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REECOL Ecological rehabilitation and long term monitoring of post mining areas

Deliverable 3.4

Report on characteristics of post-mining reclamation case study areas

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

1. Introduction

The REECOL project aims to facilitate the transition of coal mining regions towards a sustainable and climate-neutral future. This effort aligns with the European Green Deal, which outlines a comprehensive plan for Europe to become the first climate-neutral continent by 2050, and the RFCS (Research Fund for Coal and Steel) Research Programme for the Coal sector. These frameworks emphasize the need for significant reductions in carbon emissions, the phasing out of coal-fueled power plants, and the adoption of sustainable energy practices.

REECOL focuses on minimizing the environmental impacts of coal mines that are in the process of being closed. The project addresses several key areas:

- **Repurposing End-of-Life Coal-Related Assets and Infrastructures:** This involves transforming former mining sites and associated infrastructures into areas that can serve new, beneficial purposes. This could include converting these areas into green spaces, agricultural lands, or sites for renewable energy projects.
- **Ecosystem Rehabilitation:** Ensuring that the ecosystems affected by mining activities are restored is a central goal. This involves not just the physical restoration of the land but also revitalizing the flora and fauna that were impacted. REECOL aims to restore these ecosystems to a state where they can function healthily and sustainably in the long term.
- **Future Land Uses:** Planning for the future use of reclaimed mining areas is crucial. REECOL evaluates various land use options that can provide economic, social, and environmental benefits to the local communities. This might include recreational areas, agricultural uses, or new industrial developments that are environmentally friendly.

By applying emerging and innovative technologies, particularly in the areas of soil rehabilitation, REECOL aims to achieve ecological restoration that respects both environmental and social needs. Advanced technologies in soil treatment and vegetation regrowth are employed to rehabilitate these post-mining landscapes effectively. These technologies not only enhance the speed and efficiency of ecological restoration but also ensure that the rehabilitated lands are sustainable in the long run.

In essence, the REECOL project is about creating a blueprint for the successful transition of coal mining regions. By focusing on environmental sustainability, economic viability, and social equity, REECOL provides a holistic approach to managing the legacy of coal mining while paving the way for a greener, more sustainable future.

The purpose of this report is to provide a comprehensive analysis of selected post-mining reclamation case study areas across Europe. These areas represent various rehabilitation schemes identified in Task 3.2 of the REECOL project. The report characterizes the degradation status, biotic and abiotic conditions, and contamination levels of these areas, following the indicators from the classification method outlined in Task 3.1. It also examines the anticipated future use of these areas post-reclamation. By defining both the initial state of the study areas and the projected outcomes after reclamation, this report serves as a foundational document for experimental activities and monitoring solutions to be tested in subsequent work packages.

The methodology for selecting case study areas involved a collaborative process with project partners from Greece, Poland, Slovenia, the Czech Republic, and France. Each partner identified areas that exemplify diverse post-mining reclamation strategies. These areas were chosen based on their potential to facilitate the development and testing of new solutions for land reclamation (WP4) and short and long-term monitoring solutions (WP5). The selected sites include:

1) Amynteon and Ptolemais Lignite mines, Greece,
2) Mining Areas of PGG, Poland,
3) Velenje mining area, Slovenia,
4) Radovesice and Strimice Dumps, Czech Republic,
5) Konin Brown Coal Mine, Poland,
6) Mazingarbe, France.

Each case study area will undergo detailed characterization and analysis to inform the experimental and monitoring activities in the REECOL project, ultimately contributing to the development of best practices for ecological rehabilitation in post-mining regions.

2. Selection of Study Areas

The selection of case study areas for the REECOL project was conducted to ensure a comprehensive representation of various post-mining reclamation scenarios. These areas were chosen to address a wide range of challenges and opportunities associated with post-mining land reclamation and rehabilitation, thereby providing valuable insights and data for the development and testing of innovative rehabilitation and monitoring solutions. The selected sites span across different countries, showcasing diverse geological, ecological, and socio-economic conditions, which enrich the scope and applicability of the research findings. Below is an overview of each study area, highlighting the reasons for their selection.

Table 1. Selected Case Study Areas for Post-Mining Reclamation in the REECOL Project

Study Area	Country	Description of Site	Reason for Selection
Amyntaion lignite mines	**Greece**	A former lignite mining area consisting of three individual mines (Amyntaion, Anargyroi and Lakkia) and inside and outside dumping areas. There are already reclaimed areas.	Forming a pit lake in the final mining void of the Amyntaion mine is a significant and promising characteristic of the area as recreational land uses will be developed in the surrounding area, constituting the biggest artificial lake in Greece. The development of biodiversity in the area has gained interest for further research. Also, an important issue is that there is an already reclaimed area with aromatic plants. Available soil sampling data for approx. 2-3 years in the surrounding area of the pit lake.
Ptolemais lignite mines	**Greece**	It is about a complex of mines with exhausted mines and two still in operation (Mavropigi and South Field). The area also includes inside and outside dumping areas, many of which have already been reclaimed for agricultural and forest land use.	It includes areas already reclaimed and areas to be reclaimed with agricultural and forest land uses. An example of an already reclaimed area is an orchard with pilot cultivations of pear, apple, cherry, quince, and vineyards. Other types of reclamation applied in the areas are aromatic plants, apiculture, experimental greenhouse, and pilot energetic crops. Also, in the orchard area, there are available sampling data for a time series of approximately 15 years, including data for the soil and the final products (e.g. sampling of the leaves quality). Systematic controls of different types of cultivations have been performed over these years.
PGG	**Poland**	Jankowice Północ mine waste	The Jankowice Północ mine waste heap provides an example of reclamation for landscape and recreational purposes. Ultimately, it is planned to maintain low vegetation (without trees and shrubs) on the spoil heap. Currently, actions are being undertaken here to profile the terrain and establish vegetation cover. The location of the experimantal plot was selected on the non-reclined part of the heap. It will allow comparison of the effects of current reclamation methods with the techniques developed within the REECOL project.

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Study Area	Country	Description of Site	Reason for Selection
Velenje mining area	**Slovenia**	Area of subsidence between lakes (PSU) above Pit Pesje, where remediation is carried out by pre-filling the terrain and filling in the resulting subsidence by incorporating the by-products of electricity production in nearby thermal power plant.	Observation of the terrain, which is subject to a major change in the relief of the terrain in the form of subsidence and where in some parts temporary technical and biological (short-term greening of surfaces by sowing vegetation to prevent dust, better appearance and use for agriculture) rehabilitation is carried out allows monitoring and observation temporary recultivation and comparison with already rehabilitated PV (post)mining area. Over time, new animal and plant habitats have been established in the (mining) lakes and the surrounding area, all within the mining area, which must be preserved, both during mining, during the implementation of remedial works, and after the remediation has been completed. It will also contribute to more optimal planning of the final technical and biological remediation and forecasting of the situation after the completion of coal mining and the final technical and biological remediation.
Radovesice dump/Strimice dump	**Czech Republic**	Radovesice/Střimice spoil heap complex	The Radovesice - Střimice spoil heaps complex was selected as the main case study area. From the point of view of geology and pedology, most of the soil types of the Most Basin are represented here, reclamation additives were significantly used here, and the most important areas left to natural succession are located here. 6 long-term monitored experimental areas were established on these spoil heaps. On the Radovesice spoil heap there are 4 experimental areas and on the Střimice spoil heap there are 2 experimental areas.
Konin Brown Coal Mine	**Poland**	Jóźwin II B open-pit mine, internal dump	Post-mining area intended for agricultural reclamation, allowing comparison with other planned reclamation activities within the REECOL project (areas planned for research under WP4 can be compared with those carrying out planned reclamation activities by ZE PAK S.A.). The area after the technical phase of reclamation, before the biological phase, exhibits low biological activity initially determined.
Mazingarbe	**France**	A former coal mining site with a 60-meter high dump composed of black shales, covering 7.3 hectares. The site also includes two main parcels: the "west" settling basin and the "north" tailings pond. Areas are undergoing natural and managed reclamation efforts.	The site represents significant historical industrial activities, with extensive reclamation efforts making it a prime example of post-mining land transformation. The reclamation efforts involve managing contamination, invasive species, and integrating the area into an urban green belt with recreational uses.

The selected case study areas provide a diverse and comprehensive foundation for the REECOL project's research and development efforts. Each site offers unique characteristics and challenges that are critical for testing and refining reclamation and monitoring solutions. By addressing various aspects of post-mining reclamation, such as land use planning, ecological restoration, and socio-economic impacts, the project aims to generate robust and transferable insights that can inform future reclamation efforts across Europe.

Each of these selected case study areas is described in detail in the following chapters, where their specific conditions, challenges, and the reclamation approaches being tested are elaborated. This detailed examination will contribute to a deeper understanding of effective strategies for post-mining land reclamation and sustainable development.

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3. Description of Selected Study Areas

3.1. The Amyntaion and Ptolemais lignite mining areas of PPC, Greece

3.1.1. Current State

Location and Extent

Study area of Amyntaion lignite mines

Amyntaion Lignite Field is located in Florina Prefecture in Western Macedonia, North Greece. The area within the environmental permitting limits is 61.83 km^2. Figure 1 presents the plan of the Amyntaion area mines in the Amyntaion flood plain, extending from SW to the NE along the four natural lakes shown in the figure. The piezometric regime of the flood plain practically reaches ground level and has a very mild inclination from SW (Cheimaditida and Zazari lakes at elevation ca. +595) towards the NE (Petron Lake at elevation ca. +570) over about 15 km.

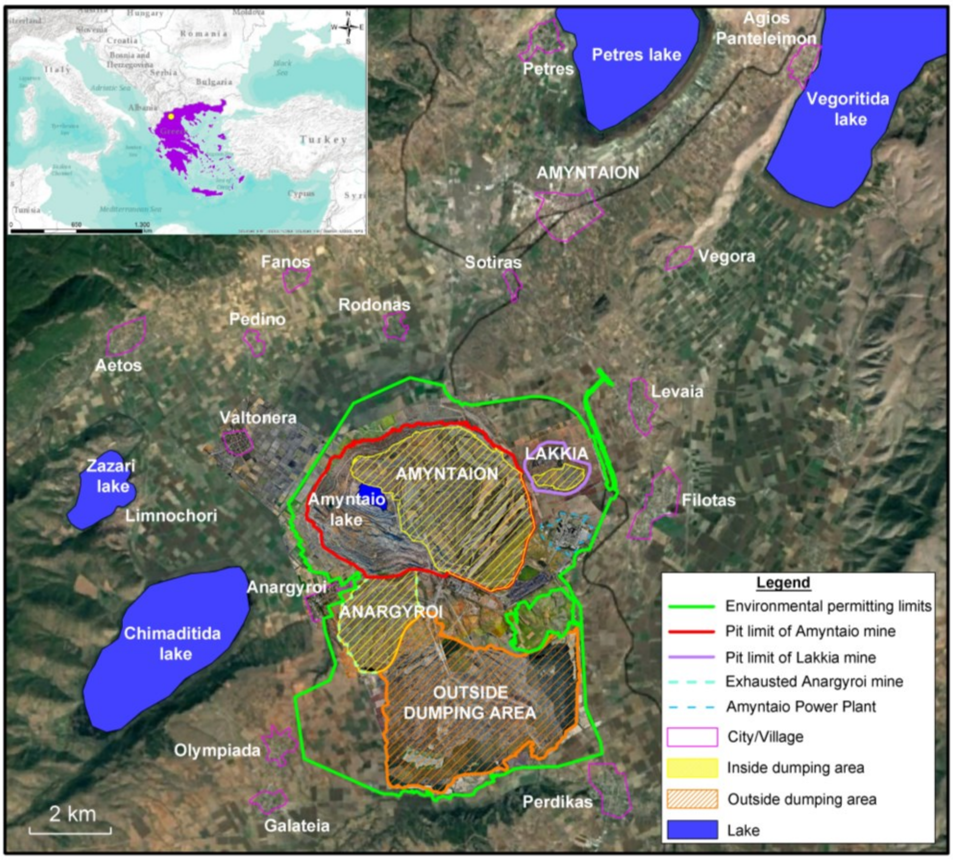

Figure 1. The location of Amyntaion mines (Anargyroi, Amyntaion, Lakkia) within the environmental permitting limits (Kavvadas et al., 2022).

Study area of Ptolemais lignite mines

The Ptolemais mining area is in the Kozani Province of the Western Macedonia Region, northern Greece. It is a complex of lignite surface mines, covering an area of 148 km2 within the Environmental Permitting Limits (Figure 2).

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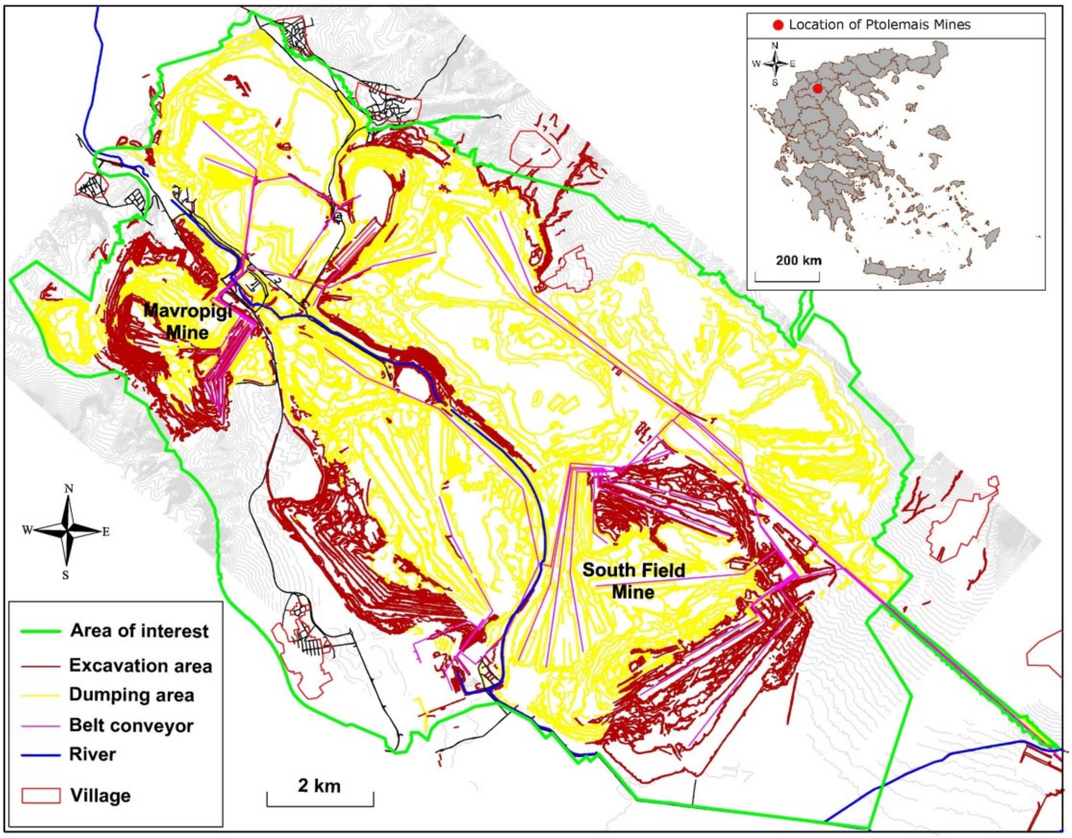

Figure 2. Location map of the Ptolemais mining area (June 2023)
(map in Greek Geodetic Reference System – GGRS87)

Current Status

Study area of Amyntaion lignite mines

In the Amyntaion area, three surface lignite mines have been exploited by Public Power Corporation (PPC) in the last 35 years: (a) the Anargyroi mine between 1984 and 2010, with 49 million tons of lignite production and 173 million m3 total excavations, (b) the Amyntaion mine between 1989 and 2020, with 179 million tons of lignite production and 1595 million m3 total excavations, and c) the smaller, but higher quality Lakkia mine, between 2013 and 2021, with 4 million tons of lignite production and 49 million m3 total excavations. A total of 232 million tons of lignite has been mined in the Amyntaion area, with total excavations of 1817 m3 and an overall stripping ratio (steriles to lignite) of 7 m3 per ton of lignite.

Figure 1 shows the current conditions with the spatial configuration of the waste dumps (inside and outside). Inside dumping was conducted mainly with spreaders (continuous surface mining) and, in some cases, with trucks and loaders (non-continuous surface mining). The internal waste dumps are estimated at ≈ 725 million m3. Currently, the region's economy depends on agriculture and energy fuel reserves. Figure 3 presents the current condition of the Amyntaion mining area, where the already reclaimed forest and cultivated areas are depicted, as well as the graded areas which are intended to host photovoltaic parks. The land use map regards the area of 45.18 km2 where the mining operations were taken place.

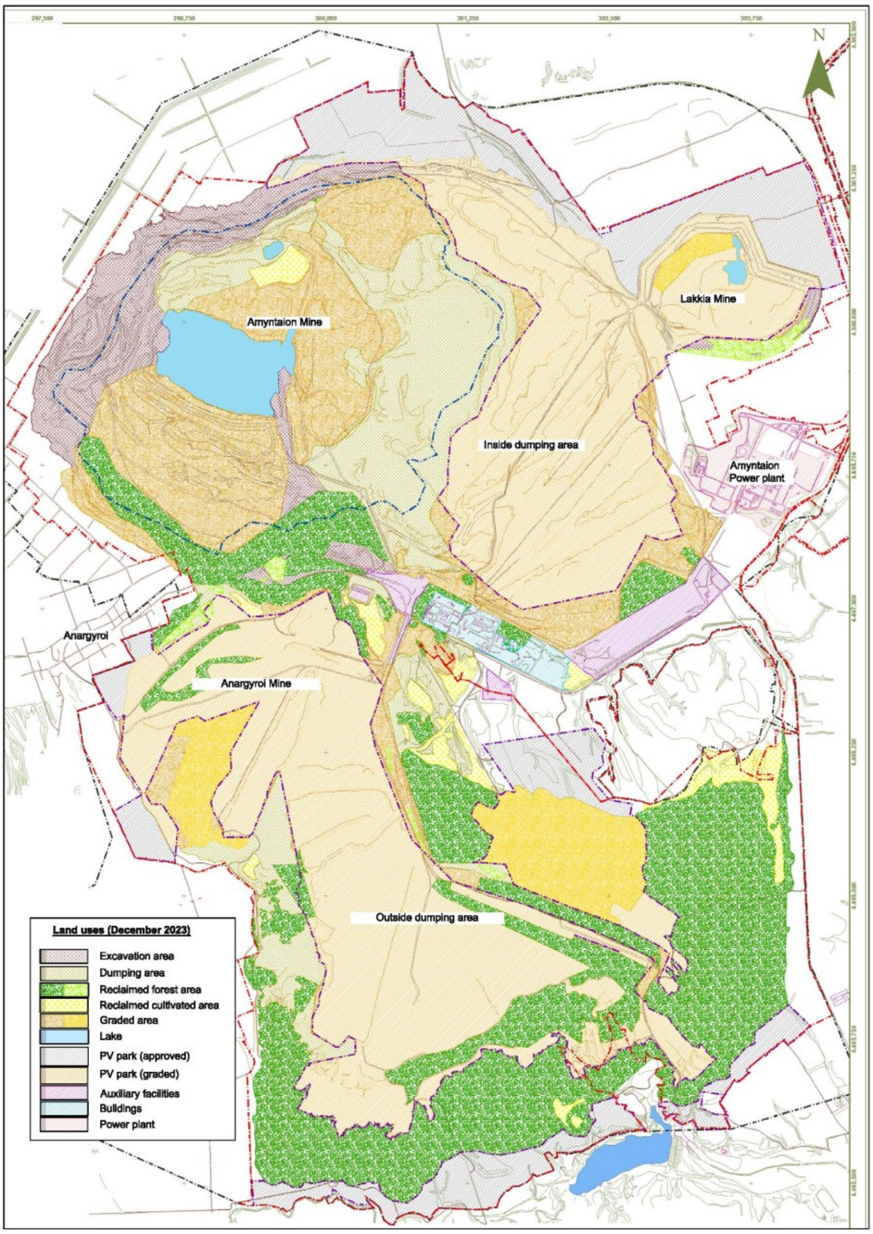

Figure 3. Allocation map of the existing land uses in the Amyntaion mining area (Technical Report of PPC, 2024)

<u>Study area of Ptolemais lignite mines</u>

In Ptolemais region, the lignite mines of Public Power Corporation (PPC) have been developing for the last 65 years, since 1957. During this period, a total of 1.5 billion tons of lignite have been extracted, with total excavations of 6.9 billion m^3, while the lignite production in 2022 was 10.49 Mt, with excavations of 47.95 million m^3 and a stripping ratio of 3.74 m^3/t (Public Power Corporation, 2021). The Ptolemais area is constituted by a complex of mines which some of them are not anymore in operation (Komanos, North Field, Main Field, Kardia). Currently, the Mavropigi and South Field mines are in operation, and according to the current planning, the exploitation of the two mines will be completed in 2026 (Figure 2). Figure 4 depicts the current conditions regarding the already reclaimed areas within the environmental permitting limits and the existing land uses in the broader area of the Ptolemais mines.

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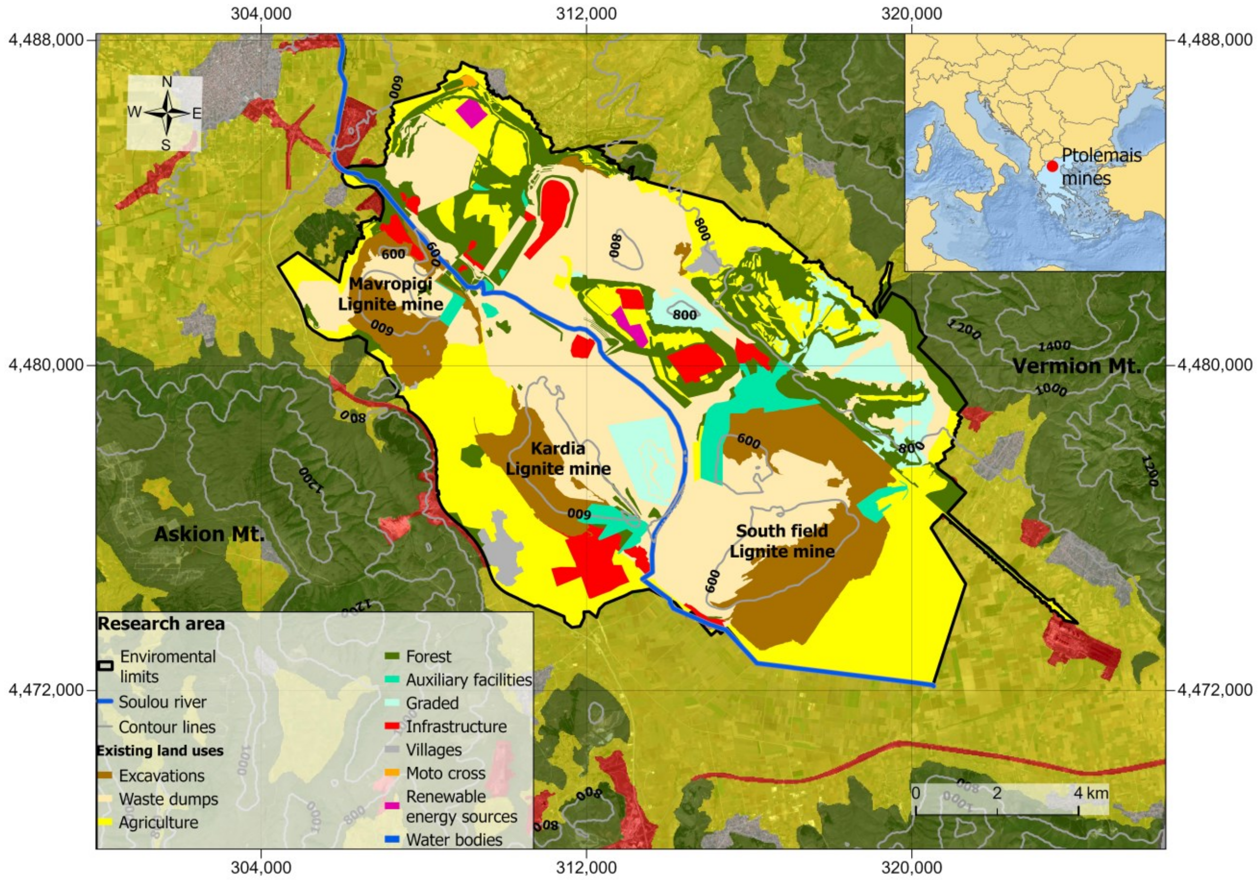

Figure 4. Current land use allocation map in the Ptolemais lignite mines and the surrounding region until 01/06/2023 (Karalidis et al. 2024).

Degradation Status

Study area of Amyntaion lignite mines

Figure 5 shows the elevation distribution in the mining area and the internal and external spoil dumping areas through the hillshade effect. The brown (higher elevation) area in the south is the external spoil dumping site. The bluish color shows the deeper part of the present Amyntaion mine where the pit lake has been developed until 434 m (June 2024).

