining areas after the activity cessation, including permanent land reclamation simultaneously with mining.

This practice is commonly recommended and applied (Fig. 4), and mining land reclamation measures should be taken into account and included in mining design documentation, Life-of-Mine Plans, and corresponding special measures should be provided in the Mine Closure Plans [2].

This practice has a number of advantages, such as reducing the reclamation period after a mine closure, decreasing the affected land area and overall environmental impact, and its provide gradual re-integration of the land into adjacent landscape and the possibility of the land reuse for other purposes [2].

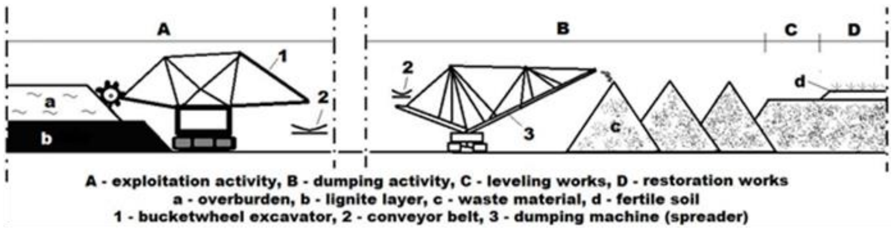

Fig. 4. Land reclamation in the process of mining

A mine closure plan must provide for dismantling buildings at risk of collapse, removing mining equipment, structures, facilities and their remnants to ensure land reclamation.

1. Forming open pit lake

Forming open pit lake within mined-out space contributes to sustainable development of mining areas and is globally used, but at the national level it is not currently applied. This method has long-term benefits irrespective of the lake use and involves increasing ecological, productive, cultural value of the landscape.

Forming open pit lake may be natural or artificial. Natural flooding occurs by accumulation of rainwater and seepage of groundwater, and artificial flooding involves transporting water through pipelines from place of abstraction (rivers, lakes, etc.) to a closed open pit.

Notice that in-pit waste dumps provide a significant risk of landsliding their slopes as they are formed by loose rocks, stability of which further decreases due to water saturation. Landsliding may happen in the dump slopes as a result of liquefaction of the waste material, or in a pit ultimate slope, where groundwater inflow causes subsoil erosion (suffusion).

The landslides may cause waves with impressive height and speed (depending on the lake area and the water table level), which may result in flooding and destroying some facilities in the affected zones.

Non-implementing the ultimate slope stability assessment analysis and corresponding stabilizing measures in mined-out pits for post-closure conditions may lead to disastrous events such as landslides which under certain circumstances may result in material and human life losses.

It is also important to restore hydrostatic level in a mining area to prevent drying springs and rivers, important for local community, in the adjacent areas. For this purpose, the following measures can be implemented:

- artificial flooding of mined-out pits to maintain the pit lake water table slightly above the natural local groundwater table;
- providing natural groundwater table rising, if hydrological and hydrogeological conditions are favorable for this within acceptable period of time.

The second case involves flooding of mined-out pit by intake of underground and surface water.

2. Waste disposal

In this case, for restoration of the natural local groundwater table in the territory adjacent to mined-out pit, it is recommended to create ground water cutoffs (Fig. 5) either at the whole perimeter of the mined-out pit envelope, or locally in the place of groundwater inflow. In addition, a system of boreholes can be drilled to inject water in the territories outside the pit enveloped with implemented ground water cutoffs.

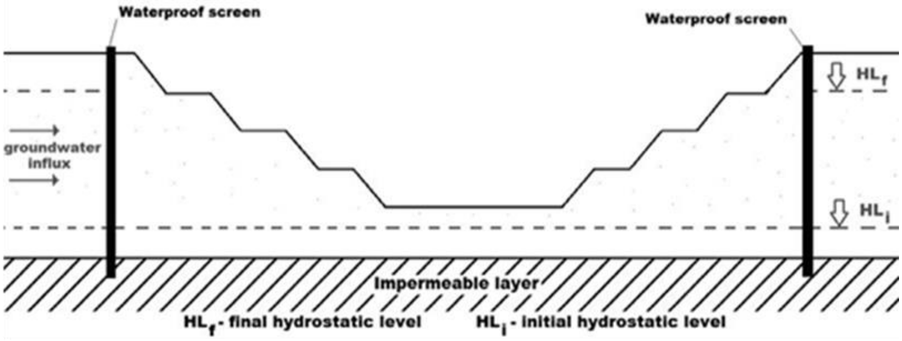

Fig. 5. Restoration of groundwater table using ground water cutoff [2]

For waste disposal within mined-out pits, the following works should be carried out:

- leveling the mined-out pit bottom;
- carrying out works preventing inflow of superficial waters;
- waterproofing the pit bottom and slopes with natural or synthetic materials;
- placing waste in compact layers separated by inert materials.

After full filling the mined-out pit with wastes, it should be covered with impermeable inert materials, a layer of vegetated soil, and the area should be further re-vegetated for various uses (agriculture, forestry or other) depending on the local conditions [8].