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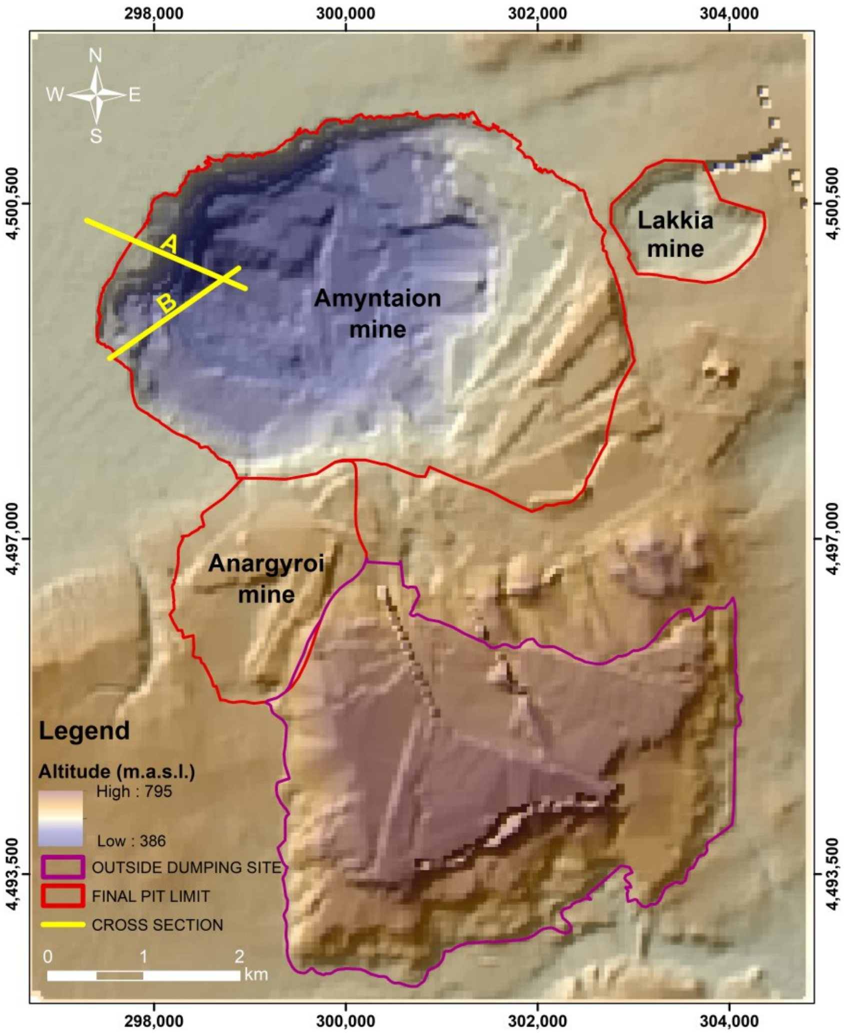

Figure 5. Digital Elevation Model (December 2021) of the Amyntaion mining area, showing the three main mines (Anargyroi, Amyntaion and Lakkia). (Kavvadas et al., 2022) Elevations are shown in hillshade effect.

LANDSCAPE INDICATORS

Figure 6 presents the distribution map of NDVI for August 2018 within the environmental permitting limits of the Amyntaion mining area, which was conducted in the context of the study of the dewatering measures of the Amyntaion mine and environmental impacts assessment on the water system for the year 2022. The NDVI ranges between 1 and -1, while the zero values show the threshold of vegetation appearance, and the values close to 1 show the appearance of younger and healthy vegetation.

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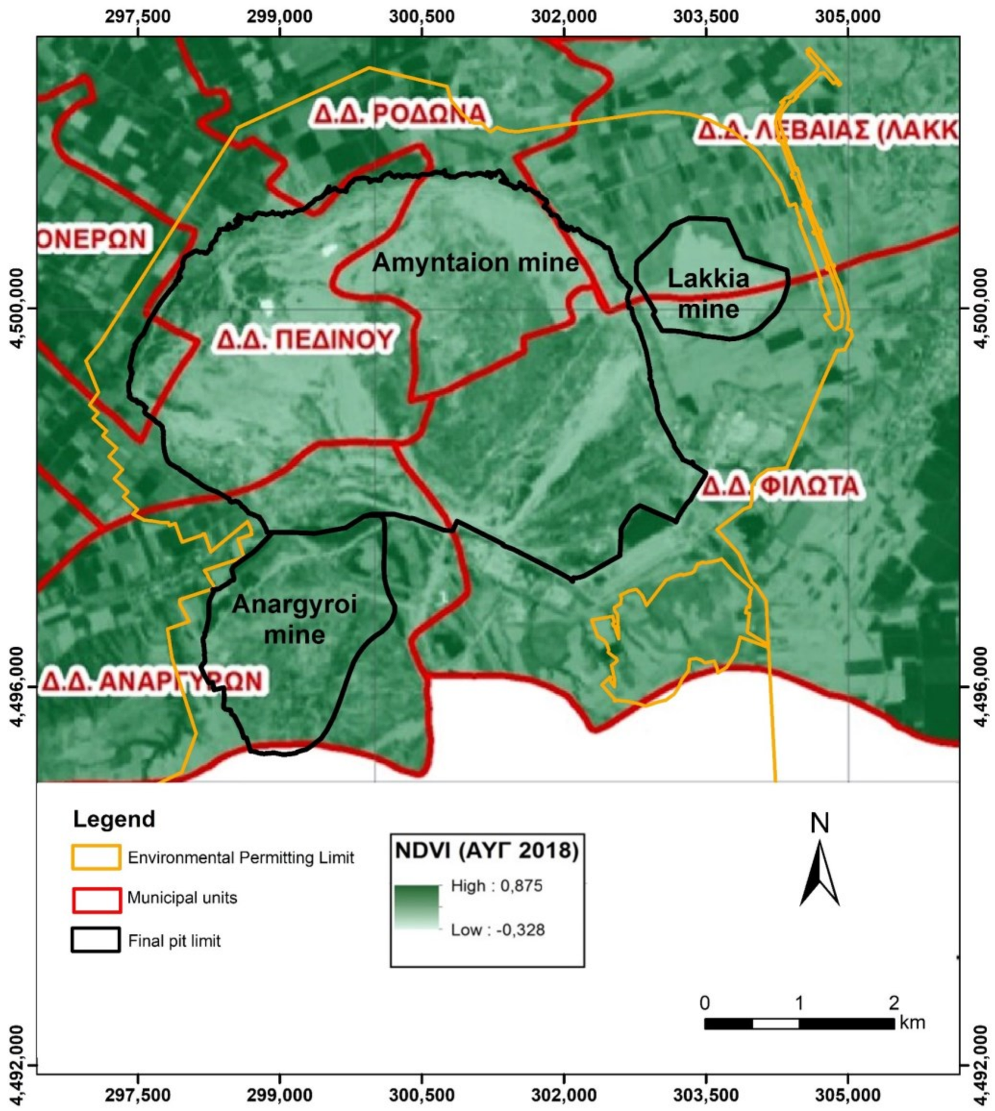

Figure 6. NDVI distribution map within the environmental permitting limit of the Amyntaion mining area (PPC, 2022)

<u>Study area of Ptolemais lignite mines</u>

The mines are surrounded by the Vermion, Askion, and Skopos mountains (Figure 7), within a complex meandering stream network. Rainwater flows into the Soulou River and discharges into Vegoritis Lake, the final receiving body of the surface runoff of the closed hydrological Ptolemais Basin (Dimitrakopoulos D & Grigorakou E, 2004; Louloudis, 1991) north of the research area. The Soulou River constitutes the primary water discharge, which makes monitoring and evaluating water quality a priority to protect the natural lake.

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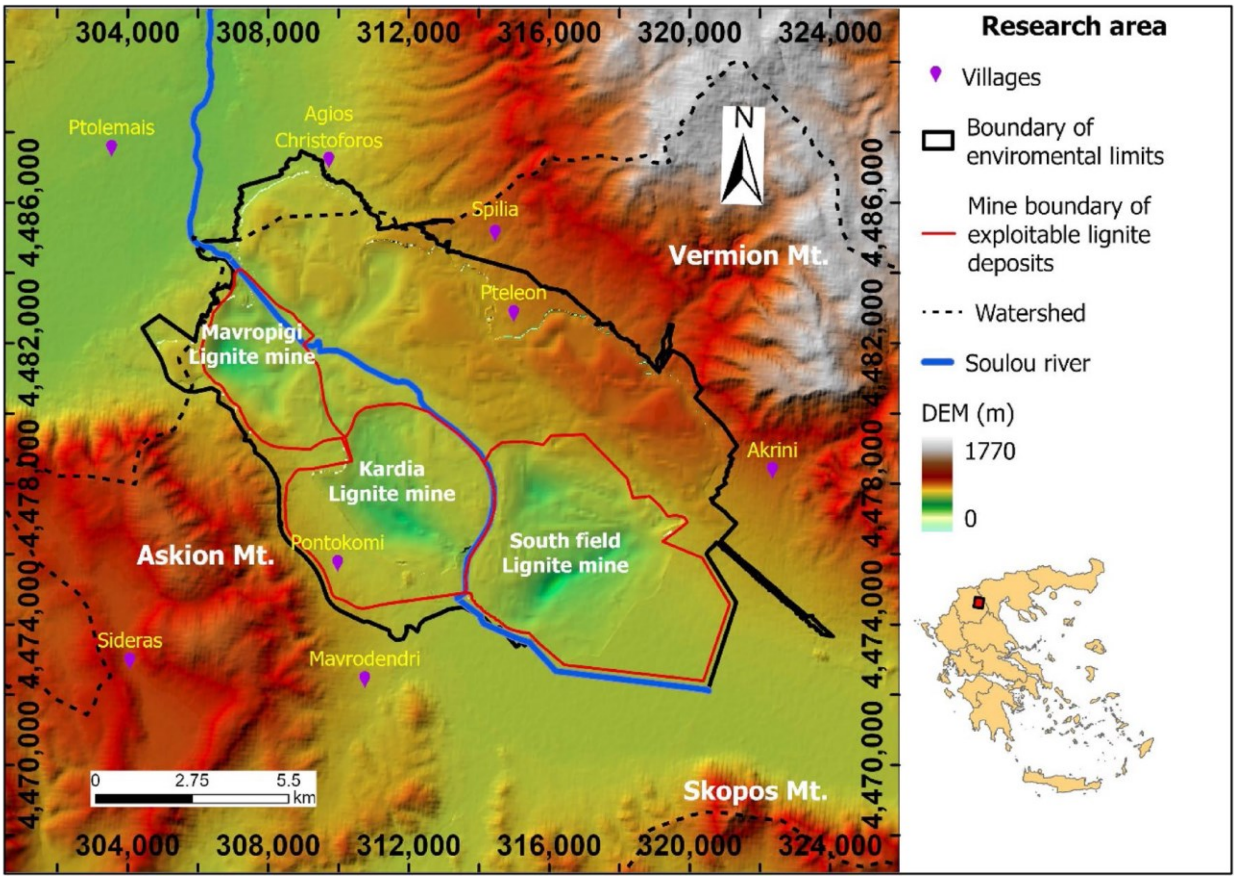

Figure 7. Digital Elevation Model of the Ptolemais mining area (Louloudis et al., 2023)

<u>LANDSCAPE INDICATORS</u>

In the research paper of Louloudis et al. 2023, several spectral and landscape indicators were investigated in the framework of water management towards an effective strategic planning in the coal phase-out era for the Ptolemais study area. The distribution maps of some selected indicators within the boundary of mine activities and the surroundings are presented and described in the following lines. The selected indicators are: Topographic Wetness Index (TWI), the Stream Power Index (SPI), the Slope Length and Steepness Factor (LS), the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI), the Modified Normalized Difference Water Index (MNDWI), the Land Surface Temperature (LST) and the Soil Moisture Index (SMI). The description of the indicators in the Ptolemais area is analytically presented in the research study of Louloudis et al. 2023.

Figure 8 and Figure 9 present the distribution of the topographic wetness index and stream power index respectively. As it can be seen from the maps, there are small areas inside the mine boundary where water flow is concentrated. The spatial distribution of the SPI shows high values in the northeast and south-southwest areas of mining activity, where the water runoff and overland flow of the Vermion, Askion, and Skopos Mts. are active.

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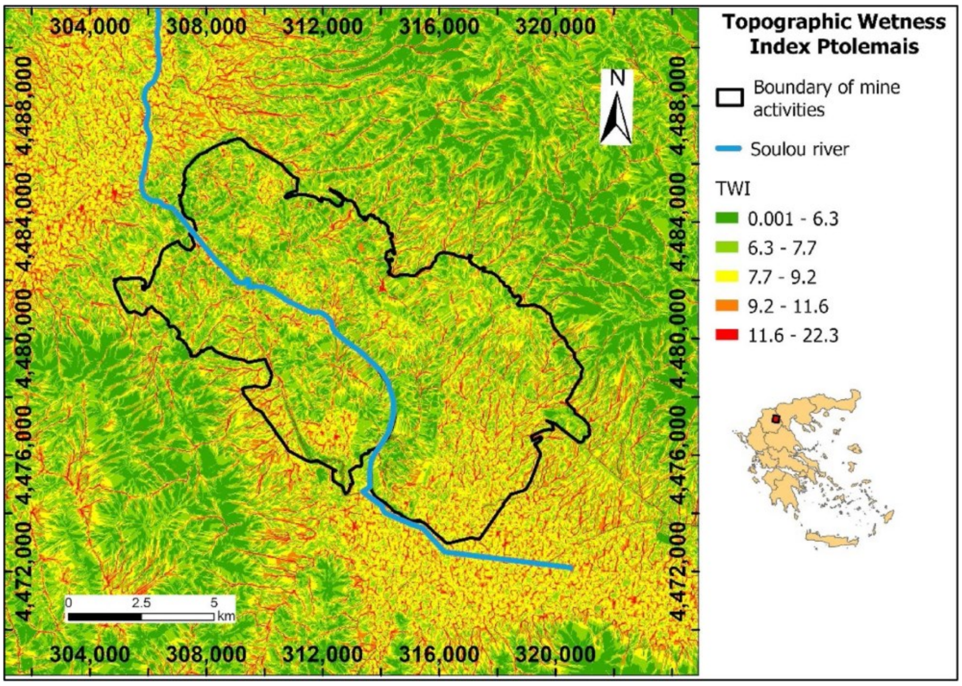


Figure 8. Spatial distribution of TWI with the combinations of two DEMs in 2022 where drainage networks are shown in red colour, (Ptolemais Basin, northern Greece). (Louloudis et al. 2023 The area of mining activities is indicated in black)

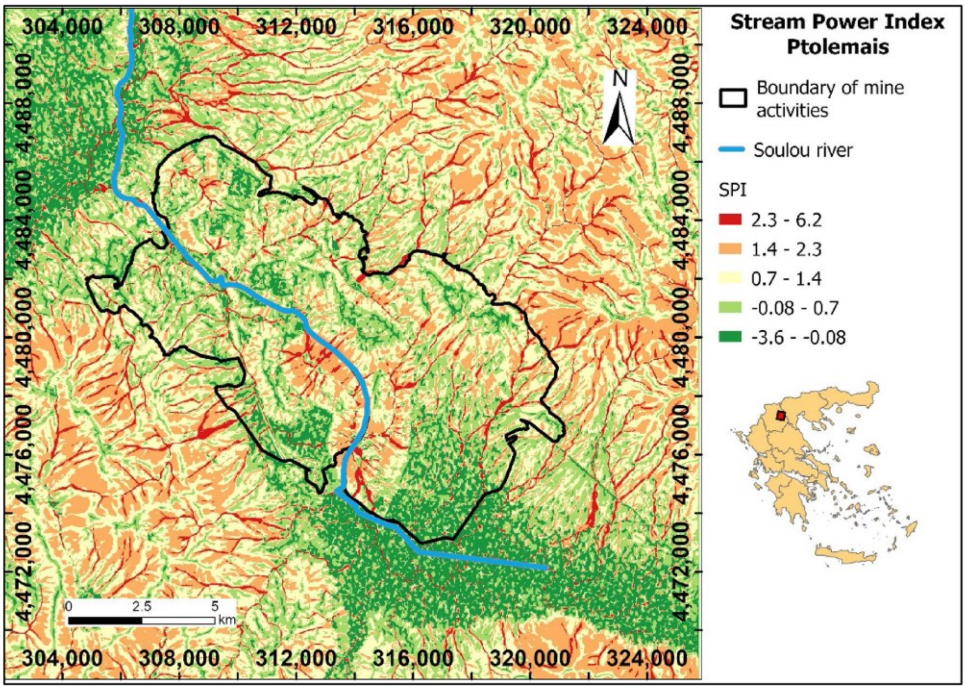


Figure 9. Spatial distribution of SPI with the combinations of two DEMs in 2022 where the high velocity of the streams is presented with red values (Ptolemais Basin, northern Greece). (Louloudis et al. 2023)
The area of mining activities is highlighted in black

Figures 10, 11A and 11B present the distribution maps of NDVI, NDWI and MNDWI where the maximum vegetative coverage is presented. Typically, high NDVI values illustrate younger and more healthy vegetation, while low values correspond to a lack of vegetation. According to Figure 10, the area of the outside waste dumping, i.e. the northern of the South Field Lignite mine, has a vegetative cover due to the mine restoration activities. Strong evidence of young and healthy vegetation also appears in the cultivated agricultural land, as shown in the southern area of the South Lignite Mine. The NDWI of Figure 11A shows the water features which are accumulated in locations with a high potential for inundation, while Figure 11B shows an improved NDWI, without noise from the urban areas.

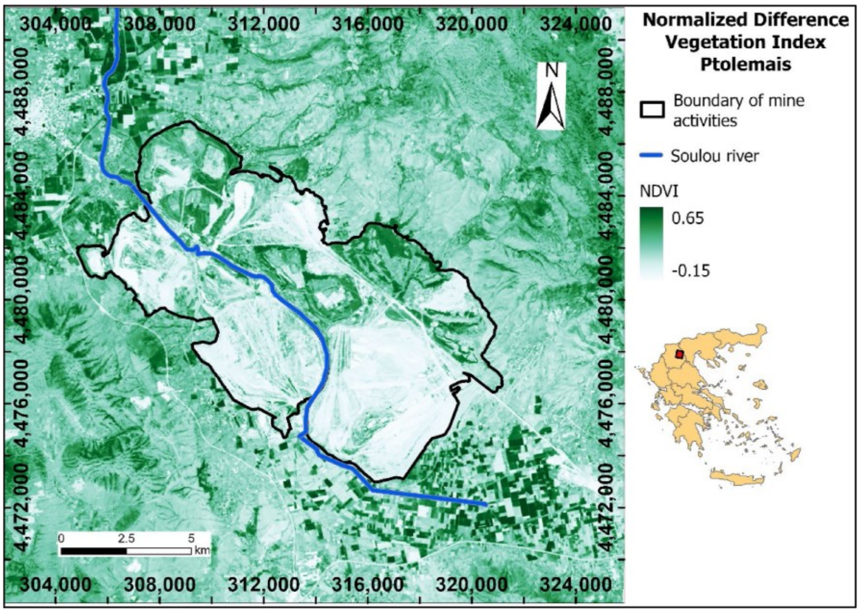


Figure 10. Spatial distribution of NDVI in July 2022 (Ptolemais Basin, northern Greece). (Louloudis et al. 2023) Higher values of NDVI suggest healthy and dense vegetation while lower values non-vegetated-surfaces

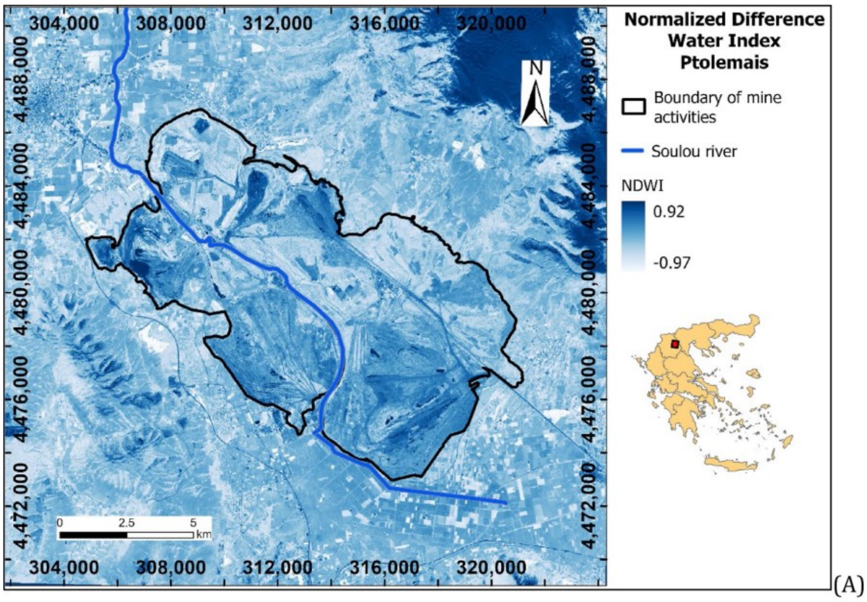
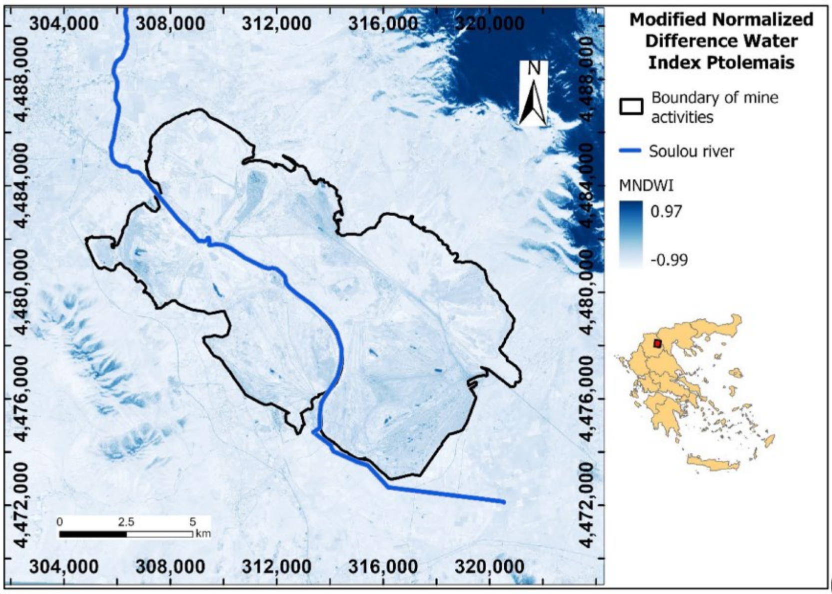


Figure 11. Spatial distribution map of NDWI (A) and MNDWI (B); indices ranging from + 1 to −1 recorded in December 2021 (Ptolemais Basin, northern Greece). (Louloudis et al. 2023)
Water features are represented by dark blue colour. The area of mining activities is outlined as black line



(B)

Figure 11 cont. Spatial distribution map of NDWI (A) and MNDWI (B); indices ranging from + 1 to −1 recorded in December 2021 (Ptolemais Basin, northern Greece). (Louloudis et al. 2023) Water features are represented by dark blue colour. The area of mining activities is outlined as black line

Figure 12 presents the Land Surface Temperature spatial distribution map in July 2022, where high temperatures are observed inside the mine sites. The mean temperature value was 34 °C, while the temperature recorded at that time ranged from 9 to 45 °C.

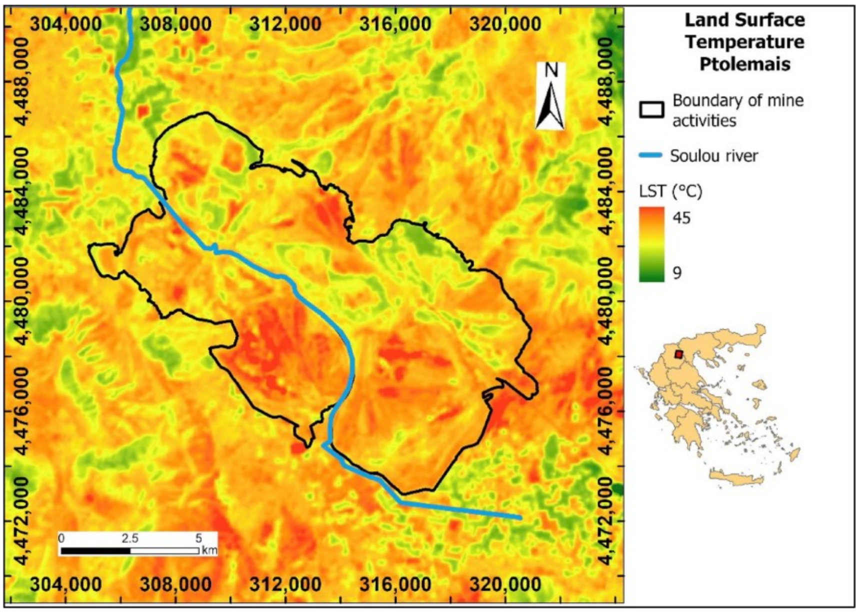


Figure 12. Spatial distribution of temperature in July 2022 (Ptolemais Basin, northern Greece). (Louloudis et al. 2023) The area of mining activities is shown

The mapped SMI distributed values (Figure 13) illustrate spots of high soil moisture values (the blue areas), in the areas outside the mine, representing agricultural land cover. The area outside of the waste rock dumping, i.e., north of the South Lignite Field and within the boundary of mining activities, also has high soil moisture. This is due to small forests as land cover, which were build up over the past years of reclamation activities.

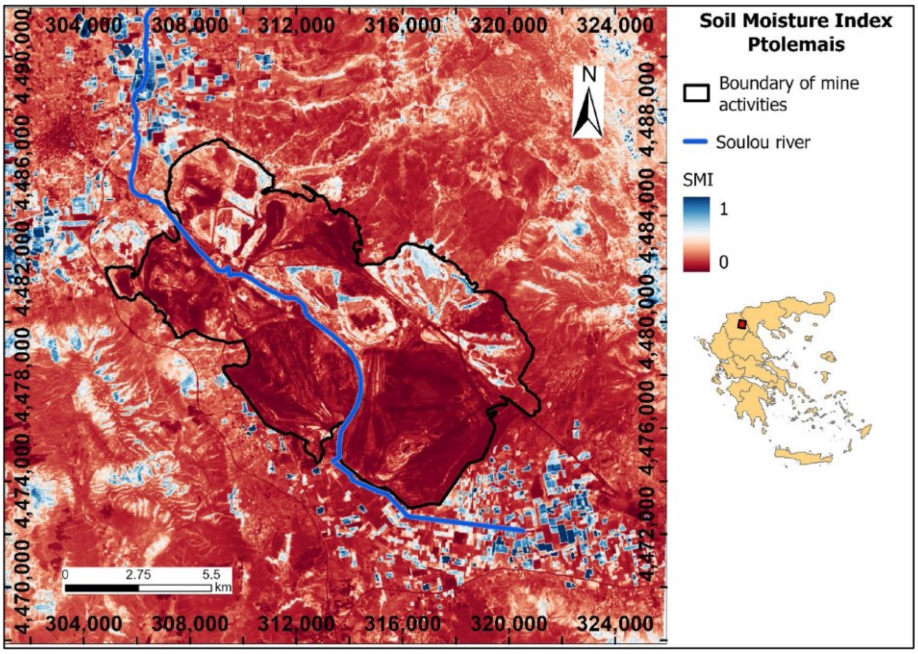


Figure 13. Spatial distribution of SMI in July 2022 (Ptolemais Basin, northern Greece). (Louloudis et al. 2023) High soil moisture values are indicated by blue colour, representing agricultural fields and forests. The area of mining activities is shown

<u>GEOTECHNICAL INDICATORS</u>

The slope length and steepness factor are indicators which calculate the soil erosion based on Digital Elevation Model (DEM). The distribution of LS values (Figure 14) for Ptolemais area indicates that water discharge is evident only in the mountains. At the same time, lower calculated values are scattered inside the boundary of the mining activity and in the agricultural area outside the mines. An important issue is the weathering intensity, which is more pronounced around Vermion Mtn.

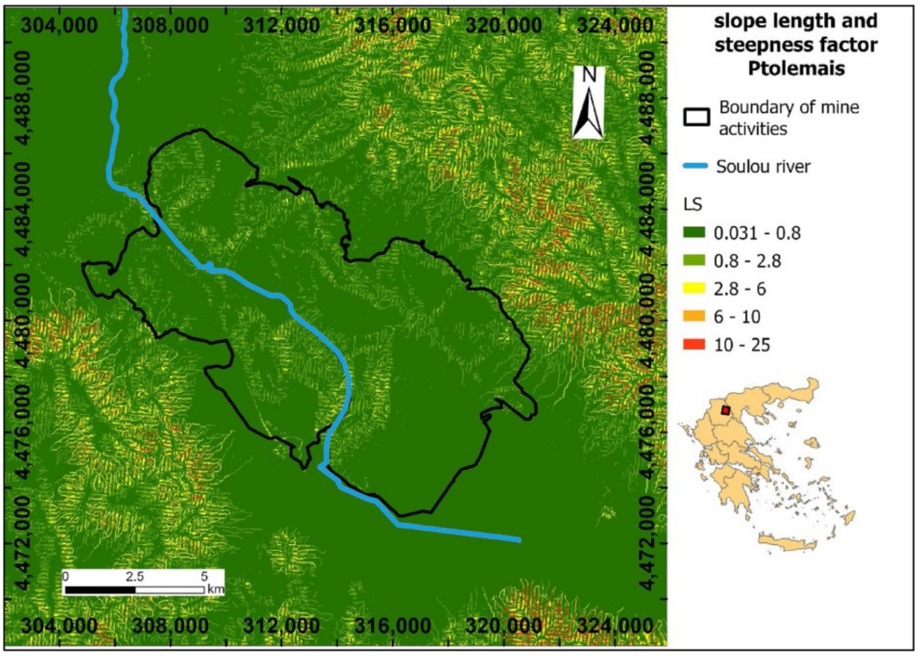


Figure 14. Spatial distribution of LS where high erosion is indicated by red colour (Ptolemais Basin, northern Greece). (Louloudis et al. 2023) The area of mining activities is shown in black

3.1.2. Future Use and Reclamation Plans

Proposed Reclamation Schemes

The reclamation issues that are investigated towards the closure of surface lignite mines of Ptolemais and Amyntaion areas in Greece, involve the following procedures as they have been planned from the Environmental Impact Assessment Study of Ptolemais and Amyntaion lignite mines of PPC, 2024:

- Prevention of access in non-authorized persons
- Safe decommissioning of the mining equipment.
- Configuration of the final excavation and dumping areas.
- Slope stability and prevention from slope erosion
- Surface runoff management
- Final land uses
- Certification of the success of mine closure

Planned Future Uses:

- **Planting forest trees with the aim of wood production, creation of livestock hoppers and development of reclaimed forest areas**, in the cases of slopes of the final excavation and dumping areas.
- **Agricultural use**, in the flat or semi-flat surfaces of the final dumping areas, except from the cases that the approved environmental terms plan forest development.
- **Recreation land uses** in the areas of pit-lakes formation and configuration of the final pit slopes. In the recreational areas are included the forest areas with higher elevations which have panoramic view.
- Installation of several types of **Renewable Energy Sources (solar, PV etc.)** in the final graded areas.

Climate Change Influence

Based on the results of the Deliverable D 3.3, concerning the predicted changes in temperature, precipitation, etc., for the site, the predictive models show that average annual precipitation through the end of the century is expected to decrease, while the average temperature is expected to increase. Also, based on multi-model mean projections average under RCP scenarios, model simulations reported by IPCC (Pachauri et al. 2015) project a 10–15% decrease in precipitation. Projected changes in the climate system are also reported in Politi et al. 2022, where surface temperature is projected to rise approximately 2oC and 3oC under scenario RCP4.5 and RCP8.5, respectively, for the Region of Western Macedonia. Also, precipitation is projected to decrease approximately 20% and 30% under scenario RCP4.5 and RCP8.5, respectively.

3.2. The mining areas of PGG, Poland

3.2.1. Current State

The mining areas of PGG cover 603 square kilometers and are located in 42 communes in the Silesian region and 3 communes in the Małopolska region. A long-term strategy assumes closing all the mines belonging to PGG by 2049. This process will lead to the appearance on the real estate market of areas with high redevelopment potential. Currently, 15 active mining plants cover about 700 hectares, most of which are located in urban areas. After the closure and removal of unnecessary infrastructure, most of these areas will be suitable for industrial and residential redevelopment. Post-mining land use planning should be performed as early as possible to choose appropriate reclamation activities. Despite the high redevelopment potential, due to the large supply, most post-mining areas will not be reused in the near future. On post-mining terrains that have not been revitalized, the spread of invasive plants and dense tree cover development are observed. These processes decrease the economic value of post-mining areas. Coal mining waste dumps are also sites of high scenic value. To protect these values, biological reclamation involves the development and maintenance of low grassy vegetation. Analyses carried out within the framework of Task 3.2 have shown that the Sośnica heap area has high potential for economic reuse. Due to the continuous waste storage process within the heap managed by PGG, it is currently not possible to set there experimental plots.

At present, arrangements are being made with the city of Gliwice to explore the possibility of implementing the reclamation methods developed within the framework of the REECOL project. The city of Gliwice is owner of the section of the heap where the deposition process has already ended.

For this reason, the experimental plot for testing new methods of greening post-mining areas was located within the Północ Waste Heap. This area is used to accommodate waste from the Jankowice mine, which is scheduled for closure in 2049.

Location and Extent

The coal deposit of the KWK ROW Ruch Jankowice mine is located in the southwestern part of the Upper Silesian Coal Basin, within the Chwałowicka basin. The coal deposit “Jankowice” is located within the Silesian province, on the territory of the following cities and municipalities: the city of Rybnik (districts: Boguszowice, Popielów), the municipality of Świerklany (villages: Jankowice, Świerklany Górne and Dolne), and the municipality of Marklowice (village: Marklowice). The Północ Waste Heap has areas of about 56 ha.

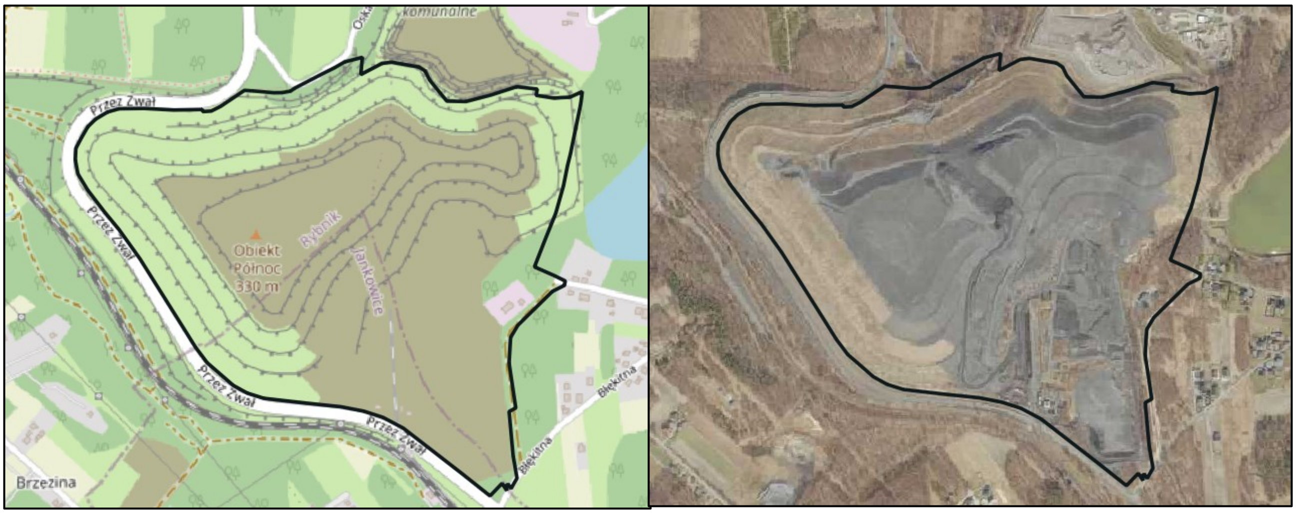


Figure 15. Location of waste heap, Jankowice Coal Mine

Historical Mining Activities

Operational resources in the entire deposit, as of December 31, 2022, amount to approximately 87.16 million tons. The mine is expected to start a new exploitation at the end of February. It is predicted that mining impacts from category I to III of the mining area will appear on the surface. Due to the nearing capacity limits of mining waste disposal sites, KWK ROW Ruch Jankowice is considering the possibility of expanding the Północ Waste Heap area to include sludge tailing.

Current Status

Currently, the storage of mining waste at the Północ Waste Heap is conducted due to the Decision of the Mayor of Rybnik No. Ek-I.6233.9.2020 dated 30.06.2017, amended by the Decision of the Mayor of Rybnik EK-I.6233.12.2020 dated 15.04.2020. The site selected for of the experimental plot is located within the part of the heap on which the waste disposal process has been completed. The target relief has been formed, and most of the slopes are already covered with vegetation. The experimental plot will be located on flat top of the heap, where biological reclamation activites connected to the restoration of soil substrate and vegetation development has not yet been carried out. The current relief of Północ Waste Heap is presented on the figure below.

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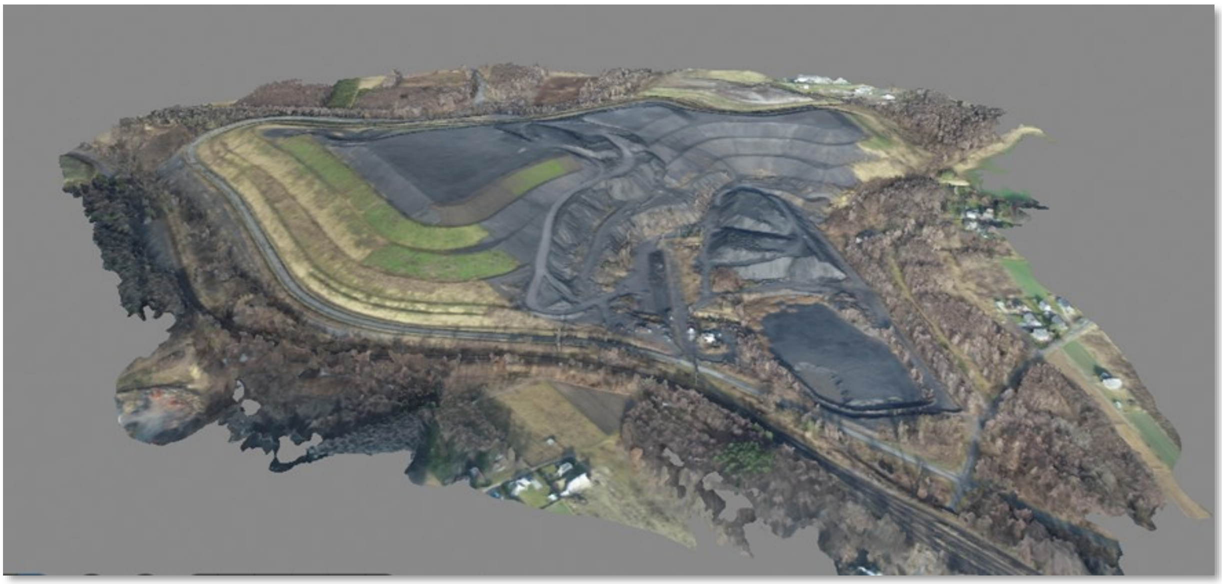

Figure 16. Current relief of Północ Waste Heap

Degradation Status:

Risk of thermal processes

Thermal condition monitoring and soil compaction observation have been conducted since September 2022. Condition of the site has been assessed as satisfactory and without concerns (report from March 2024). The average soil compaction index Is ranges between 0.96 and 0.99, which is consistent with the index value specified in the construction project and building permit.The soil compaction of over 0.95 IS indicates a low risk of thermal processes initiating within the heap (see Deliverable 3.1).

Slop stability

The Jankowice Waste Heap is distinguished by a considerable proportion of low-slope areas. The distribution of flat areas across the heap is as follows:

- Slopes with gradients less than 5°: 32.7% of the heap's area
- Slopes with gradients between 5° and 15°: 15.2% of the heap's area

The terrain with slopes less than 5°, is primarily located on the tops of the waste heap. Formed slopes with degrees between 15° and 26° cover 41.5% of the heap's area. An exemplary visualization of the degradation of the site in terms of potencial to stability loss can be seen in the table and figure below. The figure illustrates how different slope classes contribute to the overall morphology and degradation of the Jankowice Waste Heap.

Table 2. Participation of degree of land degradation in terms of potential stability loss

Degree of land degradation	Treshold value	Participation [%]
		Północ Waste Heap
high degradation	AS > 34° (67,45%)	4,4
midle degradation	AS 26°-34° (48,8%)	6,2
light degradation	AS 15° -26° (26,79%)	41,5
no degradation	AS 5°-15°	15,2
reference status (aim of rehabilitation)	AS < 5° (5.23%)	32,7

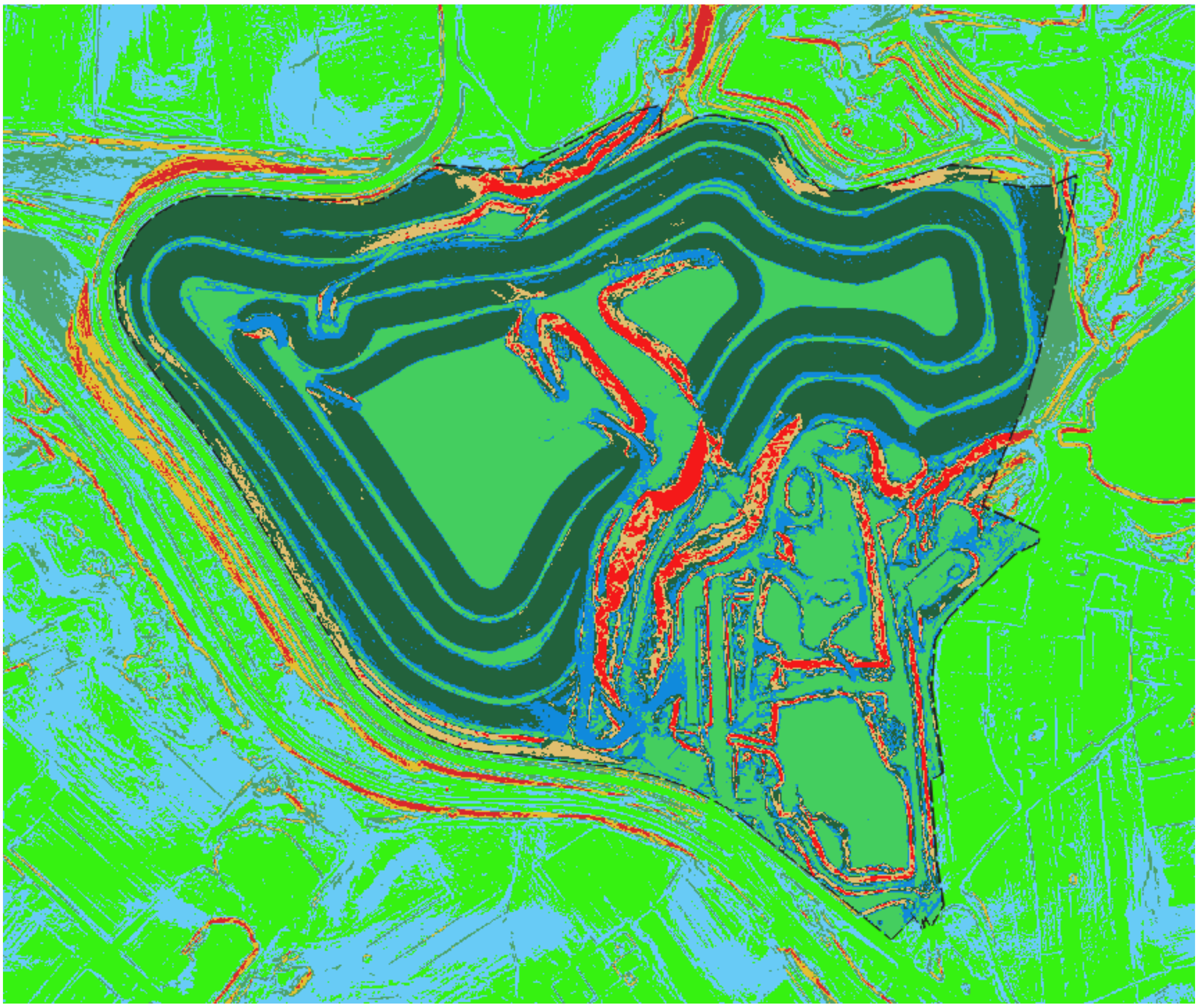

Figure 17. Participation of degree of land degradation in terms of potential stability loss

Condition for plant growth

The degree of site degradation was assessed on the basis of the NDVI indicator. In the case of the Waste Heap Jankowice Waste Heap , there are clearly visible areas with no vegetation and areas with only residual vegetation cover. Areas classified as high and medium degraded occupy over 55% of its area.. Index values above 0.4 were identified only on slopes covered with low vegetation, with the highest achieved in areas with trees growing at the base of the heap.

Table 3. Participation of degree of land degradation in terms of inappropriate condition for plant growth on analysed waste heaps as a result of NDVI indicator analysis

Degree of land degradation:	**Threshold value**	**% of area in category**
		Północ Waste Heap
high degradation	<0.05	2,3%
medium degradation	<0.4	54,6%
light degradation	<0.6	31,6%
reference status (aim of rehabilitation)	>0.6	11,5%
	average value for area:	**0.34**

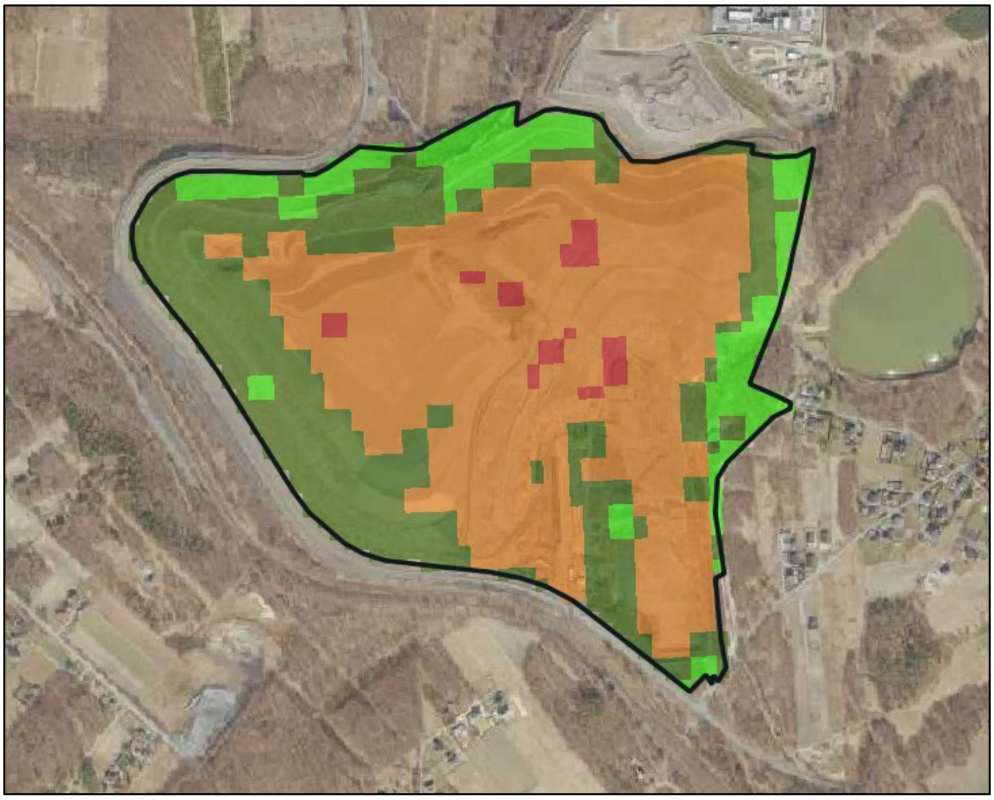

Figure 18. NDVI Indicator, Północ Waste Heap (27.07.2023)

A dedicated flight was carried out with a specialist drone equipped with a set of multispectral cameras (see Fig. 19) to precisely determine the value of the NDVI index, Fig. 20. The obtained images provided insight into the initial state of the study area, prior to the reclamation of the selected site for testing new technologies.

North view of the planned reclamation area is see on Fig. 19 (visible light camera) and Fig. 20 (NDVI index).

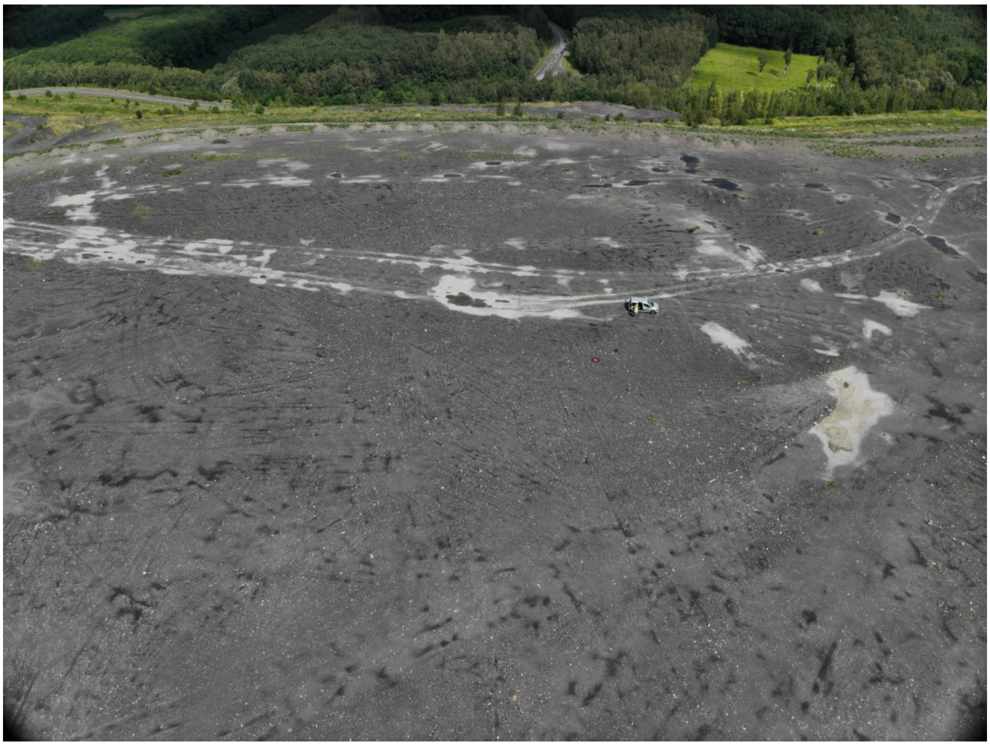

Figure 19. North view (1) of the planned reclamation area (visible light camera)

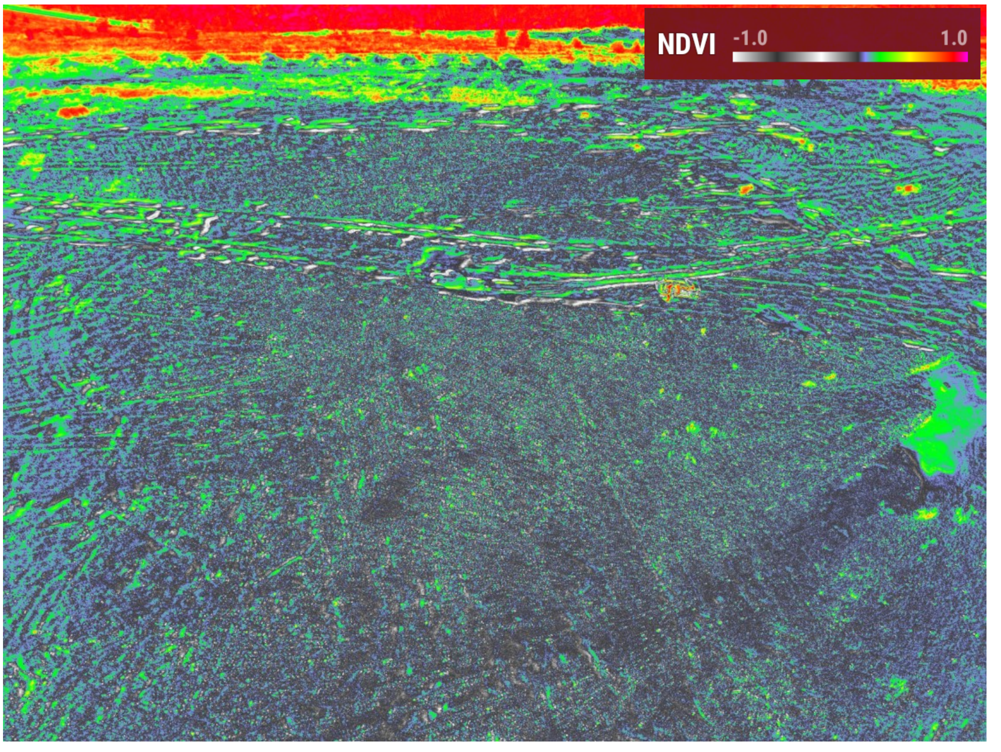

Figure 20. North view (1) of the planned reclamation area (actual value of NDVI index)

Northwest view of the planned reclamation area is see on Fig. 21 (visible light camera) and Fig. 22 (NDVI index).