Taking into account the relatively large overburden/coal ratio in the Oltenia Basin and the composition of the waste material resulting from the lignite extraction (clay, sand and gravel, without dangerous elements), the material can be used as filling material for construction of highways, and its coarse fraction can be also used as stone rip-rap for protecting various dams, slopes, etc. (Fig. 6) [2].

The advantages consist in reducing the amount of waste material to be disposed in the dumps and corresponding increasing amount of available construction materials.

Reclamation and rehabilitation of a degraded land is a complex process involving stabilization, improvement and redevelopment of degraded land so that it can be reintegrated into natural environment or economic use. Post-closure maintenance and monitoring should cover air quality, mine water discharge and quality control, acid rock drainage and metal leaching (ARDML), soil and vegetation quality, noise and vibration levels during closure and reclamation, stability and state of waste stockpiles.

Land reclamation and reuse is an important step towards sustainable development of a region and community, ensuring economic development of the affected area.

The sustainable development activities must take into account all opportunities offered by the land and the local community needs.

Fig. 6. Examples of waste material reuse

As for the requirements for harmonization of the post-closure pit use with the surrounding landscape, it is necessary to perform revegetation, using species complying with the new conditions and overall region situation.

The revegetation also ensures that fauna is also restored faster. This provides biological diversity and integrating the land into the surrounding landscape and formation of sustainable ecosystems.

Modeling a pit lake slopes, depending on the intended use, is an important step both for mitigation of possible risks, such as accidents, and for integrating the land into the surrounding terrain.

The infrastructure should be designed in such a way to minimize the impact of mining activities on the environment and communities.

The most important aspect of a mined-out pit site reclamation is that slope stability conditions should be monitored after the degraded land was returned to commercial or municipal use. It is intended to prevent landsliding phenomena. This practice contributes to reducing the number of accidents.

The useful application of the mined-out space contributes to supporting economic development through creating new businesses, new jobs for unemployed people, and mitigation of environmental impact.

Conclusions

Oltenia Energy Complex exploits four mining basins: Rovinari, Motru, Jilt, and Mehedinti, with a total of 10 operating open pits. Over the time, of a total of 19 designed and commissioned open pits, 5 open pits were closed, Cicani (1974), Balta Unchiașului (1966), Beterega (1980), Urdari (2003), and Peşteana Sud (2015). The Berbeşti Open Pit Mining Division, with its 4 related open pits, was outsourced to Govora District Heating Power Plant. The main reason for the cessation of mining activity of the 5 closed pits was exhausting reserves or the fact that the lignite extraction is no longer efficient from technical and economical view points.

The mined-out pits were naturally reintegrated into local terrain; some of them were flooded thus becoming pit lakes. Lignite mining in Oltenia Basin lasts for more than half a century and produces the most important energy resource for Romania. Oltenia Mining Basin has tremendous amounts of lignite being enough to satisfy Romania's demand for the resources for the next 20-40 years. According to current operating licenses, the last of these 10 operating pits will cease mining in 2027.

Open pit mining produces severe environmental impact. This includes negative visual impact resulting from landscape degradation, formation of deep "craters" due to pit development, generation of external waste dumps, and impact produced by mining and transporting equipment operation. Degradation of aquifer systems as a result of deep excavation causes formation of depression funnels with significant negative impact on households and agriculture in the region.

After cessation of open-pit mining, it is important to reclaim the remaining mined-out pit space and implement its cost-effective reuse with mitigation and elimination of environmental impact. In case of abandonment of a mined-out pit, a lake may naturally originate within it, having recreational and economic importance. Besides, mined-out pit space can be used for stockpiling mining wastes.

Forming open pit lake within mined-out space contributes to sustainable development of mining areas and is globally used, but at the national level it is not currently applied. This method has long-term benefits irrespective of the lake use and involves increasing ecological, productive, cultural value of the landscape.

Waste disposal in mined-out pits is an acceptable solution allowing Its advantages consist in reducing the amount of waste material to be disposed in surface dumps, elimination of negative landforms, and, after filling and complete closure of the waste dump, the land plot can be reintegrated into natural environment or economic use, according to applicable norms and rules.

Besides, there are other, less common uses of mined-out pits such as scenes for theater or music performances, filming cinema scenes, off-road activities, etc., and their advantage is commercial use of degraded lands which cannot find other applications for various reasons.

After the cessation of mining operations at the Oltenia open pits, it is recommended to carry out comprehensive studies of stability, hydrological, hydrographic and hydrogeological conditions of the mining areas to determine optimal use of each mined-out pit. In this case, geomorphology and orography, the use of surrounding lands, the distance to residential areas, regional development strategy, and local community requirements should be taken into account.

Reclamation and reuse of mined-out pits have numerous benefits and depend to a large extent on selection of the most appropriate type of use with maximum opportunities in the area. Special attention should be paid to restoration of biodiversity and reintegration of the degraded land into landscape to mitigate environmental impact, improve health and safety indicators, provide creating new jobs, development of the regional commercial and industrial life, which contribute to increasing living standards of local communities.

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