Figure 21. Northwest view (2) of the planned reclamation area (visible light camera)

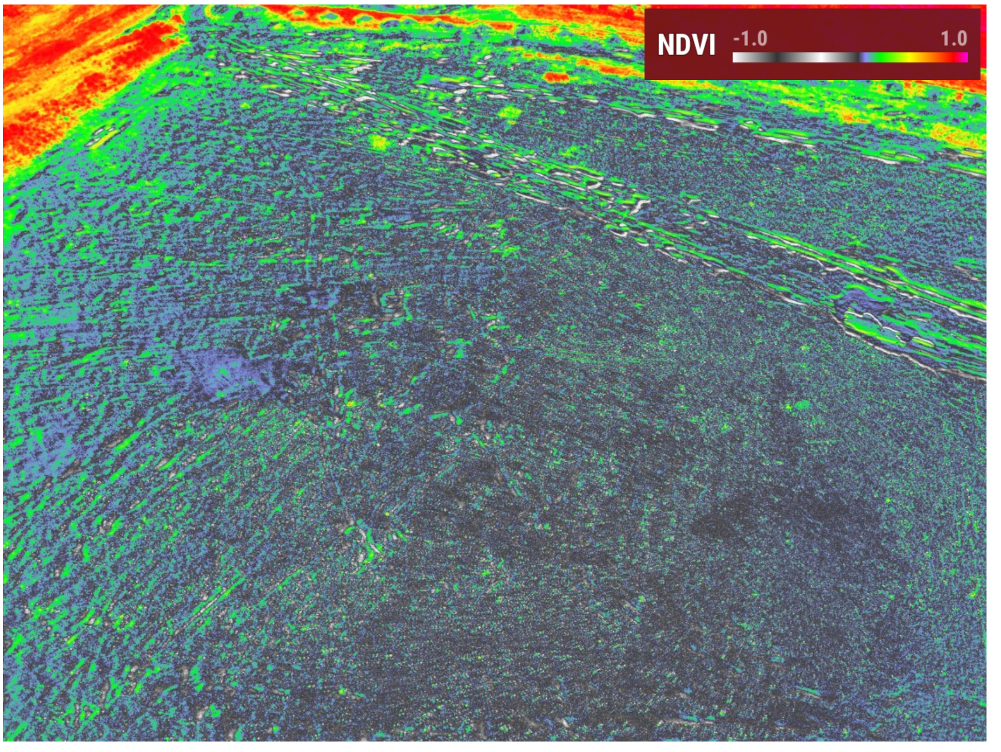

Figure 22. Northwest view (2) of the planned reclamation area (actual value of NDVI index)

Northeast view of the planned reclamation area is see on Fig. 23 (visible light camera) and Fig. 24 (NDVI index).

Figure 23. Northeast view (3) of the planned reclamation area (visible light camera)

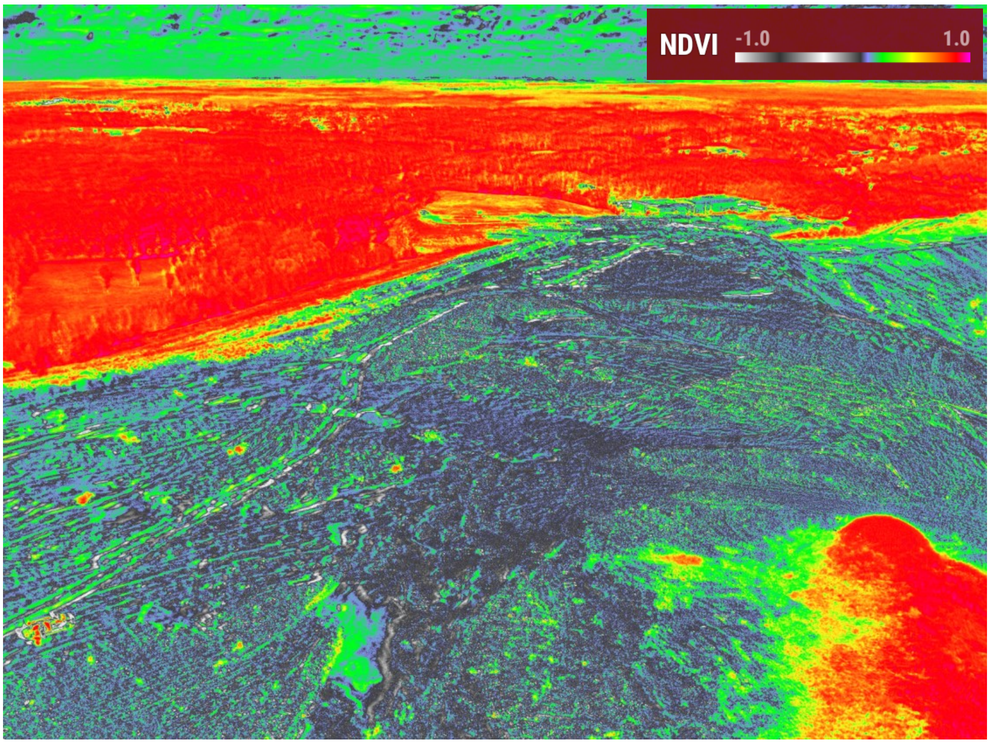

Figure 24. Northeast view (3) of the planned reclamation area (actual value of NDVI index

3.2.2. Future Use and Reclamation Plans

- **Proposed Reclamation Schemes:** protection of the site against water erosion and thermal processes and preparation for recreation proposes.
- **Planned Future Uses:** tourists and local residents.
- **Climate Change Influence:** the predicted climate change may cause the following risks:
  - an increase in the frequency of occurrence of soil droughts (due to change in precipitation structure increase in temperature)
  - an increased water erosion (due to change in precipitation pattern)
  - an increase in the risk of thermal phenomena (due to increase in temperature)

3.3. The mining area of PV, Slovenia

3.3.1. Current State

The Velenje coal mine is in the northern part of Slovenia, in the Šaleška basin (fig. 25).

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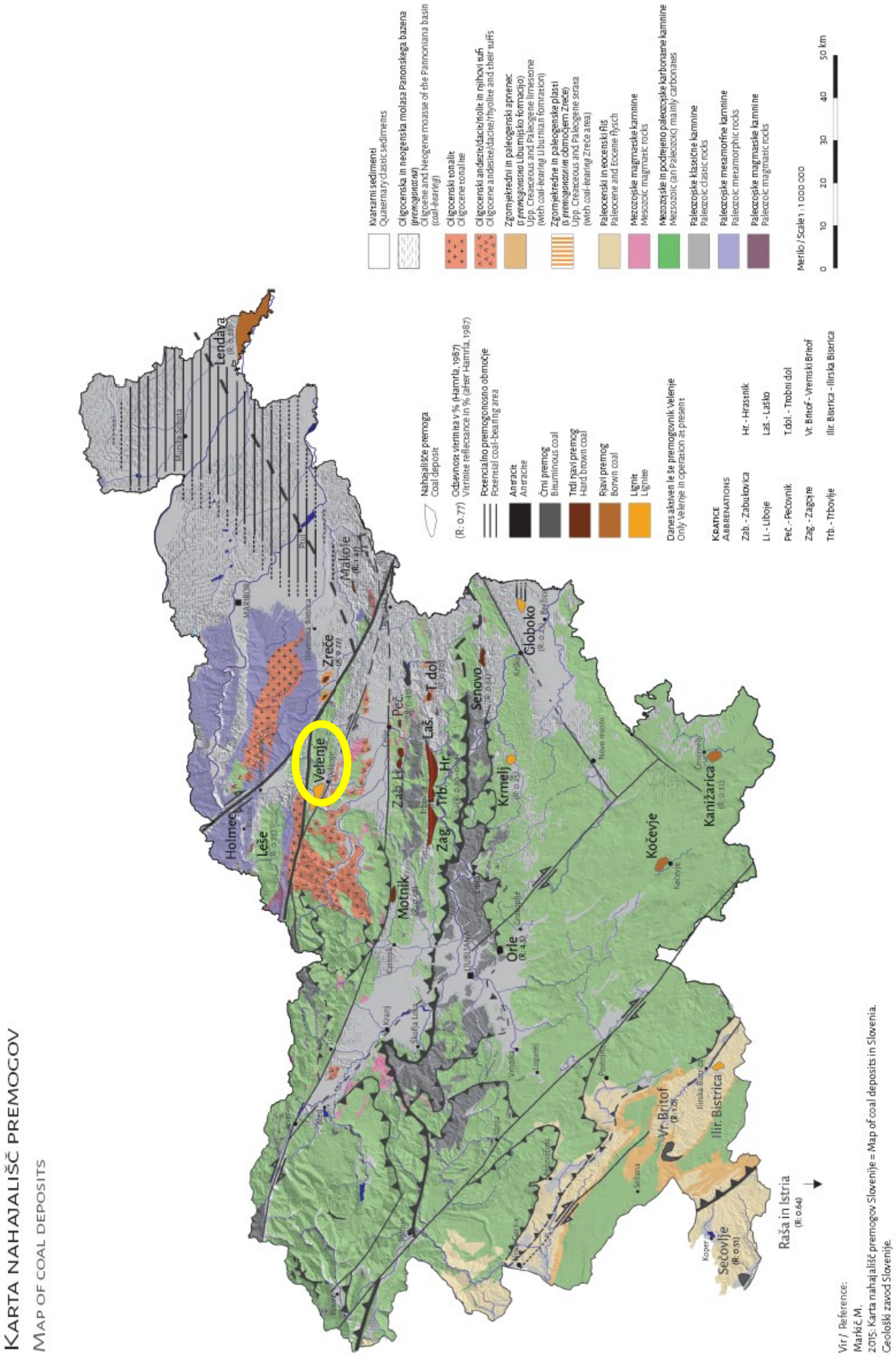

Figure 25. Šaleška basin - yellow ellipse; Map of coal deposits in Slovenia; (M.Markič, GEOLOGICAL SURVEY OF SLOVENIA, 2015)

The mining area (fig. 26) covers 1104 hectares, of which the influential mining area is 560 hectares. The water surface of the lakes in the affected area covers 200 hectares, while rehabilitation is carried out on land with an area of 360 hectares.

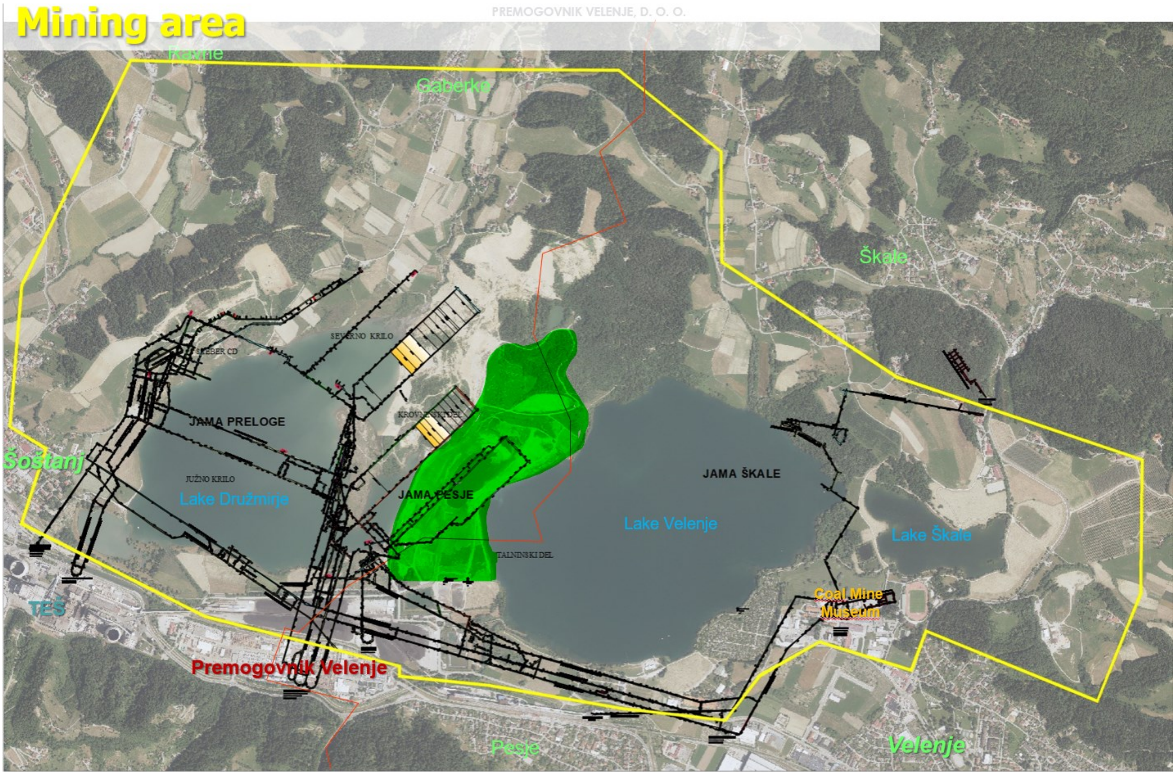

Figure 26. Mining area (inside yellow polygon); Case site: Active subsidence filling area PSU (green hatch). Underground mine objects (black lines) (Original PV archive)

Coal mining at PV started in the eastern part of the mining area. In this area, excavation has been completed and final rehabilitation has been carried out and the areas have been handed over for purposes other than mining, such as agricultural activities, sports and recreational areas and facilities, industrial and civil facilities and the underground coal mining museum.

The lignite extraction technology in the Velenje Coal Mine is carried out using the Velenje Mining Method (VMM), where the layers above the excavation fill the empty space behind the longwall. Sinking of the layers extends all the way to the surface where the influence of mining appears in the form of subsidence up to several meters above the longwall site.

The extent of the influence area of excavation depends on the size, shape and number of excavation fields, the depth and method of excavation, and the number, position and shape of safety pillars. The greatest ground subsidence occurs directly above excavated coal. Due to the large number of excavation levels (height 5-15 meters), which lie one below the other, and the mutual influences of excavation in the individual pits of the coal mine, the surface is subject to subsidence several times. Effects on the surface are manifested in the form of subsidence of the terrain, horizontal movements of the terrain and in the form of the formation of cracks.

Subsided terrain is mostly flooded with water from surrounding watercourses so that these areas are permanently excluded in the sense of primarily agricultural or other land use. The land settles gradually but relatively quickly and as such requires constant control and monitoring of the condition of both the land itself and the buildings on it. We carry out three types of mining rehabilitation works of terrain. Terrain above closed part of the mine must be maintained, which includes road and path maintenance, mowing green areas, tree maintenance, drainage maintenance, and the like. Above the active part of the mine, we carry out ongoing rehabilitation, first by removing vegetation and fertile soil, levelling and filling cracks and maintaining accessible land and maintaining land (covering with fertile soil and greening), which will not be affected by mining for a long time. The third set of rehabilitation is rehabilitation the areas between the two lakes, where subsided terrain is filled with materials from elsewhere and ensure a constant level of the terrain to prevent the merging of the two lakes.

The area of active ongoing subsidence rehabilitation (PSU) (fig. 27), which is our case site, is located on the surface above the coal mine excavations in the area between Lake Velenje and Lake Družmirje Lake. To fill the subsidence at PSU, we use an average of 700,000 cubic meters of several materials, such as fly-ash and gypsum mixture (byproduct of nearby thermal power plant cleaning block is gypsum, fly ash is byproduct of burning coal in thermal power plant) and excavated materials (soil) from construction projects in vicinity.

Figure 27. Subsidence remediation area PSU-within the green polygon.
Black lines are underground mining objects. (Original PV archive)

Areas where subsidence are small, or subsidence will occur in months also in principle we cover degraded terrain with earth and grass and where it makes sense, we also plant bushes and trees with the aim of preventing dust from rising and arranging the space on the spot.

After technical remediation, those parts of degraded surfaces that do not have fertile soil on top are covered (soil is loaded, transported and installed with the help of construction machinery) with at least 20 cm of fertile soil. The fertile soil is obtained from a dedicated landfill from other parts of the mine area, or excavated material from elsewhere or specially prepared soil, if available, is used. These areas are sown with grass, native shrubs and trees are planted, in accordance with the planting plan, which brings it as close as possible to the original condition and surroundings. It is fertilized if necessary and watered in the dry season. The course of natural succession, we let the lakes restore themselves to a natural balance. Of course, local fishing associations take care of the fish life in the lakes. Other animals and plants are left to the natural development of the lake and lakeside habitat.

3.3.2. Future Use and Reclamation Plans

Proposed Reclamation Schemes

The reclamation of the Velenje mining area involves a multi-stage approach to address the varying levels of degradation and prepare the site for future use. The reclamation activities are categorized into technical reclamation, temporary recultivation, and biological reclamation.

1) Technical Reclamation:

- Subsidence Management: Subsided terrain is primarily flooded with water from surrounding watercourses, permanently excluding it from agricultural or other land uses. Constant monitoring and maintenance of these areas are required to ensure stability.

- Maintenance of Closed Mine Areas: This includes road and path upkeep, mowing green areas, tree maintenance, and drainage maintenance.
- Active Mine Areas: Ongoing rehabilitation includes removing vegetation and fertile soil, leveling and filling cracks, and maintaining accessible land.
- PSU Area Rehabilitation: The area between Lake Velenje and Lake Družmirje is actively managed to prevent the merging of the two lakes. Approximately 700,000 cubic meters of materials, such as fly ash, gypsum, and soil from construction projects, are used annually to fill subsidence and maintain the terrain level.

2) Temporary Recultivation:

- Areas with minor subsidence or areas expected to subside soon are covered with earth and grass. Bushes and trees are planted where appropriate to prevent dust and improve the local environment.

3) Biological Reclamation:

- After technical remediation, degraded surfaces are covered with at least 20 cm of fertile soil. This soil is sourced from dedicated landfills within the mine area or from other locations.
- These areas are sown with grass, and native shrubs and trees are planted according to a planting plan that aims to restore the landscape to its original condition. Fertilization and irrigation are applied as needed.

Reclamation According to Use:

1) **Agricultural Reclamation:** Areas designated for agricultural use are rehabilitated by covering the land with fertile soil and planting grass, native shrubs, and trees. This approach aims to bring the land as close as possible to its original condition and make it suitable for agricultural activities.
2) **Forest Reclamation:** Land that was originally forested before mining activities is restored to forest areas. Based on municipal zoning acts and the mining rehabilitation project, these areas are planted with native tree species to reestablish forest ecosystems. Some forest areas may be re-categorized for other purposes if deemed appropriate.
3) **Hydric Reclamation**: Watercourses affected by mining activities are maintained to integrate seamlessly with the surrounding environment. Before flooding subsided terrain, the fertile upper layer of soil is removed and used for rehabilitation in other parts of the mine area. Streams and lakes are managed according to water management community guidelines and spatial plans to ensure ecological balance and water quality.
4) **Natural Succession:** In some areas, natural succession is allowed to take its course, particularly in and around the artificial lakes. Local fishing associations manage fish populations, while other animals and plants are left to establish naturally, creating balanced and self-sustaining ecosystems over time.
5) **Other Reclamation Activities:** Additional reclamation efforts include repairing minor damage to residential buildings on the outskirts of the mining area. This typically involves fixing cracks or minor structural rehabilitation to ensure the safety and usability of these buildings.

By implementing these comprehensive reclamation strategies, the Velenje mining area aims to transform degraded landscapes into stable, productive, and ecologically balanced environments. These efforts will support sustainable land use, enhance biodiversity, and improve the overall quality of life for local communities.

Climate Change Influence

Climate change will significantly impact the reclamation and future use of the Velenje mining area. Projected temperature increases of 1°C to 4°C by 2100, depending on the scenario, will extend the growing season and necessitate adjustments in vegetation selection and reclamation schedules. Precipitation changes, with an expected 10% increase in annual mean precipitation by 2100 under RCP4.5, will require enhanced water management strategies to prevent flooding and soil erosion. The frequency of extreme weather events will increase, posing risks to land stability and infrastructure, thus demanding adaptive management practices. Additionally, shifts in seasonal patterns, such as more summer days with temperatures exceeding 25°C and fewer cold days, will affect plant growth and biodiversity, necessitating the selection of heat-tolerant species and strategies to enhance ecosystem resilience. Addressing these climate impacts will ensure the sustainability and success of reclamation efforts in the Velenje mining area.

3.4. Radovesice dump/Strimice dump, the Czech Republic

3.4.1. Current State

Location and Extent:

The Radovesice/Střimice spoil heap complex is situated in the central part of the Most Basin. Both dumps are external dumps of the Bílina open pit mine, which is the largest quarry in the Czech Republic. The Radovesice spoil heap is situated between the foothills of the České středohoří Mts. in the north and the town of Bílina in the south. The Střimice spoil heap is located east of the town of Most, north of the Bílina open pit mine.

The area of the Radovesice spoil heap - Bílina open pit mine - Střimice spoil heap is approximately 35 km^2, the actual area of the Radovesice dump is 1,950 ha, and the actual area of the Střimice dump is 388 ha.

The situation of the Most Basin is shown in Figure 28. The case study area is situated approximately between the towns of Bílina, Most and Litvínov.

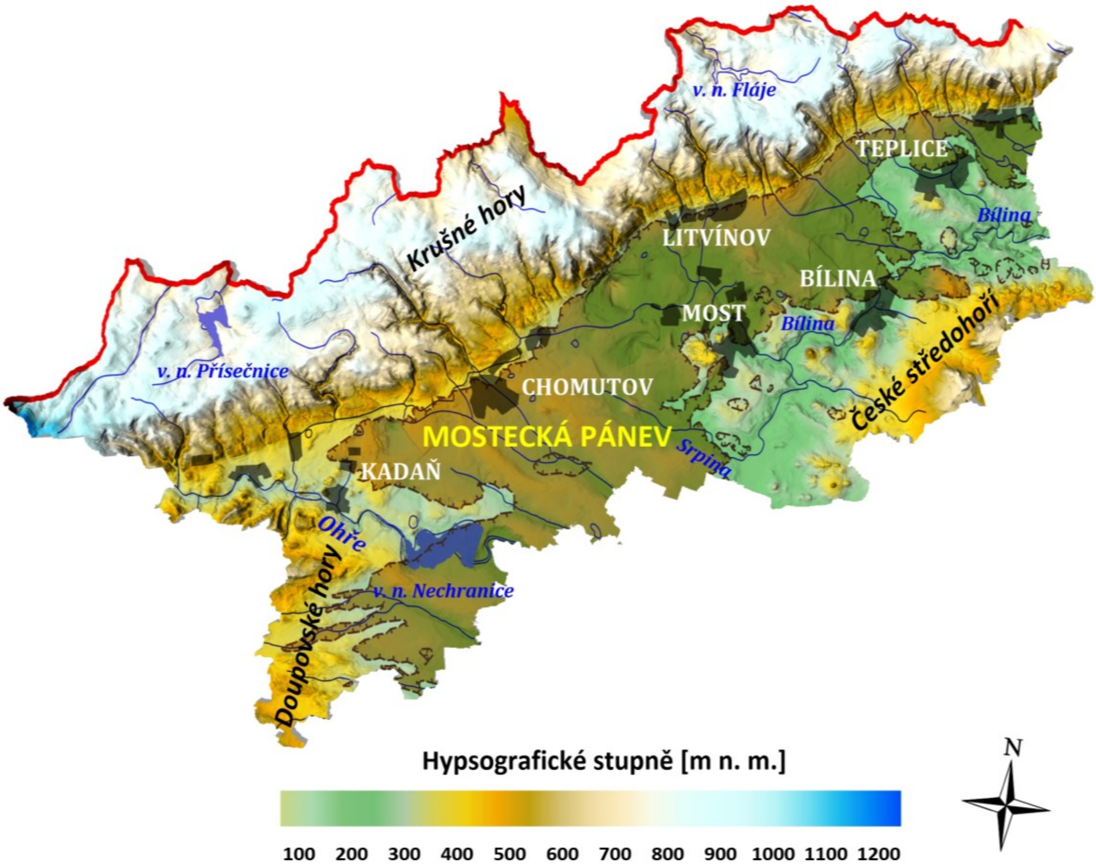

Figure 28. The Most Basin situation

Historical Mining Activities

The extensive Bílina open-pit mine was created in the 1970s by combining several smaller open-pit mines. Coal and overburden soils are constantly mined here. Mining is planned to end between 2030 and 2035.

The Radovesice spoil heap is located in the once-famous Radovesice Valley, which was located east of the town of Bílina. Archaeological records prove human settlement since the Neolithic and Bronze Age. The Radovesice spoil heap project was created in 1966, the actual foundation was started in 1969–1970. The municipality of Radovesice disappeared in the years 1968-1971, the municipality of Hetov in the years 1969-1971 and the municipality of Drínek in the years 1969-1975. The foundation of soil on the Radovesice dump was completed in 2003. The pedological characteristics of the overburden soils of the Bílina open pit mine, which were placed on the surface of the dump, were quite unfavourable.

The first stage of recultivation of the Radovesice spoil heap was started with forest reclamation in 1986 (30 ha), when the marl was already used to create a rooted horizon. As part of the following second stage, an extensive marl was created on an area of 120 ha, which was used even after the mining mine was backfilled until 2010. This was followed by the stages Radovesice III – Radovesice XVII. With the exception of experimental areas left to natural succession (Radovesice XVIIA, B), in all cases, marl was used to create a rooted horizon. The methodology of their application was developed based on the results of research works. Instead of the original layer of 0.6 m, only 0.2 - 0.3 m was applied in recent years and the emphasis was placed on embedding them into the ground surface [1]. For agricultural reclamation, topsoil hidden from the surface of the original terrain and placed at the Hetov landfill was used.

Two areas of 20 ha and 32 ha (Radovesice XVIIA and Radovesice XVIIB) were left to experimental natural succession. These are today the largest successional areas in the Most Basin and one of the largest in the Czech Republic.

Table 4. Total area and method of reclamation of individual reclamation stages (plan)

Reclamation stage	Total area (ha)	agricultural (ha)	Forestry (ha)	Hydric (ha)	other (ha)
etapa I	30,40		30,40		
etapa II	110,40		11,45	0,70	98,25
etapa III	52,00		49,40		2,60
etapa IVA	8,98		8,98		
etapa IVB	27,70		27,70		
etapa V	8,92				8,92
etapa VI	44,36		16,41	0,47	27,48
etapa VII	82,75		45,19		37,56
etapa VIII	116,33	67,44	48,48		0,41
etapa IX	75,76	51,90	19,73		4,13
etapa X	93,45		32,74	2,52	58,19
etapa XIA	5,74				5,74
etapa XIB	56,23		9,73	0,75	45,75
etapa XII	85,23		58,48	1,83	24,92
etapa XIII	96,06		16,66	1,38	78,02
etapa XIV	50,74		21,13	0,90	28,71
etapa XVA	6,81				6,81
etapa XVB	5,39				5,39
etapa XVI	5,66			0,08	5,68
etapa XVIIA	19,51*			1,09	18,42
etapa XVIIB	33,90*			1,17	32,73

* research area left to long-term natural succession (including spontaneously formed water bodies

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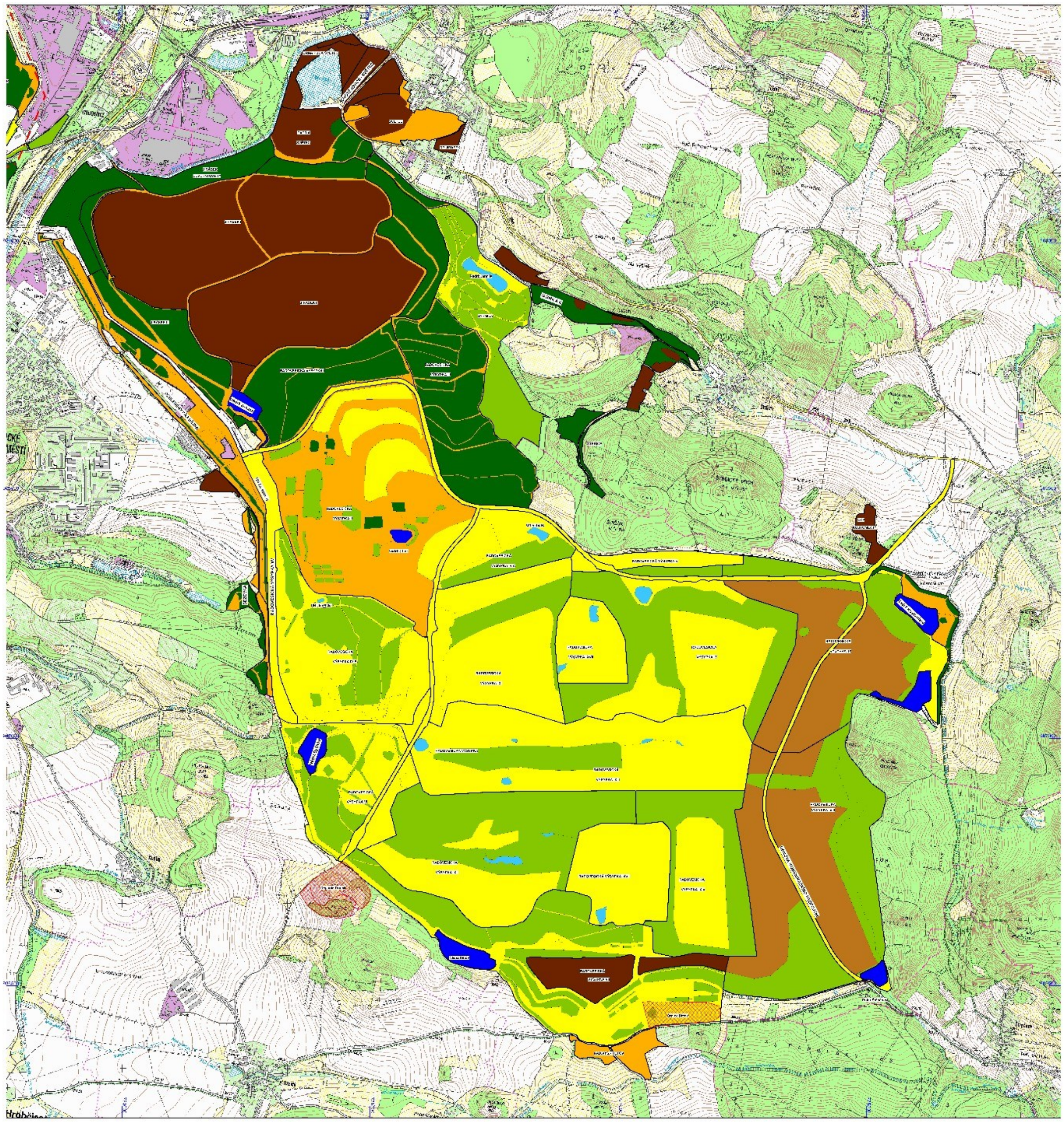

Figure 29. Schematic map of the planned and realised reclaimed areas of the Radovesice spoil heap

In picture 29, agricultural reclamation is marked in brown, forestry reclamation in green, other reclamation in yellow and hydric reclamation in blue.

The Střimice spoil heap is located east of Most. It was established in the years 1959 – 1973. Due to the extremely phytotoxic properties of the surface zone of the spoil heap, the original forest reclamation practically died out. At the same time, a significant influence of erosion phenomena was manifested. At the suggestion of VUHU, bentonites from the Red Hill quarry were then used for reclamation. Recultivation was started in 1984. The layer of applied bentonite soil was set at 50 cm. After ploughing, weeding was carried out and forest reclamation was carried out later. In 1988, agricultural reclamation was started on the dump plain with a total area of 89 ha. At this reclamation event, VUHU has not yet participated, but has been monitoring for 30 years. 2 long-term monitored experimental areas were established on this spoil heap.

Table 5. Total area and method of reclamation of individual reclamation stages (realised)

Reclamation stage	Total area (ha)	Agricultural (ha)	Forestry (ha)	Hydric (ha)	Other (ha)
etapa I	230,40	230,40			
etapa II	130,40		130,40		
etapa III	27,20*				27,20

* research area left to long-term natural succession

Figure 30. Situation of the reclaimed and succession areas of the Střimice spoil heap

Current Status:

The Radovesice spoil heap has an elongated shape from the southeast to the northwest, and its territory belongs to the highlands of the České Středohoří Mts. itself. It is the most extensive spoil heap in the Moste Basin. Due to its scope, importance and the extremely unfavourable character of loose soils, local marlstones were used as a reclamation additive. These form the geological surface of the erosion valley in the bedrock of the landfill. The recultivation properties of marls are worse than in the case of bentonites, the application methodology was also based on research by VÚHU gradually adjusted, but overall, the event was successful. The characteristics of the created seasoning horizon are still used today by VÚHU monitored. 4 long-term monitored experimental areas were established on this spoil heap. The pedological parameters of the soils of the selected succession and reclaimed areas are shown in next tables.

Experimental area Radovesice XVIIA

The experimental succession area of Radovesice XVIIA with an area of approx. 20 ha was selected in the northern part of the landfill. The predominant soil type here is a heterogeneous dump mixture of brown clay, grey clay loam and grey sandy loam with an increased content of brown clay. Brown - grey kaolinitic - illitic clays also appear. The southern border of the area is the area of "sand dunes". There are also two large natural water reservoirs and several small bodies of water and wetlands in the area. Some small bodies of water turn into wetlands over the course of the year. The surface is approximately 32 years old. At present, it is already a fragmented, aesthetic area with several spontaneously formed, permanent bodies of water (see Figure 31).

Table 6. Pedological parameters of soil profile - Radovesice XVIIA (natural succession)

Sampling interval (m)	Nc (%)	Cox (%)	$CaCO_3$ (%)	pH KCl	Acceptable nutrients (mg.kg^{-1})			Sorption capacity		
					P	K	Mg	S	T	V
								mmol/100 g		(%)
2024										
0,00-0,60	0,10	2,9	0,6	6,9	8	262	880	16	16	100

Figure 31. Succession area Radovesice XVIIA - overall situation

Experimental area Radovesice XVIIB

The succession area of Radovesice XVIIB with an area of 32 ha was selected in the southern part of the landfill. The soil composition of the upper horizon is like to that of area XVIIA. In the eastern part of the area, sandy soils are more prominently represented, which form the natural boundary of the area. There are several of natural water bodies and smaller wetlands. The surface is approximately 22 years old. At present, it is also a fragmented, aesthetic area with numerous spontaneously formed, permanent bodies of water.

Experimental area Radovesice I

The experimental recultivated area of Radovesice I, with an area of approximately 30 ha, was based on one of the first areas recultivated with the use of marls. This area was established in 1991 and is thus the oldest monitored experimental area in the Most Basin. The original landfill soil consisted of sandy clays and sands. This is the area where the original, unmodified method of applying saliva and slag was applied.

Experimental area Radovesice VI

The experimental recultivated area of Radovesice VI with an area of approx. 44 ha was established in the western part of the Radovesice spoil heap. A modified marls application methodology was already used here. A layer of 0.2 - 0.3 m thick silt was brought to the surface of the terrain and plowed to a depth of up to 0.5 m. The original fill soil consisted of sandy clays and sands. Currently, it is a very aesthetic area with a balanced share of forest reclamation, grass reclamation and hydric reclamation (Syčivka water reservoir – Figure 32).

Table 7. Pedological parameters of soil profile - Radovesice VI (reclaimed area – marl application)

Sampling interval (m)	Nc (%)	Cox (%)	$CaCO_3$ (%)	pH KCl	Acceptable nutrients (mg.kg^{-1})			Sorption capacity		
					P	K	Mg	S	T	V
								mmol/100 g		(%)
2024										
0,00-0,20	0,10	2,3	7,1	7,1	3	238	864	17	17	100
0,20-0,60	0,06	1,5	6,2	6,3	3	218	725	14	14	100

Figure 32. Newly created reclamation landscape (Radovesice VI, Syčivka reservoir

The Střimice spoil heap is located east of Most. Reclamation of the dump is mostly completed, a unique reclamation using bentonite was applied here. The layer of applied bentonite soil was set at 50 cm. After ploughing, weeding was carried out and forest reclamation was carried out later. In 1988, agricultural reclamation was started on the dump plain with a total area of 230 ha. At this reclamation event, VUHU has not yet participated, but has been monitoring for 30 years. 2 long-term monitored experimental areas were established on this spoil heap.

Experimental area Střimice I

The research experimental area Střimice I with an area of 2 ha was enclosed in a small, non-reclaimed peripheral part of the Střimice landfill. The estimated age of the area is 45 years, research has been ongoing here since 1998. The predominant soil type here is a heterogeneous mixture of overburden soils from the coal seam formations of the Bílina open pit mine. Sandy clay loams and sands with a significant admixture of coal and siderite predominate. These are extremely acidic, phytotoxic soils (see Figure 33). A unique development of erosion grooves with a depth of up to several meters can be observed on the surface. This phenomenon is probably the most prominently developed here in the entire area of the Most Basin. Considering the extremely acidic character of the area, minimal plant representation was found here, but rare acid-loving species may occur.

Table 8. Pedological parameters of soil profile – Střimice I

Sampling interval (m)	Nc (%)	Cox (%)	$CaCO_3$ (%)	pH KCl	Acceptable nutrients ($mg.kg^{-1}$)			Sorption capacity		
					P	K	Mg	S	T	V
								mmol/100 g		(%)
2024										
[2]0-0,50	0	4,8	0,5	4,1	0	62	115	6	20	28
[2]0- 0,50	0	5,1	0,4	3,9	0	54	143	3	8	39

Figure 33. Succession area Střimice I

Experimental area Střimice II

The Střimice II experimental area with an area of 10 ha was defined on the top of the landfill reclaimed with the use of bentonite. The age of the area is approx. 30 years, research has been ongoing here since 1992. Bentonite was used on this area to meliorate the surface of unsuitable, phytotoxic landfill soils and to create a seasoning soil horizon. Forest reclamation was carried out on the area.

Table 9. Pedological parameters of soil profile – Střimice II (2024)

Sampling interval (m)	Nc (%)	Cox (%)	$CaCO_3$ (%)	pH KCl	Acceptable nutrients ($mg.kg^{-1}$)			Sorption capacity		
					P	K	Mg	S	T	V
								mmol/100 g		(%)
2024										
0,00-0,50	0,06	1,8	1,0	6,9	9	247	223	16	156	100
0,50-0,90	0,04	1,1	8,3	7,5	4	268	978	31	31	100
pod 0,90	0,01	2,7	0,4	4,8	1	102	193	3	8	39

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Figure 34. Soil profile with bentonite – Střimice II

Degradation Status:

There are practically no degraded soils in the area of the Radovesice spoil heap. Within the case study area, an example of a degraded area is the non-reclaimed part of the Střimice spoil heap.

It is a degraded area contaminated with coal mass and hazardous trace elements. It was described in more detail in the previous chapter. The following tables characterize the soil parameters.

Table 10. Site 3-Střimice I– risky trace elements situation (2021)

locality	content in the sample (mg . kg^{-1})											
	As	Be	Cd	Co	Cr	Cu	Mo	Ni	Pb	V	Zn	Hg
S1/0-0.5m	21,1	1,04	0,21	15,6	44,6	28,9	0,54	36,2	50,7	112,5	101,3	0,130
S2/0-0.5m	35,1	1,24	0,23	15,6	48,2	36,8	0.43	35,6	42,8	94,1	90,2	0,067
common soils*	20	2.0	0.5	30	90	60	---	50	60	130	120	0.3

- - limit values according to Decree No. 153/2016 Coll.

Table 11. Site 3-Střimice I – other pollutants situation (2021)

locality sampling interval (m)	S [%]	organic compounds [%]	pH KCl	presence of Fe sulphides
S1/0-0.5m	3,2	3.7	4,9	**YES**
S2/0-0.5m	4,3	4,9	3.8	**YES**

3.4.2. Future Use and Reclamation Plans

Proposed Reclamation Schemes

The planned recultivation activities are somewhat different at both locations forming the case study area.

In the case of the **Radovesice spoil heap,** it is necessary to respond to new challenges and requirements placed on reclamation works. These must meet the needs of the residents of the region affected by mining, adapt to economic and ecological requirements and new research results, and withstand various risk factors. An example can be the reclamation of the Radovesice spoil heap. Considering the area of the landfill, the problematic nature of the original landfill soils, the very demanding technical reclamation with the use of saliva, the well-thought-out establishment of areas left to natural succession and long-term pedological and biological research, this is one of the most significant reclamation actions in the Czech Republic.

In accordance with the reclamation schemes of the Czech Republic, a balanced combination of forestry, agricultural and hydraulic reclamation will be implemented on the site. As part of the REECOL project, modifications to existing reclamation methods can be implemented here. Increased emphasis will be placed on areas left to natural succession.

Short-term monitoring will be implemented at the locality, and long-term monitoring at characteristic sites. The main methods of monitoring will be soil mapping and taking characteristic samples. For each sample, granularity determination, evaluation of mineralogical composition on Siemens X-ray diffractometer, determination of soil reaction, determination of $CaCO_3$ content were carried out, determination of the content and quality of oxidizable carbon and humus, determination of nitrogen content, determination of sorption capacity and determination of the content of acceptable nutrients according to Melich III. In the case of areas left to natural succession, biodiversity will be monitored, including the use of a drone.

In the case of the **Střimice spoil heap**, most of the reclamation work has already been implemented. The location was selected as part of the case study area for some exceptional parameters. The landfill consists of extremely phytotoxic coal clays and sands. Therefore, a unique recultivation using bentonite was implemented here. This procedure is already impossible today for economic reasons.

Therefore, emphasis will be placed on monitoring, the methodology of which will be similar to that in the case of the Radovesice spoil heap. An experimental research area left to natural succession, where a unique acidophilic flora occurs, will also be monitored.

Ecologically and economically appropriate methods of recultivation of such a degraded area can be tested in a large area left to natural succession (outside the experimental area).

Figure 35. Monitoring the development of the soil profile in the reclaimed area

Planned Future Uses

In the entire territory of the case study area, the further development of areas of agricultural and forestry reclamation is expected.

In the case of the **Radovesice spoil heap**, emphasis will be placed on the use of a large part of the locality as a suburban recreation zone. Forests are established as soil protection, suburban and for short-term recreation. The rugged plateau will be made up of forest and meadows. Each area has a designated future use. There are areas designated for economic forest, recreational forest, agricultural activity, cycle paths, educational trails, sports activities and meadows with a view and with explanatory boards. A campsite at the Kostomlaty water reservoir will also be included. Currently, a hunting and fishing area has been created for the area of the dump, and the road connection through the dump from Bílina to Kostomlat, Štěpánov and Razice was recently completed. Established succession areas will form an important landscape-forming element.

In the case of the **Střimice spoil heap,** in addition to forestry and agricultural reclamation, emphasis will be placed on research into the reclamation of extremely degraded areas and the development of succession in extreme conditions.

Research will be carried out on the experimental areas, which will favourably influence the reclamation methodology. Examples can be changes in the methodology of applying fertilizable soils during technical recultivation or a response to the risk of increased occurrence of dry periods in times of climate change.

Climate Change Influence

This is not a specific problem of the Radovesice/Střimice spoil heaps, it concerns all reclaimed sites in the Most Basin. Research into the effects of climate change on reclamation is dealt with in more detail in Task 3.3 within the REECOL project.

Briefly, we can state a definite rise in temperatures since at least 1960. This trend will continue into the 1930s and probably beyond. Impacts on mining are small and reclamation will not be fundamentally affected either. The impacts of changes in precipitation are much more serious for reclamation.

The wider area of the Most Basin, lying in the rain shadow of the Ore Mountains, is known as a dry area within the Czech Republic, regardless of climate change. Evaluating the long-term development of precipitation is much more complicated than it is in the case of temperature. The trend is not clear-cut, in the period 1991 - 2013 a rather moderate increase in precipitation can be observed, while the period 2015 - 2019 was, on the contrary, very dry.

The results of the simulations with the ALADIN-CLIMATE / CZ model do not predict a total reduction of the annual totals of precipitation but indicate a significant variability of the average totals of precipitation. The forecasted values signal the risk of an increase in soil moisture deficit in the second half of spring and summer, considering increased evaporation due to higher temperatures. The occurrence of individual dry periods is quite likely.

Despite some uncertainty in rainfall forecasts, the very dry period 2015 - 2019 with the extremely dry year 2018 is a warning. The dry period can also be seen in the results of the biological cover (tree, shrub and herbaceous level) research carried out on the succession area of Radovesice (see picture no. 36).

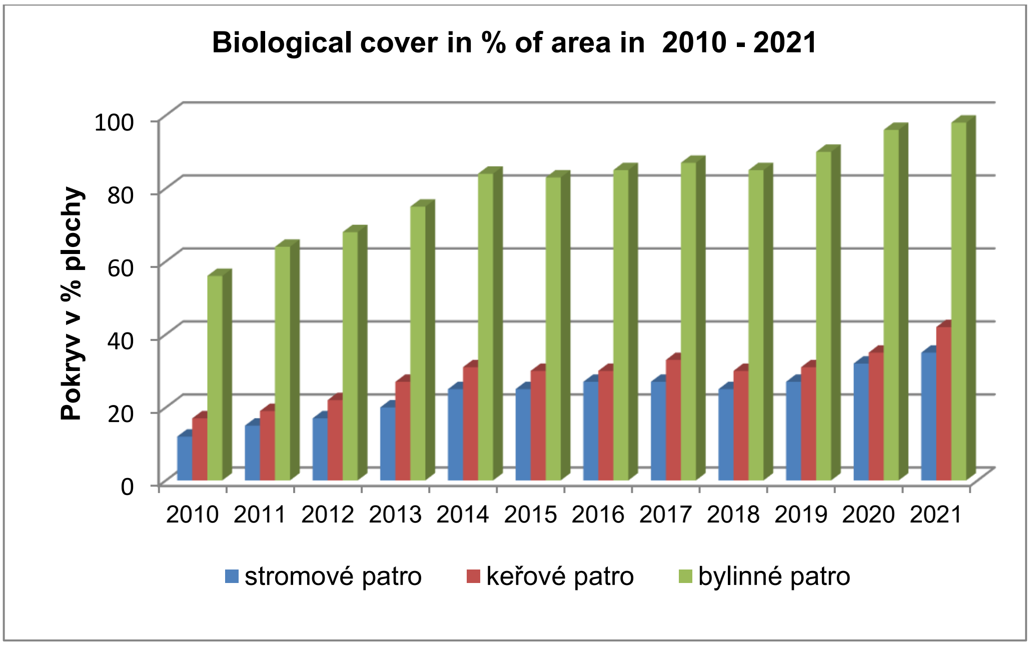

Figure 36. Temporal development of the biological cover of the succession area Radovesice

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However, if this trend continues, the number of reclamation sites affected by the drought will increase. In the long term, the costs of reclamation could increase extremely due to the costs of plantings and the need for a radical change in the reclamation methodology.

Based on these findings, it is necessary to develop recultivation adaptation methodologies within the project (modification of recultivation procedures, selection of a suitable assortment of resistant wood species, etc.).

3.5. The mining areas of the Konin Brown Coal Mine, Poland

3.5.1. Current State

The Konin Brown Coal Mine, specifically the Jóźwin II B open-pit mine, is located in the eastern part of the Greater Poland Voivodeship, primarily within the northern part of the Konin County. It spans across Kleczew and Wilczyn municipalities, covering an area of 47,3 km² (fig.37). The broader mining area known as Pątnów encompasses approximately 420 km² and includes additional municipalities such as Ślesin, Kazimierz Biskupi, Konin, Kleczew, Ostrowite, Słupca, Golina, Wilczyn, and Skulsk (fig. 38). Geographically, this region falls within the Central Polish Lowlands in the Greater Poland Lake District, characterized by flat and slightly undulating terrain formed by the last glaciation

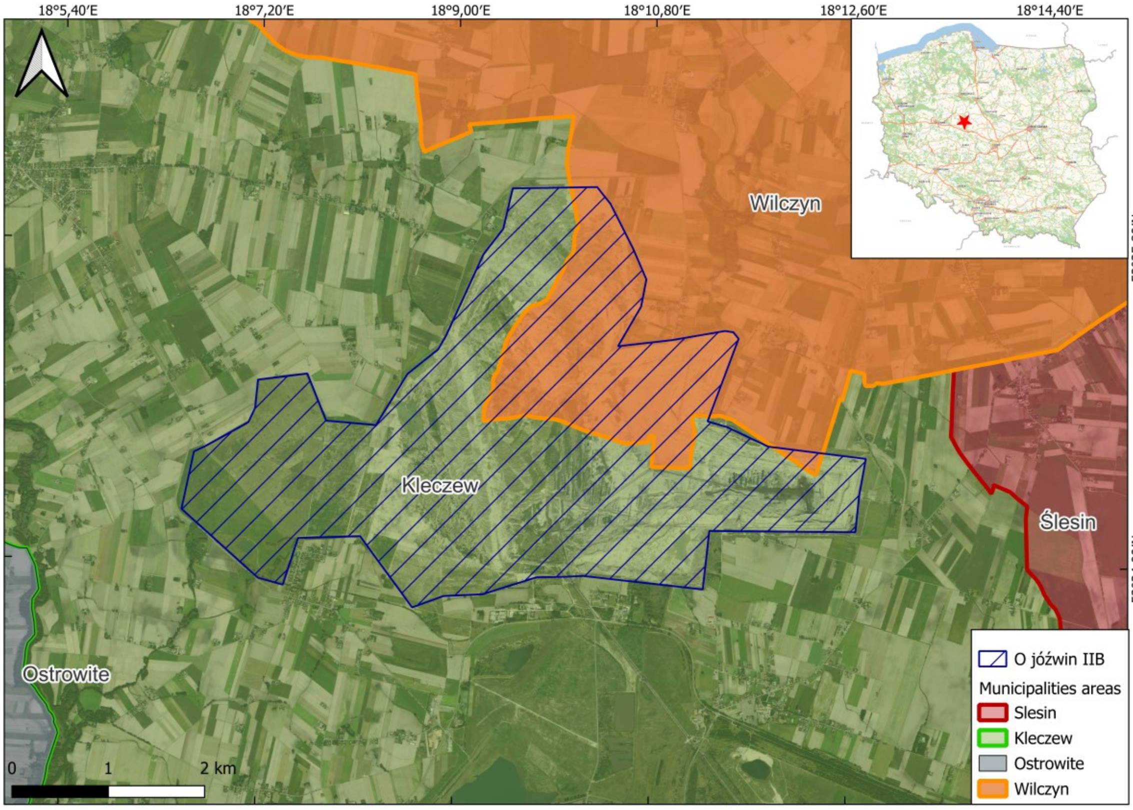

Figure 37. Jóźwin II B open-pit mine on the municipalities Wilczyn and Kleczew

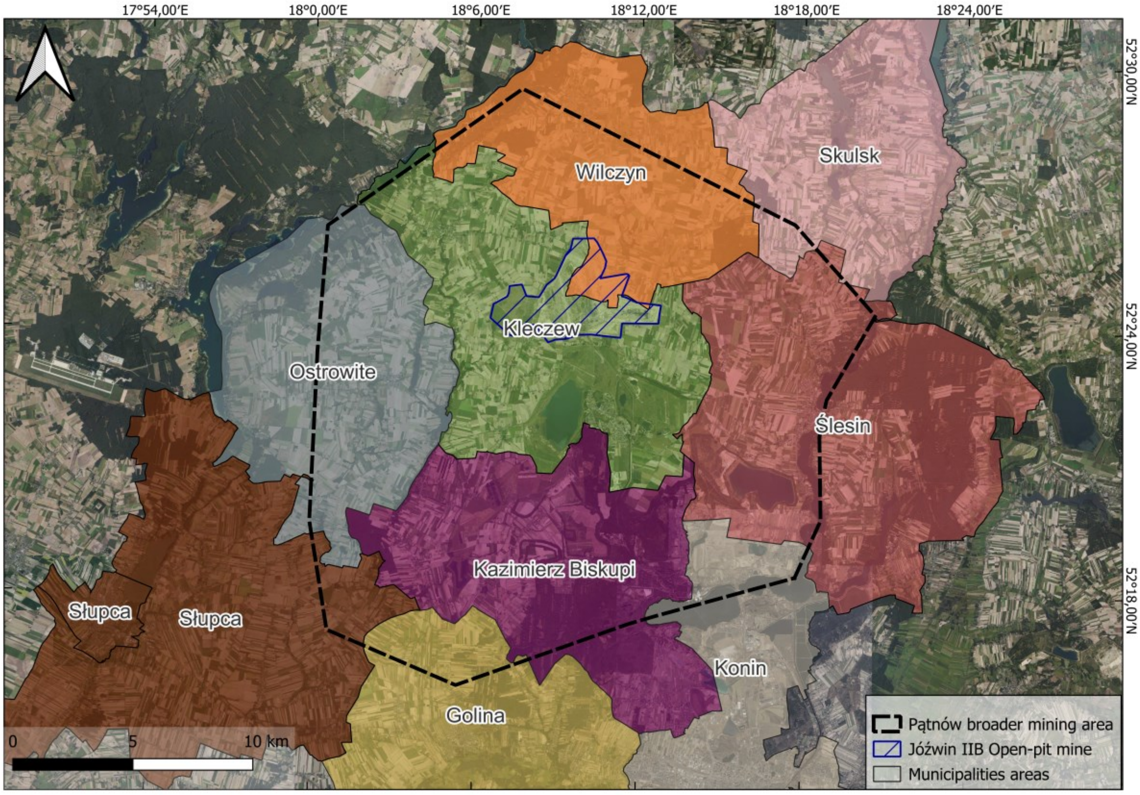

Figure 38. Pątnów broader mining area on the municipalities around

Historical Mining Activities

The Konin Brown Coal Mine has a long history of lignite extraction using open-pit methods. The Jóźwin II B mine, part of the larger Pątnów IV mining area, was officially established by a decision of the Minister of Environmental Protection, Natural Resources, and Forestry on August 30, 1993. The primary activity involves the surface mining of lignite, which is a significant segment of the Pątnów lignite deposit, also referred to as the Konin deposit, located within the Konin-Turek coal basin. The mine has caused considerable alterations to the landscape, including the formation of external and internal dumps, deep excavation pits, and extensive industrial infrastructure

Current Status

Currently, the Jóźwin II B mine is in the process of decommissioning, which is planned to span from January 1, 2024, to December 31, 2029. This includes the dismantling of mining infrastructure, remediation of environmental impacts, and reclamation of the land. The reclamation efforts are multifaceted, involving technical and biological rehabilitation aimed at transforming the post-mining landscape into agricultural, forestry, recreational, and aquatic environments. Specific measures include the stabilization of slopes, creation of water reservoirs, and restoration of vegetation.

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Degradation Status

Normalized Difference Vegetation Index

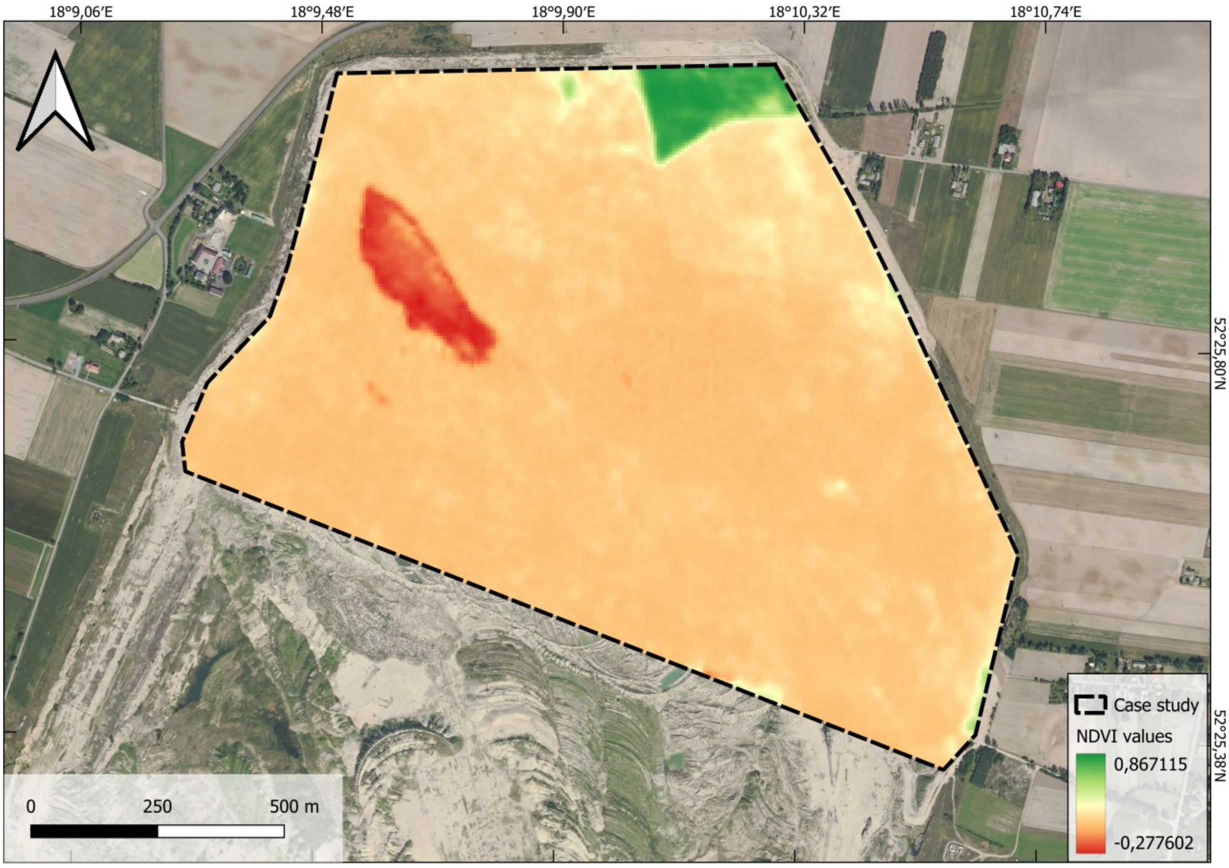

Figure 39. NDVI on case study in Jóźwin II B mine

Table 12. Numerical values of NDVI on case study – Jóźwin II B

NDVI value	Numer of pixels [-]	Area [m²]	Percentage share
0>	1 207	4 4991.66	3.06
0	5	186.38	0.01
0 - 0.1	17 237	642 519.61	43.74
0.1 - 0.2	18 140	676 179.48	46.03
0.2 - 0.3	1 438	53 602.32	3.65
0.3 - 0.4	244	9 095.25	0.62
0,4<	1 141	42 531.47	2.90
sum	**39 412**	**1 469 106.15**	**100.00**

The provided NDVI (Normalized Difference Vegetation Index) data offers a detailed insight into the vegetative status of a specific area. NDVI is a widely used remote sensing index that measures and monitors plant growth, vegetation cover, and biomass production from satellite imagery.

The data reveals that low NDVI values, specifically between 0 and 0.2, dominate the landscape. The 0 to 0.1 range, covering 43.74% of the area, indicates either bare soil, water, or areas with very sparse vegetation. The 0.1 to 0.2 range, which constitutes 46.03% of the area, represents regions with minimal vegetation. Together, these two categories account for nearly 90% of the total area, highlighting extensive regions lacking substantial vegetative cover.

Moderate NDVI values between 0.2 and 0.4 are less prevalent. The 0.2 to 0.3 range, making up 3.65% of the area, signifies regions with moderate vegetation cover. The 0.3 to 0.4 range, representing only 0.62% of the area, indicates areas with healthier and denser vegetation. High NDVI values greater than 0.4 comprise 2.90% of the area, corresponding to regions with dense and healthy vegetation, likely areas where plantings have already been carried out.

The data highlights the presence of a water reservoir, identifiable by the extremely low NDVI values, indicating an area devoid of vegetation. The majority of the area requires significant intervention for vegetative improvement, as evidenced by nearly 90% of the area falling within the 0 to 0.2 NDVI range. It is crucial to classify this site under 'Necessary Fundamental Modification' to address the extensive lack of vegetation.

Topographic Wetness Index

The TWI (Topographic Wetness Index) helps identify places where water can potentially store, places of increased moisture. It is based on calculations on slope information. In the case studied, TWI was calculated spatially using SAGA software. The resulting visualization, however, allows only a visual determination of where such places are located (fig. 40). In order to analyze the exact number of places where water can potentially be stored (mostly concave or flat areas), a python library rasterio was used, on the basis of which a script was created and checked exactly how many pixels are located for a given value of the slope of the terrain (0-2 degrees of slope, fig. 41), as well as what values the TWI raster pixels take for the same points - based on these, the mean and median value (TWI ~8) were calculated (tab. 13). These were used to assume a value for flat terrain - that is, a limiting value above which TWI indicates potentially wet sites.

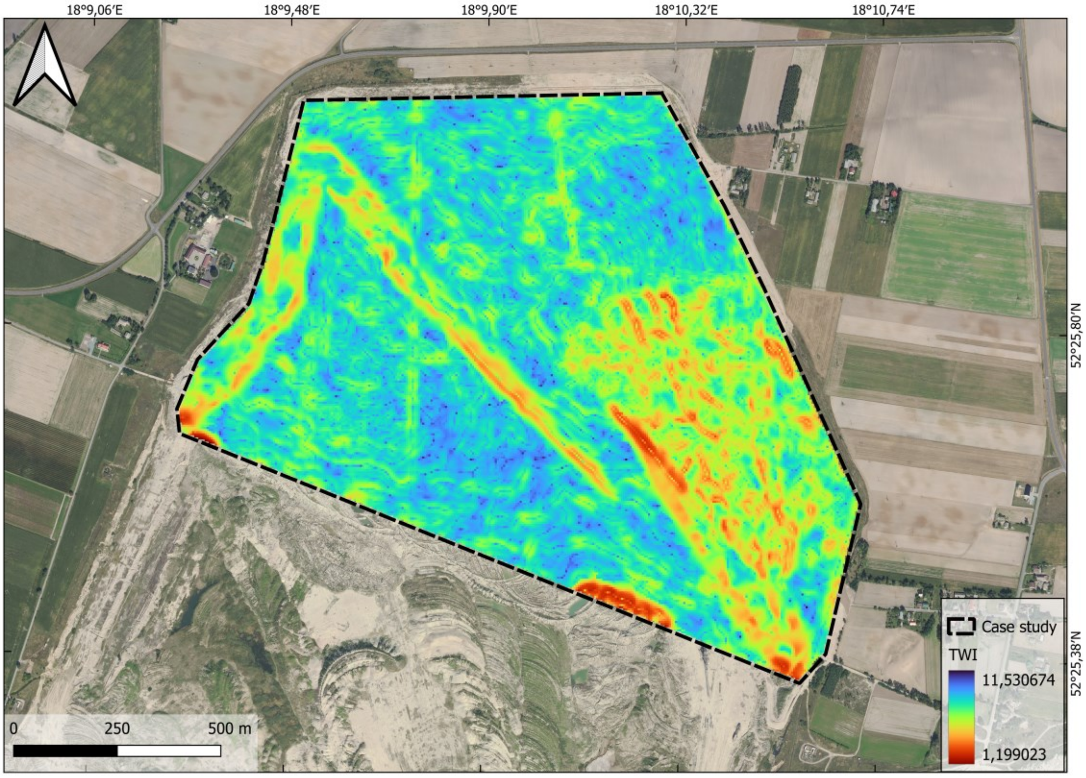

Figure 40. Spatial visualization of the TWI index in the studied area of the heap in the northern part of the Jóźwin IIB open pit.

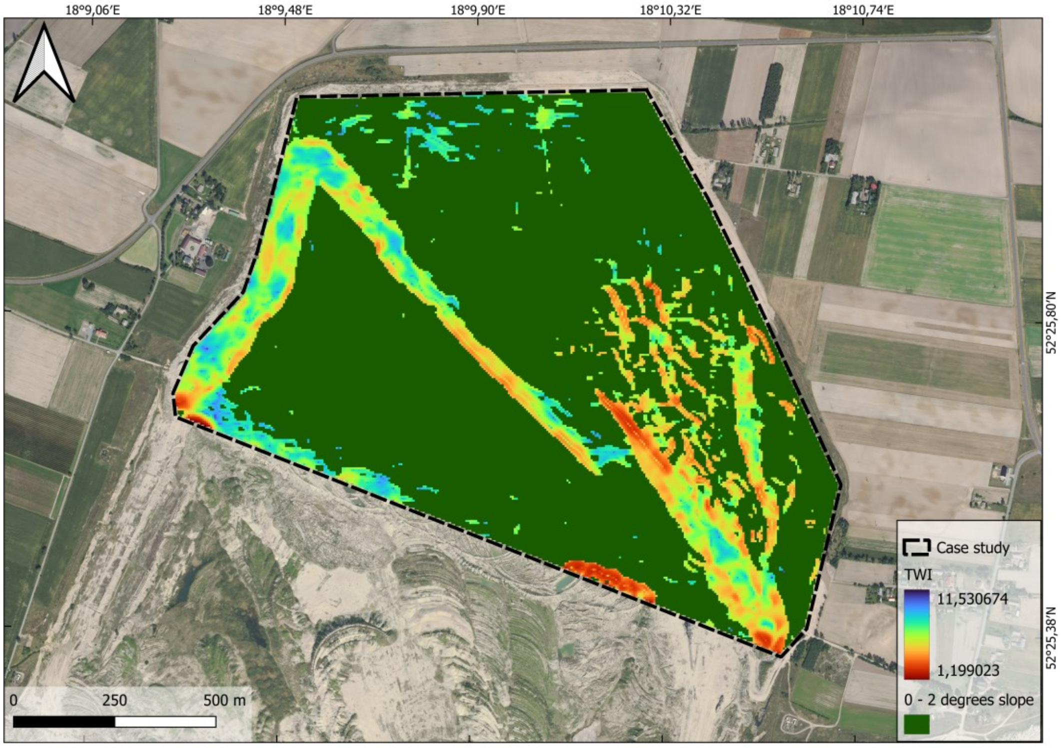

Figure 41. Spatial visualization of the TWI index in the studied area of the heap in the northern part of the Jóźwin IIB open pit with superimposed flat terrain mask.

The results obtained showed that wet sites account for 40% of the total site (tab. 13), which, although it seems unfavorable, the relatively even distribution of these areas and the majority of the values oscillating around the flat terrain (fig. 42) make the site classified as within the normal degree of degradation. In this direction, it does not require the necessary measures to improve conditions. This is especially supported by reclamation plans, according to which plantings are to be established in the area under study in the near future, and water flooding in the lower parts of the area. The steepest slopes, on the other hand, are to be sodded.

Table 13. Division of pixels containing TWI information into above and below 8 (Jóźwin II B)

TWI value	Numer of pixels [-]	Area [m^2]	Percentage share
<8	34 353	858 825	59.97
8<	22 926	573 150	40.03
Sum	57 279	1 431 975	1

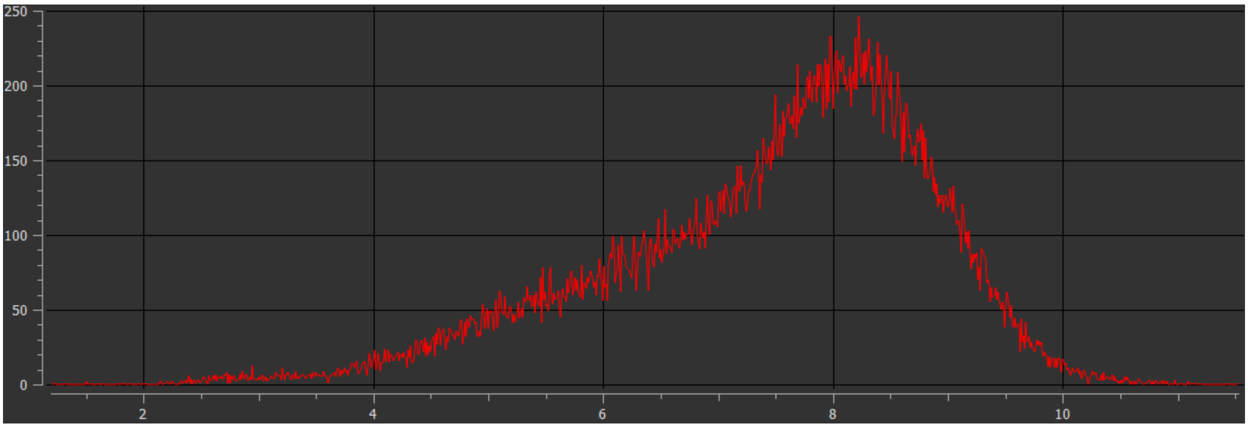

Figure 42. Histogram of TWI raster pixel values. As you can see, the peak of the values falls around TWI = 8 (Jóźwin II B)

RUSLE Index

The RUSLE (Revised Universal Soil Loss Equation) index is an advanced tool for assessing soil erosion, allowing the estimation of average annual soil losses due to water erosion. The RUSLE formula considers five key factors: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management practices (C), and support practices (P). Each of these factors has a crucial role in determining the erosion potential of an area. RUSLE is widely used in agriculture, natural resource management, spatial planning, and environmental protection, aiding in the identification of erosion-prone areas and the development of preventive strategies. In this case study, data for component indicators was collected from different sources. R-Factor was acquired directly from European Soil Data Centre (ESDAC), LS-Factor and P-Factor was calculated on DEM data form polish spatial geodatabase geoportal.gov.pl, C-Factor was calculated on spectral data from Landstat spectral data (due to USGS database) and K-Factor was calculated on data from *in-situ* surveys of soil on reclamation area (tab. 14).

Table 14. Sources of component indicators in RUSLE calculating

Component indicator	Source of data
R-Factor	European Soil Data Centre (ESDAC)
K-Factor	In situ surveys
LS-Factor	Geoportal database
C-Factor	USGS database
P-Factor	Geoportal database

After calculating the index, several important conclusions can be drawn for the area. First of all, although the results are concentrated at low values (fig. 43), the RUSLE value of less than 1.4 t/ha/year, which is the optimal value for soils, is only 14% of the total area of the study area (tab 15). Mainly these values are concentrated in the northeastern part where there are plantings (fig. 44). Vegetation cover significantly reduces the value of the RUSLE index, due to the formation of a root ball holding the soil and thus reducing susceptibility to erosion. The highest values of the index are found in areas of steep slopes (Fig 45), but both these and other areas are to be eventually covered with vegetation, which will significantly reduce susceptibility to erosion. Nevertheless, as of now, the analyzed area should be classified as in need of improvement to reduce soil erosion.

Table 15. RUSLE indicator values in specifical ranges

Range	Pixels	Percentage [%]	Area [m^2]	Area [km^2]
0 – 1.4	7 863	13.67	196 631.04	0.20
1.4 – 633	49 673	86.33	1 242 179.02	1.24
Total	57 536	100.00	1 438 810.06	1.44

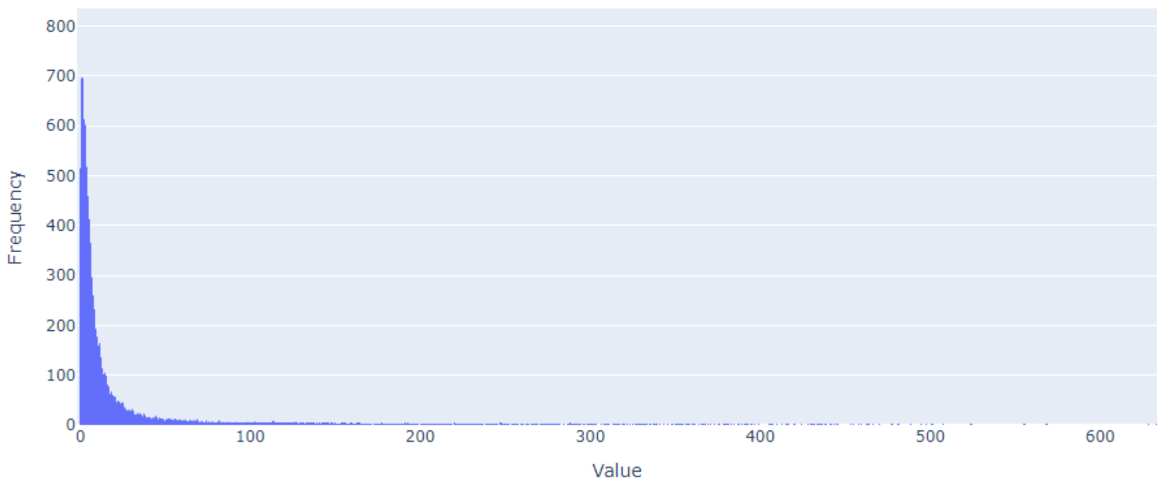

Figure 43. Histogram of the resulting raster values

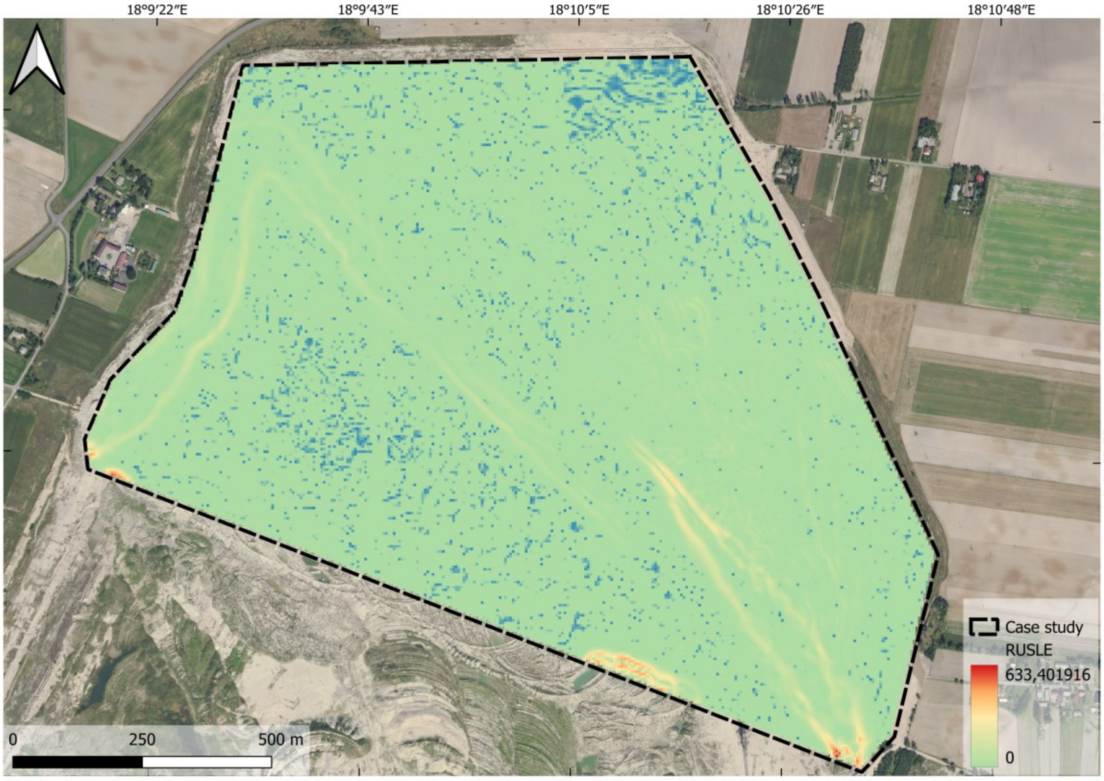

Figure 44. Spatial visualisation of RUSLE index. Blue means places where RUSLE ≤ 1.4

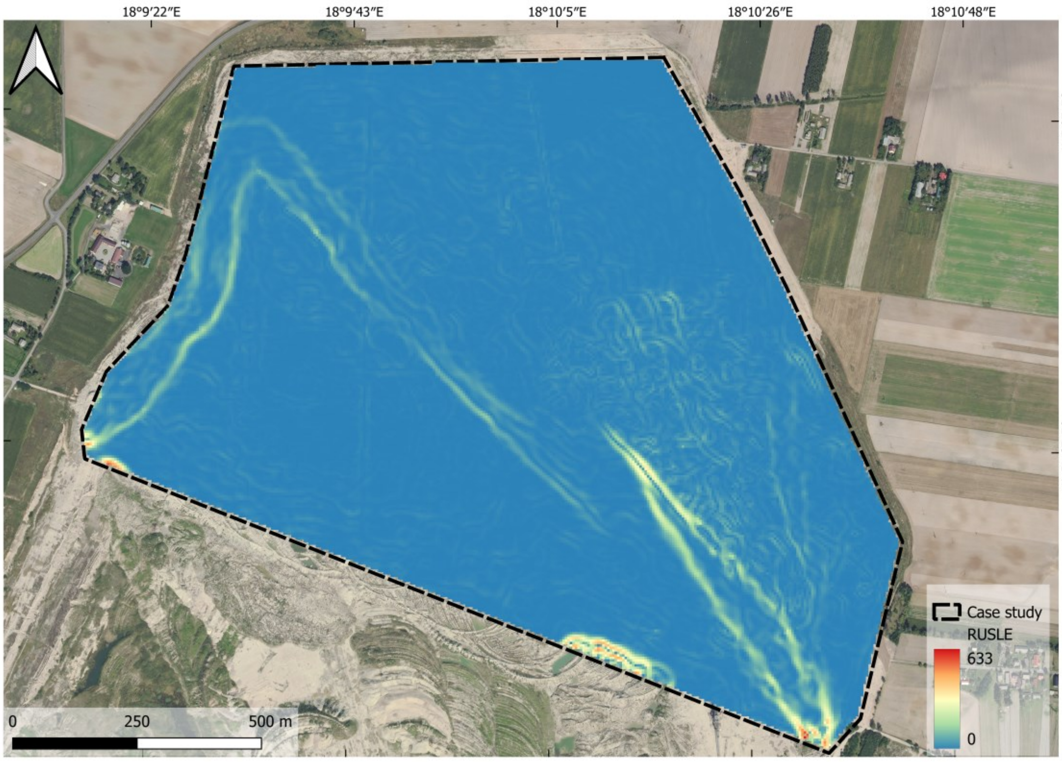

Figure 45. Spatial visualization of RUSLE with highlithed steep slopes, which are places with top RUSLE values

3.5.2. Future Use and Reclamation Plans

Proposed Reclamation Schemes

The reclamation of the Jóźwin II B open-pit mine involves a multi-faceted approach focusing on technical and biological restoration. The primary activities include:

1. **Technical reclamation:**
   - Earthmoving and Profiling - This involves the relocation and shaping of earth masses within the internal dump to align with the surrounding undisturbed terrain. It also includes the formation and profiling of the final pit slopes to accommodate the planned Jóźwin water reservoir.
   - Construction of Reclamation Roads - These roads will provide access to areas undergoing agricultural and forestry reclamation.
   - Drainage Systems **-** Establishing peripheral ditches to manage surface water runoff into existing water bodies.

2. **Biological reclamation:**
   - Agricultural Reclamation - This includes plowing, cultivation, mineral fertilization, and sowing of grasses and legumes to restore the land for agricultural use.
   - Forestry Reclamation **-** Planting of various tree species such as European larch, Scots pine, pedunculate oak, sessile oak, small-leaved lime, Norway maple, sycamore maple, beech, hornbeam, silver birch, black locust, black alder, blackthorn, and cherry plum to reforest the area.
   - Recreational Reclamation **-** Similar to agricultural reclamation, but focused on preparing the land for recreational purposes.
   - Water Reclamation **-** Creating a reservoir with an expected water level at about +93 m above sea level. The reservoir will cover an area of approximately 840 hectares with depths varying between 43 and 69 meters.

Planned Future Uses

The post-reclamation uses of the Jóźwin II B area are intended to be diverse and sustainable, as mentioned above focusing on agricultural, forestry, recreational, and aquatic applications (fig. 46).

- Agricultural use - Restored land will be used for crop cultivation and pasture, contributing to the local economy and food production.
- Forestry use - Reclaimed areas will be reforested to enhance biodiversity, provide timber resources, and contribute to carbon sequestration efforts.
- Recreational use - Certain areas will be developed for recreational activities, such as parks and leisure spaces, improving the quality of life for local communities.
- Aquatic use - The creation of a large reservoir will serve multiple purposes including water storage, recreational activities like fishing and boating, and potentially as a wildlife habitat.

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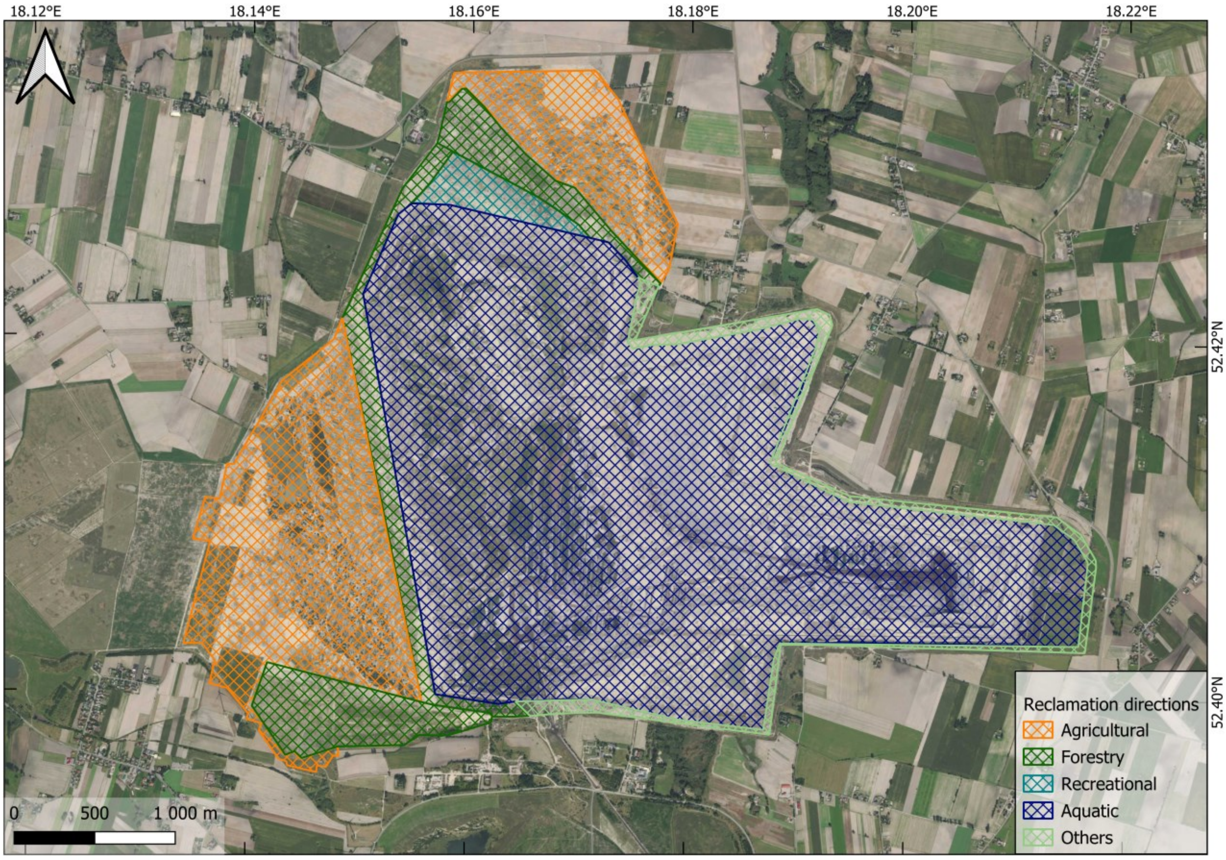

Figure 46. Spatial presentations of reclamation directions on Jóźwin IIB open-pit mine

Climate Change Influence

The Jóźwin Open-pit Mine in Konin County, Poland, is expected to face significant climate change impacts. Projections for 2051-2060 under RCP4.5 and RCP8.5 scenarios indicate rising temperatures and altered precipitation patterns. These changes suggest significantly warmer summers and milder winters, with increased precipitation in early spring and shifts in peak rainfall to July. These climatic shifts pose challenges for agriculture by increasing soil moisture deficits and thermal stress on crops, while forestry efforts may be hindered by moisture stress and higher temperatures affecting tree growth and survival. Additionally, water reclamation efforts could be impacted by variability in water levels and higher evaporation rates, necessitating effective management strategies to maintain ecological balance and water quality.

3.6. The former mining site in Mazingarbe, France

3.6.1. Current State

Location and Extent

The former mining site in Mazingarbe is situated in the Pas-de-Calais department, designated by the administrative code 62, within the Hauts-de-France region in northern France. This region was formerly known as the North-Pas de Calais region before administrative restructuring. Mazingarbe itself is located in a historically significant mining basin, contributing to the rich industrial heritage of the area.

Geographically, the site lies within the watershed of several small watercourses: Le Surgeon, La Fontaine de Bray, La Loisne, and Le Fossé d'Aisnes et d'Auchy. These watercourses play a crucial role in the local hydrology and are integral to the ecological dynamics of the region. The site's proximity to these water bodies necessitates careful consideration in reclamation efforts to ensure water quality and ecological balance are maintained.

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Covering an extensive area of approximately 7.3 hectares, the Mazingarbe site is a notable feature within the local landscape. The most prominent landmark of the site is a substantial dump, standing at a height of 60 meters. This dump is composed predominantly of black shales, a byproduct of the coal mining activities that took place over a century. The sheer volume of this dump is impressive, containing approximately 1 million cubic meters of material, making it a significant geomorphological feature.

The site's historical significance is underscored by its size and the remnants of its industrial past. The black shale dump is not only a physical reminder of the coal mining era but also a symbol of the extensive industrial activities that shaped the region's economic and social landscape. The site's location within the Hauts-de-France region places it within a broader context of post-industrial redevelopment initiatives aimed at revitalizing former mining areas. Given its substantial size and historical importance, the Mazingarbe site represents both a challenge and an opportunity for reclamation and future use.

Historical Mining Activities

The mining activities at the Mazingarbe site have a rich and complex history, reflecting the broader industrial development of the region. Coal extraction began at this site in 1860 and continued until 1963, marking over a century of intensive industrial activity. The site was a hub for various industrial processes, including coal mining and associated activities.

During its operational period, the site evolved into a large industrial complex that extended beyond coal extraction. In 1897, facilities for carbochemistry and coking plants were established. These plants played a critical role in processing coal into coke, a crucial input for steel production and other industrial processes. The coking plants operated until 1984, reflecting the site's long-term industrial significance.

In addition to coking plants, the site also hosted nitrogen fertilizer production facilities starting in 1922. This production continued until 1988, contributing to agricultural productivity and the broader industrial economy. Another significant industrial activity at the site was ethylene production, which took place from 1953 to 1965. Ethylene is a key raw material in the chemical industry, used in the production of plastics and other synthetic materials.

The culmination of these industrial activities left a substantial environmental footprint. The extensive extraction and processing activities resulted in the accumulation of waste materials, including the large dump composed of black shales. By 1977, following the end of coal extraction, the well was backfilled, and significant portions of the industrial installations were dismantled, leaving behind the distinctive landscape that characterizes the site today.

The historical significance of the Mazingarbe site is also marked by the economic and social impact it had on the local community. The coal mining and industrial operations provided employment for a substantial portion of the local population, shaping the socio-economic fabric of the region. The cessation of these activities in the latter half of the 20th century led to significant socio-economic changes, necessitating efforts to reclaim and repurpose the site for future use.

Current Status

The Mazingarbe site is currently in a state of transformation, undergoing significant reclamation efforts to mitigate the impacts of its industrial past. The site consists of two main parcels: the former "west" settling basin and the former "north" tailings pond (Figure 47.). These areas have seen varied developments in recent years, with natural vegetation gradually reclaiming parts of the site.

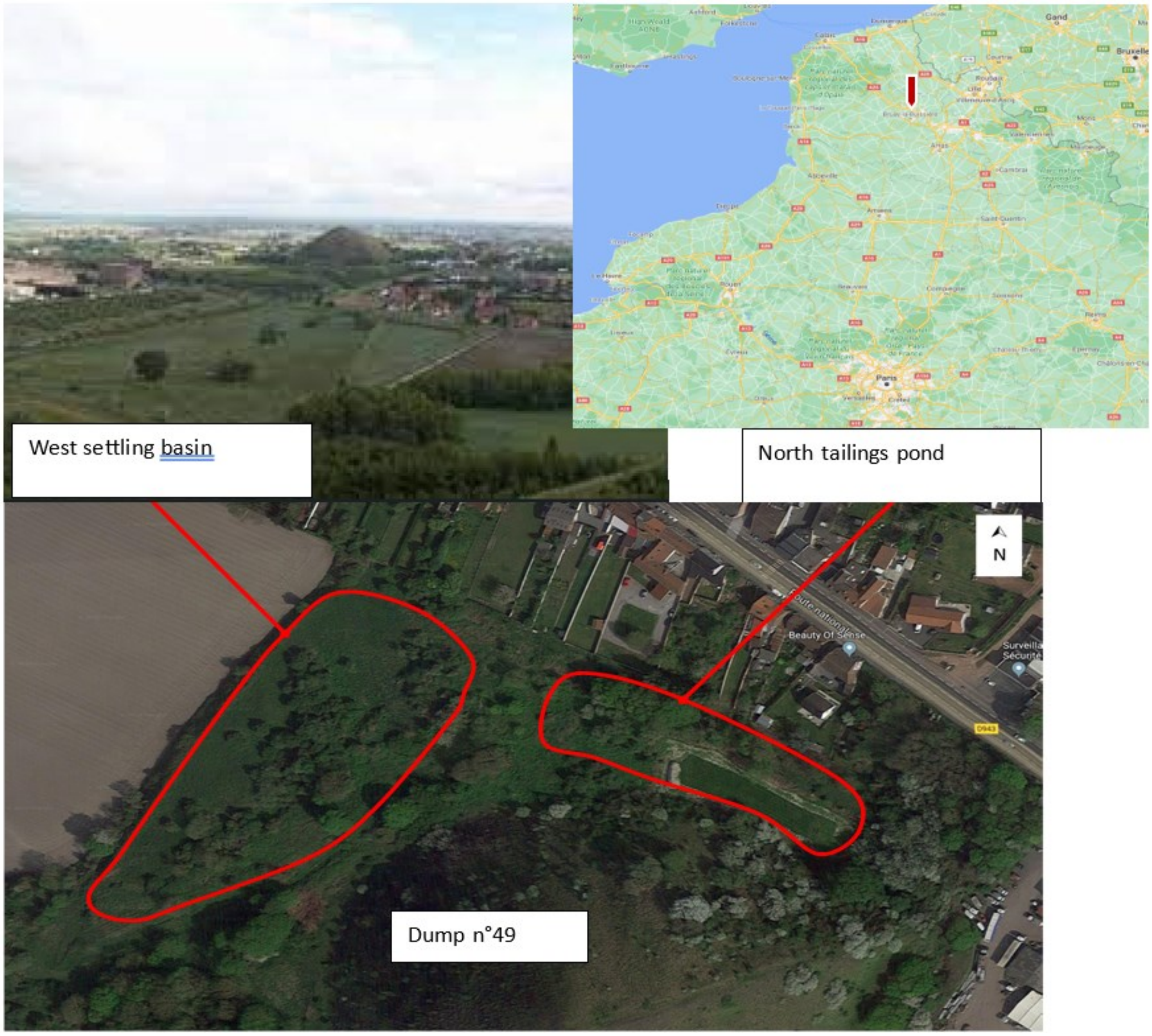

Figure 47. Location of the French case study and satellite views of the case study

The site remains a mix of reclaimed land and areas still showing signs of industrial degradation. On one part of the site, natural vegetation has spontaneously developed, creating a green cover that helps stabilize the soil and reduce erosion. This natural reclamation has been beneficial in restoring some ecological balance to the area.

However, contamination remains a significant issue, particularly in the basins where industrial residues have accumulated. The soil in these areas contains elevated levels of metals and other pollutants, a legacy of the site's industrial activities. These contaminants pose ongoing challenges for environmental restoration and safe public use.

An invasive species, the Caucasian hogweed, has extensively colonized parts of the site, complicating reclamation efforts. This invasive plant species is difficult to manage and poses a risk to both local biodiversity and human health due to its toxic properties. Recent reclamation strategies have focused on controlling and eliminating this invasive species.

To address these issues, a reclamation strategy was initiated in December 2023. This involves covering the contaminated areas and the invasive Caucasian hogweed with 3-4 meters of construction materials from various sites. This approach aims to eliminate the invasive species, prevent the spread of contaminants, and create a barrier to protect the new environment from further contamination.

The NPC Public Land Establishment (EPF NPDC) previously owned the site but has since transferred ownership to local authorities who are working in partnership with reclamation companies. The current management focuses on flattening the basins beneath the dump and finding sustainable solutions to restore the site. The goal is to transform the area into a safe, usable space for the public while preserving its historical significance.

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The future vision for the Mazingarbe site involves its integration into an urban green belt, with plans to develop walking and hiking trails that allow for public enjoyment and educational opportunities. The dump, devoid of invasive species, will remain as a cultural heritage landmark, symbolizing the site's industrial past and its ongoing transformation.

Degradation Status

The Mazingarbe site exhibits various indicators of degradation, reflective of its industrial past. Key aspects of the degradation status include:

1. **Contamination:**
   - The site shows contamination, particularly in the basins, due to previous industrial activities. This includes the presence of metals and other pollutants.
   - Preliminary results from soil sampling (November 2023) reveal elevated concentrations of several trace elements in the top-soil, such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), selenium (Se), and zinc (Zn). The orange lines in the table 16. indicate excessive values for these metals, based on soil situation analysis values (ASPITET) comparison.
   - The presence of these contaminants poses ongoing challenges for environmental restoration and safe public use. The elevated levels of metals, particularly in the topsoil, necessitate the implementation of risk reduction measures to prevent further environmental and human health impacts.
   - pH (water): The pH value of the soil is 7.9, indicating neutral to slightly alkaline conditions.
   - Trace Element Extractability: The percentage of total arsenic, cadmium, copper, lead, and zinc extractable in NH_4NO_3 (1M) solution shows relatively low extractable concentrations, suggesting limited immediate bioavailability but potential long-term risks (table 16).

Table 16. Trace element total and extractable (NH_4NO_3 1M) concentrations in top-soil samples and concentrations in green leaves and dry stems of the Caucasian hogweed collected in November 2023 on the field trial (soil mean are calculated from 4 samples; plant mean are calculated from 3 sub-samples made from 1 composite).
Orange lines indicated excessive values for a given metal, based on soil situation analysis values (ASPITET) comparison

Element	Soil Mean (µg/g)	Soil SD (µg/g)	Leaves Mean (µg/g)	Leaves SD (µg/g)	Stems Mean (µg/g)	Stems SD (µg/g)
As	14.6	2.85	0.3	0.01	<0.025 (QL)	
Cd	5.1	1.37	0.1	0.02	0.1	0.0
Co	7.7	4.81				
Cr	318.8	57.13	4.3	0.67	0.3	0.1
Cu	92.2	11.99	7.1	0.38	5.4	0.6
Fe	15075.0	6245.73				
Hg	1.8	0.73				
Mn	502.5	272.69				
Ni	31.7	11.44				
Pb	82.5	30.93	1.4	0.09	0.1	0.1
Sb	2.0	0.21				
Se	19.4	2.65				
Zn	694.0	145.72	76.8	1.48	14.4	4.4
pHwater	7.9	0.04				
As (%total)	0.07	0.02				
Cd	0.06	0.02				
Cu	0.56	0.10				
Pb	0.04	0.01				
Zn	0.08	0.02				

2. **Vegetation:**
   - An invasive species, the Caucasian hogweed, has extensively colonized parts of the site, complicating reclamation efforts. This plant is difficult to manage and poses a risk to local biodiversity and human health due to its toxic properties.
   - Efforts to control and eradicate the Caucasian hogweed are ongoing. The reclamation strategy involves covering contaminated areas and the invasive species with construction materials to eliminate the plant and prevent the spread of contaminants.

Overall, the degradation status of the Mazingarbe site underscores the need for comprehensive reclamation efforts. Addressing soil contamination, managing invasive species, and restoring vegetation cover are key priorities to transform the site into a safe and sustainable environment for future use.

3.6.2. Future Use and Reclamation Plans

Proposed Reclamation Schemes and Planned Future Uses

The reclamation of the Mazingarbe site involves several strategic actions aimed at mitigating contamination, managing invasive species, and preparing the area for safe public use. The proposed reclamation schemes include:

1. **Contamination Mitigation:**
   - The primary strategy to address soil contamination involves covering the contaminated areas, particularly those affected by the invasive Caucasian hogweed, with 3-4 meters of construction materials. This approach effectively isolates the contaminated soil, preventing the spread of pollutants and minimizing the risk of human and environmental exposure.
   - The materials used for covering are sourced from various construction sites, ensuring that they meet the necessary standards for safety and environmental compatibility.

2. **Invasive Species Management:**
   - The Caucasian hogweed, an invasive species extensively colonizing parts of the site, poses significant ecological and health risks. To eradicate this species, the contaminated areas it inhabits are covered with construction materials, effectively removing its presence and preventing its regrowth.
   - Ongoing monitoring and management are essential to ensure that the invasive species does not re-establish itself. This includes periodic inspections and potential additional treatments if necessary.

3. **Vegetation Restoration:**
   - Natural vegetation has already begun to reclaim parts of the site, providing a green cover that stabilizes the soil and promotes ecological balance. The reclamation plan includes enhancing this natural regeneration by introducing native plant species that are well-suited to the local conditions.
   - Phytomanagement techniques, such as the use of Miscanthus x giganteus and biochar produced from miscanthus (as demonstrated in the MisChar research project), are implemented on part of the site to further improve soil health and support vegetation growth.

4. **Soil and Environmental Monitoring:**
   - A comprehensive field trial has been established to precisely characterize the contamination and ecological properties of the soil. This involves comparing soils affected by the Caucasian hogweed with nearby uncontaminated soils.
   - Regular soil sampling and analysis are conducted to monitor the effectiveness of the reclamation efforts and ensure that contaminants remain contained. Parameters such as trace element concentrations, soil pH, and microbial activity are measured to assess soil health and contamination levels.

5. **Public Use and Integration into Urban Green Belt:**
   - Post-reclamation, the site is planned to be integrated into an urban green belt, providing a valuable recreational and educational resource for the local community. Walking and hiking trails will be developed around the reclaimed areas, allowing public access while ensuring safety.

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- The 60-meter high dump, free from invasive species, will be preserved as a cultural heritage landmark. Interpretive signage and educational materials will be installed to inform visitors about the site's industrial history and the reclamation process.

6. **Risk Reduction Measures:**
   - To minimize risks associated with soil contamination, risk reduction measures are implemented, such as creating physical barriers to prevent direct contact with contaminated soil. This includes the use of geotextiles and other protective layers beneath the construction materials used for covering.
   - Additional measures, such as dust suppression techniques, are employed to prevent the dispersion of contaminants during and after reclamation activities.

These proposed reclamation schemes are designed to address the complex challenges presented by the Mazingarbe site, transforming it into a safe, sustainable, and valuable asset for the community while preserving its historical significance. The ongoing monitoring and adaptive management ensure that the reclamation efforts remain effective and responsive to any emerging issues.

4. Rehabilitation and Monitoring Solutions

The case study areas selected for the REECOL project are integral to the development and testing of new solutions for post-mining land reclamation and the monitoring of ecosystem rehabilitation. These areas will be used extensively in Work Package 4 (WP4) and Work Package 5 (WP5) to address various challenges and opportunities associated with post-mining landscapes. By leveraging the unique characteristics of each site, the project aims to generate valuable insights and practical solutions that can be applied across Europe.

Work Package 4: Development of New Solutions for Post-Mining Land Reclamation and Their Testing in Case Study Areas

Work Package 4 (WP4) focuses on delivering innovative solutions to enhance the properties of degraded soils in post-mining areas and to introduce plant species that are beneficial for industrial use. This work package includes the following key objectives:

- **Development and Testing of Technological Solutions for Soil Remediation and Regeneration:** New technologies will be developed and tested to remediate and regenerate soils that have been degraded by mining activities. This involves improving soil structure, nutrient content, and overall fertility to support new vegetation and land uses.
- **Identification and Implementation of Revegetation Methods:** Methods for revegetating post-mining terrains with high redevelopment potential will be identified and analyzed. This includes selecting appropriate plant species and developing techniques to establish and maintain vegetation cover on these challenging sites.
- **Introduction of Desired Plant Species:** New solutions will be developed and tested for planting desired species in post-mining areas. These plants could serve various purposes, including ecological restoration, industrial use, and economic development.
- **Cost-Benefit Analysis of Proposed Solutions:** The costs and benefits of the proposed reclamation solutions will be thoroughly analyzed to ensure they are economically viable and can be implemented effectively on a larger scale.

The experimental work will be conducted in real conditions, using the post-mining field plots identified within the selected case study areas. This practical approach ensures that the solutions developed are tested in environments that closely resemble the actual conditions found in post-mining landscapes.

Work Package 5: Short and Long Term Monitoring of Ecosystem Rehabilitation

Work Package 5 (WP5) aims to establish effective methodologies for monitoring the short and long-term rehabilitation of mining areas. This work package includes the following objectives:

- **Defining Monitoring Methodologies:** WP5 will define the most appropriate methodologies for monitoring the rehabilitation progress of post-mining areas. This includes selecting relevant indicators and metrics to assess ecological recovery and the success of reclamation efforts.

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- **Development of a Monitoring Toolbox:** A comprehensive toolbox of methods and bio-indicators will be developed to measure key ecological functions in both initially degraded and rehabilitated ecosystems. These tools will be tailored to fit the specific rehabilitation approaches defined in WP4.
- **Experimental Work and Testing:** Experimental work will be conducted on samples acquired from the selected post-mining field plots. The effectiveness of the proposed monitoring tools and methodologies will be tested and validated to ensure they provide accurate and reliable data.
- **Data Interpretation and Use**: WP5 will provide the means for interpreting the collected data, enabling stakeholders to understand the progress and outcomes of rehabilitation efforts. This will facilitate informed decision-making and continuous improvement of reclamation practices.

By utilizing the case study areas in WP4 and WP5, the REECOL project aims to develop and validate practical, cost-effective, and scalable solutions for post-mining land reclamation and ecosystem rehabilitation. These efforts will contribute to the broader goals of sustainable development and climate neutrality in Europe.

4.1. New Rehabilitation Solutions (WP4)

The tasks within Work Package 4 (WP4) will focus on developing and testing new rehabilitation solutions in selected post-mining areas. These efforts will be carried out in specific locations known for their unique challenges and opportunities in post-mining land reclamation. The primary locations involved in these activities include the mining areas of PGG in Poland, the Konin Brown Coal Mine in Poland, and Mazingarbe in France. Each of these sites will serve as a testing ground for innovative soil remediation, revegetation techniques, and the introduction of desired plant species, providing valuable insights and practical solutions for broader application.

4.1.1. Development of directed succession methods for revegetation on postmining terrains with a high redevelopment potential

In the first step, physicochemical and ecotoxicological analyses of the hard coal waste material within the analyzed study site will be carried out. A laboratory simulation will be conducted to determine the conditions under which a managed succession of low-growing plant species can be established. The germination tests will involve selecting herb and grass species capable of competing with invasive plants and trees. Low-cost methods to enhance the growth of these desired plants will be tested, including the application of fertilizers, organic matter, and pH correction. Additionally, processed mine tailings as a fertilizing product will be tested. Mine tailings from PGG, rich in silica, potassium, CaO, and MgO, will be utilized for their valuable nutrients. To further enhance the product's value, organic waste will be used to provide essential nutrients for plants, including nitrogen, phosphorus, potassium, and organic matter. Changes in soil properties and the structure and health of the vegetation will be monitored during the growing seasons by implementing long and short-term monitoring methods (see Deliverable 5.1 and 3.1).

4.1.2. Development of a technology for non-contact remediation and control of soil parameters with use of biowaste

The non-contact soil remediation system being developed within Task T4.2 is a complex of machines and equipment designed to spray water, seed mulch, and organic fertilizers in various proportions. This system aims to restore and improve the environmental and functional qualities of spoil heaps. It is transportable on conventional vehicles, using trailers or agricultural platforms for ease of mobility.

The system comprises several essential components: a spray cannon, a pumping unit, and tanks for water, seed mulch, and bio-waste. It operates based on data analysis of NDVI indicators obtained from drone flights, which inform the specific actions to be taken by the system.

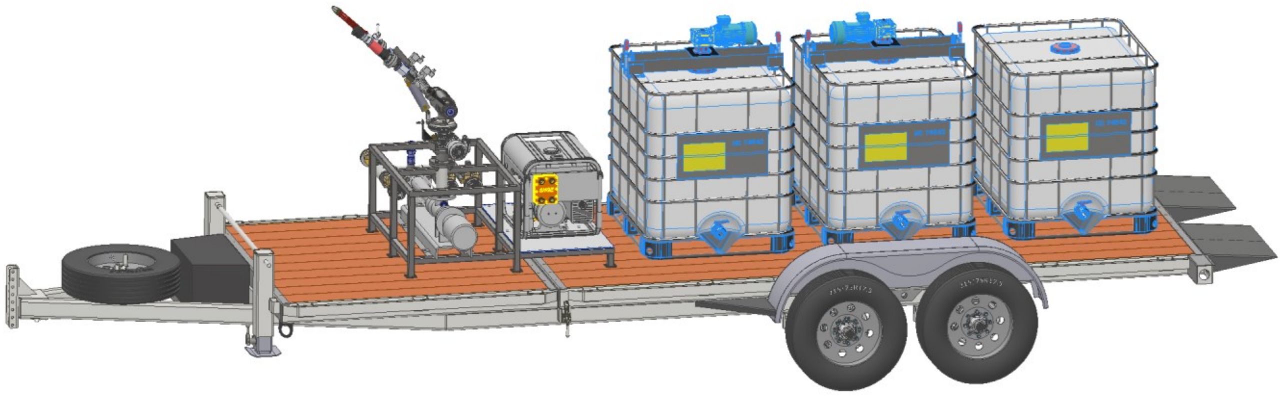

Figure 48. Non-contact soil remediation system – model 3D

To test this technology, a test field of 60m x 40m was established, allowing for the evaluation of the device's efficiency and performance, as well as the impact of different reclamation phases on plant growth. This field is divided into 10m x 10m quarters to study nine different test variants.

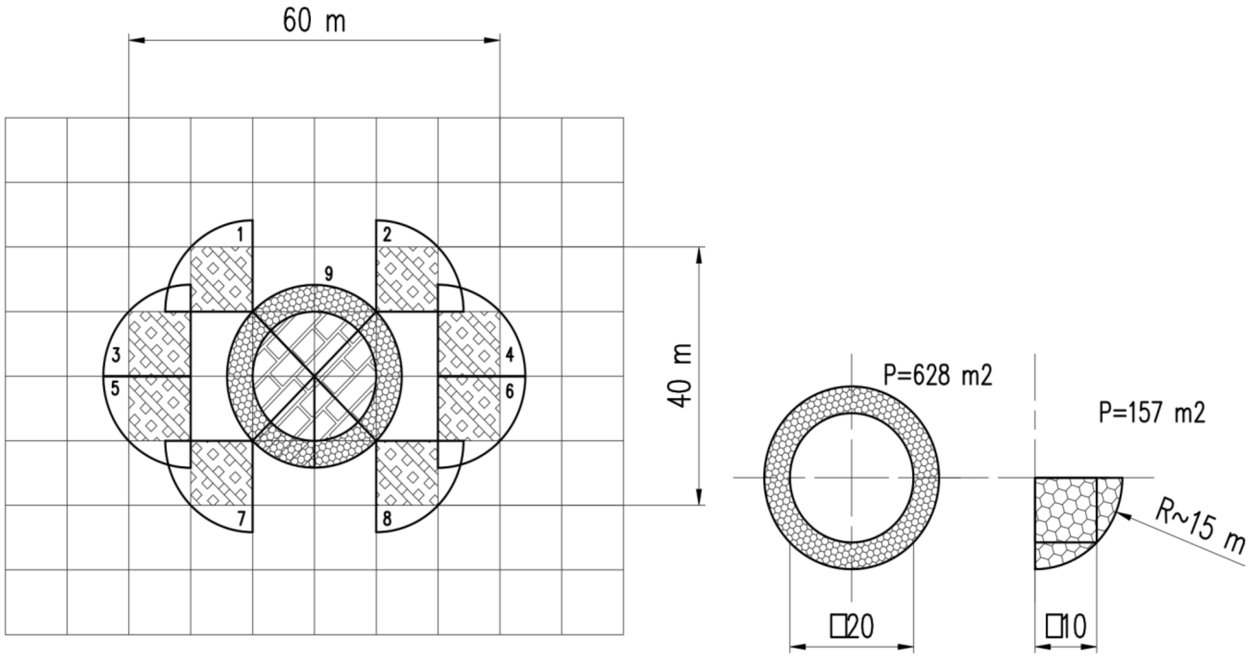

Figure 49. Minimum dimensions of the test field, allowing to perform 9 - iu test variants of the developed technology

Test variants implemented on the selected test field, in 10mx10m quarters:

1. No work will be carried out in this plot - the reference plot,
2. The device will spray the seeds themselves on the reclaimed plot - no additional work for the entire duration of the tests
3. The device will spray only seeds on the reclaimed plot - water spraying throughout the trials
4. The device will spray bio-waste (obtained from task 4.1) on the reclaimed plot - water spraying throughout the tests
5. The device will spray bio-waste (obtained from task 4.1) on the reclaimed plot - without any additives for the entire duration of the trials
6. The device will spray seeds (selected in task 4.3) with mulch - without any additives for the entire duration of the trials
7. The device will spray seeds (selected in Task 4.3) with mulch - spraying water throughout the trials

8. The device will spray bio-waste (obtained from Task 4.1) and seeds (selected under Task 4.3) with mulch onto the reclaimed plot - without any additives throughout the trials
9. The device will spray bio-waste (obtained from task 4.1) and seeds (selected from task 4.3) with mulch onto the reclaimed plot - spraying water throughout the trials

A DJI Mavic 3 Multispectral drone will be used to identify and monitor the test fields. This drone, equipped with high-resolution RGB and radiometric sensors, will analyze vegetation health and provide data for the remediation system.

Figure 50. DJI Mavic 3 Multispectral with equipment mounted

Preliminary selection of active or in the process of reclamation heaps belonging to the Polish Mining Group S.A. (underground mines)): Selected spoil heaps belonging to PGG, fig. 51: KWK Sośnica **(1)**, KWK ROW Ruch Chwałowice **(2)**, KWK ROW Ruch Rydułtowy **(3)**, KWK ROW Ruch Marcel **(4)**, KWK ROW Ruch Jankowice **(5)**.

Figure 51. Chosen heaps localizations owned by PGG S.A

Due to the capabilities (range) of the drone and the applicable legal regulations (open category A2), a fragment of the given landfill where the research area could potentially be located was registered.The following figure shows the location of a selected section of the heap, using the example of the Marcel mine (Figure 52.).

Figure 52. Selected area on the KWK ROW Ruch Marcel heap (dimensions ~600m x 350m)

After preliminary selection of the area on a given dump, dedicated flight paths for the DJI Mavic 3M UAV were developed, based on which it was possible to create orthophotomaps. An important issue was the appropriately high resolution of the obtained photos, not exceeding 5cm/pixel. Figures 53a and 53b show the flight route on the example of the waste heap of the Chwałowice mine, belonging to PGG S.A.

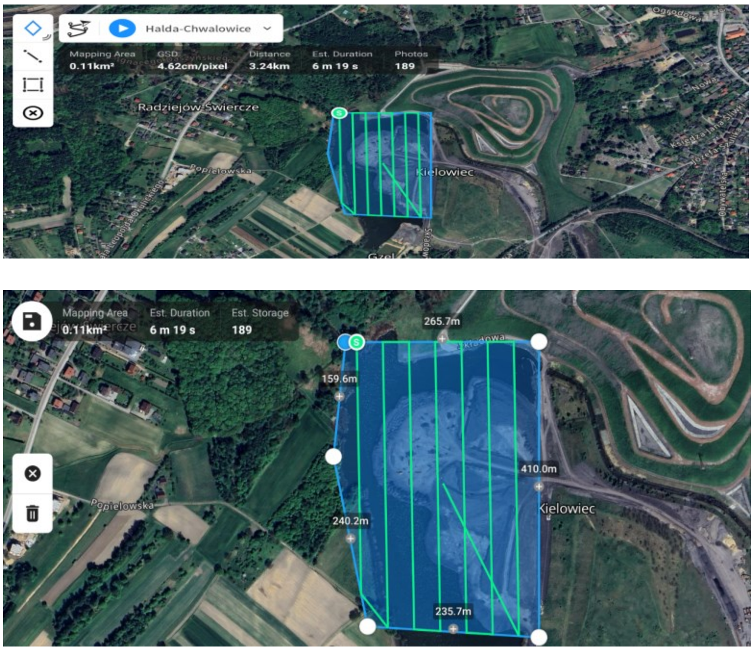

Figure 53. Path plan of global raid for KWK Chwałowice: view presenting estimated parameters as duration, resolution and count of photos (a), dimensions and area of flight (b)

Below is the effect of the raid, in the form of an orthophotomap, composed of images taken during the global raid, using the example of the heap belonging to the Rydułtowy mine (Figure 54).

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Figure 54. Global raid photos stitched into orthophotomap – KWK ROW Rydułtowy

Combining images taken during global raids into orthophotos, made it possible to create digital terrain models (DTMs). The purpose of developing the models was to determine the slopes of the terrain and to assess the feasibility of conducting experimental studies on heap reclamation. The following geometric models were developed: KWK Sośnica, KWK ROW Chwałowice, KWK ROW Rydułtowy, KWK ROW Marcel, KWK ROW Jankowice, **fig. 55**.

Geometric models made it possible to develop the contours of individual dumps. On this basis, the selection of the dump and the area to be reclaimed was facilitated, so that it could be accessed by a motor vehicle with the required equipment. An example of the geometric model developed for the selected North heap, Jankowice mine, is shown in Fig 55.

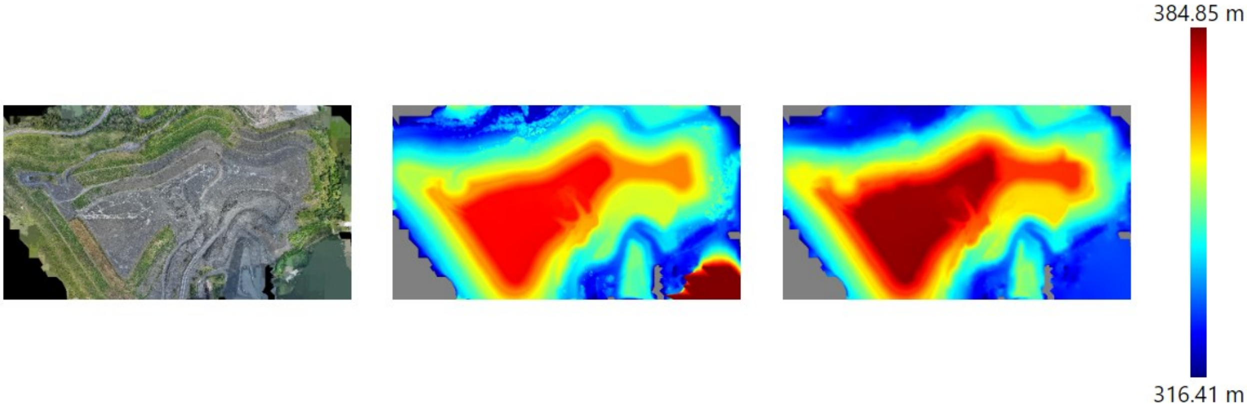

Figure 55. Geometric model of selected area of waste heap Północ of KWK Jankowice

The test field for testing the non-contact soil reclamation technology will be located at waste heap Północ of Jankowice mine, near the GIG research field, which will also allow comparative observations of the effects of the technology.

4.1.3. Development of a technology for soil regeneration by composts of high biological activity

Mining activities and the consequent modification of natural landscapes have significantly disrupted ecosystem balance, leading to adverse changes in the physical, chemical, and biological conditions of soils. Open-pit mining, in particular, results in the removal of vegetation and topsoil, which in turn affects soil fertility by causing acidification, nutrient depletion, and leaching. Various in-situ and ex-situ techniques, including excavation, solidification, stabilization, soil washing, electroremediation, and phytoremediation, can mitigate these impacts. However, a low-cost and ecological alternative is soil stabilization using composts made from organic wastes (such as feathers and straw) and lignite.

This technology leverages the ability of organic matter to bind nutrients, thereby increasing their bioavailability and facilitating vegetation establishment. The resulting revegetation helps reduce pollution spread by wind or water erosion and minimizes metal leaching. Additionally, the composting process can be accelerated by inoculating the compost with selected bacterial strains, which enhance the decomposition of organic matter and the production of humus compounds, thereby boosting soil microbiological activity. This approach not only addresses post-mining soil reclamation but also promotes a circular economy by reusing organic wastes and lignite.

The REECOL project aims to ensure long-term environmental protection and sustainable development of mining regions in transition. One of the key tasks, led by the "Poltegor-Institute," focuses on developing soil regeneration technology using high biological activity composts. This technology involves preparing a compost mixture of brown coal, solid organic waste, and selected microorganisms to enrich post-mining soils with mineral and humic substances, thereby enhancing soil microbiological activity.

Preliminary research has been conducted to determine the optimal compost mixture composition, including elemental analysis of chicken feathers, brown coal, and wheat straw. Chemical, microbiological, and biochemical tests have also been performed on soil samples from the targeted recultivation area. Additionally, bacterial and actinomycete isolates with desirable biochemical abilities (e.g., proteolytic, cellulolytic, and carbon biosolubilization) have been identified and tested for compatibility.

Based on these research findings, three bacterial strains with the desired properties have been selected. The composting process has been scaled up from laboratory to semi-technical size, with ongoing evaluations to identify the most effective composting technique. The resulting compost product will be applied to selected post-mining areas to assess its reclamation potential and overall effectiveness.

4.2. Monitoring Solutions (WP5)

Effective monitoring is crucial for assessing the quality and success of reclamation efforts in post-mining areas. Monitoring enables the identification of optimal reclamation methodologies and the long-term tracking of pollutant occurrences, ensuring that environmental and functional qualities of reclaimed lands are maintained. The monitoring activities will be conducted in various locations, including mining areas of PPC (Amynteon, Greece), PGG (Poland), PV (Slovenia), Radovesice dump/Strimice dump (Czech Republic), Konin Brown Coal Mine (Poland), and the former mining site in Mazingarbe (France).

The main goal of short-term monitoring is to assess the reclamation quality of the selected areas and subsequently determine the most effective reclamation methodologies. Long-term monitoring, on the other hand, aims to evaluate the persistent occurrence of pollutants and ensure the ongoing health and stability of the reclaimed ecosystems. Both short-term and long-term monitoring involve some identical laboratory methods, but long-term monitoring focuses on selected characteristic soil sites to provide a comprehensive understanding of ecological changes over time.

4.2.1. Examples of Monitoring Methodologies in the Czech Republic

The following sections present examples of short-term and long-term monitoring methodologies as conducted by VÚHU in the Czech Republic. These examples illustrate the detailed approaches used to ensure effective reclamation and long-term sustainability of post-mining landscapes.

Short term monitoring methodology

Mthodology of pedological mapping and soil sampling

The survey of the terrain is carried out using test pits to a depth of 0.6 m in the soil profile of each investigated site. Determining the number of sampling points per 1 ha depends on the heterogeneity of the soil, usually one test pit is made per square 50 x 50 m.

Soil samples are taken from the exposed wall of the test pit and only from horizons that are macroscopically different (granularity, colour). The amount of soil taken for one sample is 1 - 1.5 kg, in the case of gravel representation in the soil above 20%, it increases to 3 - 5 kg. The sampling points are recorded in the working map. Photo documentation is always carried out during sampling.

Methodology of pedological mapping and soil sampling

The approved internal methodical procedures of the testing laboratories of VÚHU and VÚMOP accredited ČIA o.p.s. according to ČSN EN ISO/IEC 17025.

The following soil analyses are used for short-term monitoring of recultivation areas in the conditions of the Most Basin:

- Granular analysis
- Determination of soil reaction
- Determination of humus content
- Determination of soil sorption capacity

Granularity evaluation

It is a basic physical-mechanical test of soils from the point of view of their recultivation use. Medium-grained to fine-grained, even-grained rocks are most suitable for recultivation. The granular composition of soils is determined by the percentage representation of different size fractions of soil particles. An important criterion is the percentage representation of the fraction with a grain size below 0.01 mm, which enables the soil to be classified according to "Novák" into seven soil types. Another important criterion is the mass fractions, which take into account 3 fractions according to the "NRCS USDA" soil granularity triangle diagram (clay below 0.002 mm, dust 0.02 - 0.05 mm, sand 0.05 - 2 mm).

According to size, soil particles can be divided into skeleton (above 2 mm), which further distinguishes coarse sand (2-4 mm), gravel (4-30 mm) and stones (above 30 mm), and secondly into fine soil (below 2 mm), which is classified according to the criteria listed below. The increasing content of the skeleton and the increase in the size of its grains in the surface layer make it difficult to work the soil and worsen the conditions for plant rooting.

Most of the classification systems are based on the evaluation of soil types according to the content of the I. granularity category up to 0.01 mm, such as the Novák scale used in our country.

Table 17. Soil granularity evaluation

Content of grain fraction < 0,01 mm (%)	Soil type	Soil evaluation
0 – 10	sandy	light granularity
10 – 20	loam - sandy	light granularity
20 – 30	sandy - loam	middle granularity
30 – 45	loam	middle granularity
45 – 60	clay - loam	fat granularity
60 – 75	clayey	fat granularity
>75	clay	fat granularity

Loam soil is optimal for recultivation. In the case of sandy, loamy and clay soils, it is recommended to adjust the granular composition of the upper horizon.

Determination of soil reaction

Soil reaction is one of the most important soil characteristics. E.g. the solubility of various compounds, the binding strength of exchangeable ions and the activity of various microorganisms largely depend on whether the soil is acidic, neutral or alkaline.

An active soil reaction involves the concentration of hydrogen ions in an aqueous extract or soil suspension. In this case, H+ ions bound by the sorption complex are not included in the determination.

The soil exchange reaction is defined as the ability of the soil to change the pH of neutral salt solutions (KCl). KCl solution is most often used, when K+ ions displace H+ ions from the sorption complex. The exchange soil reaction is a more stable value than the active reaction and is always about 0.5 pH units lower.

The evaluation of the soil reaction is given in the following table.

Table 18. Soil reaction evaluation (pH)

Soil reaction (pH)	pH_{H20}	pH_{KCl}
very acid	< 4,9	< 4,5
acid	5,0 – 5,9	4,6 - 5,5
lightly acid	6,0 – 6,9	5,6 - 6,5
neutral	7,0	6,6 - 7,2
lightly alkaline	7,1 – 8,0	> 7,2
alkaline	8,1 – 9,4	-
very alkaline	>9,4	-

Most plants cannot grow on soils with a pH reaction of < 3.5 and > 9. The adjustment of the soil reaction of the upper horizon can therefore be recommended for strongly acidic, alkaline and strongly alkaline soils.

Determination of humus content

The term humus refers to a wide range of organic substances in various stages of transformation, mixed or not mixed with a mineral component. There are significantly fewer of these substances in soils than mineral substances, but their importance for soil fertility is decisive. The content of humus is determined by conversion from the laboratory determined content of oxidizable carbon. Humus content in soils can be evaluated according to the following criteria:

Table 19. Humus content evaluation

Humus content (%)	Evaluation
<1	very low
1,0 – 2,0	low
2,1 – 3,0	middle
3,1 – 5,0	high
>5,0	very high

Soil fertility increases with humus content. In the case of a very low humus content, the application of organic fertilizers can be recommended. In the case of brown coal basin soils, it is particularly important not to confuse oxidizable carbon and humus with organic carbon mass, the effect of which is, on the contrary, phytotoxic.

Determination of soil sorption capacity

The sorption capacity of the soil is defined as the increase in the concentration of the substance at the phase interface compared to the surrounding environment. Both organic and inorganic components are involved in soil sorption. As their contribution to the total sorption is difficult to distinguish, there is often talk of a so-called sorption complex, which is characterized by a cation exchange capacity. This is denoted by the symbol KVK, (the older designation T is still used) and is given in mmol/100g. For the soils of the Czech Republic, KVK is evaluated according to the following criteria:

Table 20. Sorption capacity (KVK) evaluation

KVK value	Evaluation
8 – 12 mmol/100 g	very low - low
13 – 24 mmol/100 g	middle
25 – 30 mmol/100 g	high
>30 mmol/100 g	very high

Soil quality increases with increasing KVK value.

Determination of the content of acceptable nutrients

To determine the quality of the content of acceptable nutrients in the soil, the contents of acceptable phosphorus, potassium and magnesium were selected. The evaluation is given in the following table 21.

Table 21. Acceptable nutrients P, K, Mg content (Mehlich III methodology)

Content	P ($mg.kg^{-1}$)
low	< 50
middle	51 - 80
good	81 –115
high	116 –185
very high	> 185

Content	K ($mg.kg^{-1}$)		
	Soil		
	Light grain	Middle grain	Fat grain
low	< 100	< 105	< 170
middle	101 - 160	106 - 170	171 - 260
good	161 - 275	171 - 310	261 - 350
high	276 - 380	311 - 420	351 - 510
very high	> 380	> 420	> 510

Content	Mg ($mg.kg^{-1}$)		
	Soil		
	Light grain	Middle grain	Fat grain
low	< 80	< 105	< 120
middle	81 – 135	106 - 160	121 – 220
good	136 – 200	161 - 265	221 – 330
high	201 – 285	266 - 330	331 – 460
very high	> 285	> 330	> 460

Long term monitoring methodology

pH:

- Soil reaction is one of the most important soil characteristics. E.g. the solubility of various compounds, the binding strength of exchangeable ions and the activity of various microorganisms largely depend on whether the soil is acidic, neutral or alkaline.
- ČSN EN ISO/IEC 17025:2018
- Initial, short term and long term
- The value of the soil reaction (pH) strongly influences and limits the possibility of the development of herbaceous, shrub and tree layers and thus strongly influences biodiversity. It is an important manifestation of soil contamination. Acceptable pH values range from 5.0 - 7.5.

Granular composition:

- The granular composition of soils is determined by the percentage representation of different size fractions of soil particles. An important criterion is the percentage representation of the fraction with a grain size below 0.01 mm. It is a basic physical-mechanical test of soils from the point of view of their recultivation use. Medium-grained to fine-grained, even-grained rocks are most suitable for recultivation.
- ČSN EN ISO/IEC 17025:2018
- Initial, short term and long term
- The granular composition of the soil significantly affects the possibility of the growth of woody plants and thereby affects biodiversity. Determining the grain size composition is important for describing the structure and texture of the soil. Granularity is also of fundamental importance for the water regime of the site. Acceptable values for the content of the granular fraction below 0.01 mm are in the range of 25 - 60%.

As content:

- Arsenic is the only risky trace element that occurs in significantly dangerous concentrations in the soils of the Most Basin. Its source is coal seam soils and, above all, soils affected by the wash from the nearby Ore Mountains (ores of non-ferrous metals).
- ČSN EN ISO/IEC 17025:2018
- Initial, short term (only at sites where elevated content was detected during the initial survey), long term (only at sites where elevated content was detected during the initial survey together with other risk trace elements according to Decree No. 153/2016 Coll.
- The increased content of arsenic is (at least in the conditions of the Most Basin) an important cause of soil contamination. They can also occur in topsoil on agriculturally reclaimed areas. Acceptable As contents in soil must be lower than 0.20 $mg.kg^{-1}$

Fe sulphides content:

- The occurrence of iron sulphides (pyrite and marcasite) in reclaimed sites is possible only in sites with soils from coal seam layers.
- ČSN EN ISO/IEC 17025:2018
- Initial
- The occurrence of iron sulphides (pyrite and marcasite) in soils leads to their gradual decomposition into sulphates, adversely affects pH and causes soil contamination. Their presence in the soil is undesirable.

Gypsum content:

- Crystalline gypsum occurs in some types of Tertiary clays. They form macroscopically visible white coatings and crystals.
- ČSN EN ISO/IEC 17025:2018
- Initial, short term (only at sites where elevated content was detected during the initial survey), long term (only at sites where elevated content was detected during the initial survey)

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- The occurrence of gypsum is an important source of soil contamination (salinization). It causes an extremely alkaline soil reaction, the death of a few trees and thus adversely affects biodiversity and possible forest reclamation. The presence of gypsum in the soil is undesirable.

Sulphur content:

- The occurrence of sulphur in reclaimed sites is possible only in sites with soils from coal seam layers. It occurs on similar surfaces as iron sulphides.
- ČSN EN ISO/IEC 17025:2018
- Initial
- The occurrence of iron sulphides (pyrite and marcasite) in soils leads to their gradual decomposition into sulphates, adversely affects pH and causes soil contamination. Their presence in the soil is undesirable.

5. Conclusion

This report, as part of Task 3.4 of the REECOL project, aimed to identify and provide a detailed analysis of selected post-mining reclamation case study areas across Europe. By examining the current state of these areas, this report establishes a solid foundation for the experimental activities and monitoring solutions planned in Work Packages 4 (WP4) and 5 (WP5).

Summary of Findings

1) **Current State Analysis:**
   - The report presents a comprehensive overview of the current degradation status, biotic and abiotic conditions, and contamination levels of the selected study areas.
   - These areas, located in Greece, Poland, Slovenia, the Czech Republic, and France, represent a diverse array of post-mining landscapes, each with unique characteristics and reclamation challenges.
2) **Selection of Study Areas:**
   - The chosen sites were selected through a collaborative process involving project partners from the respective countries. The selection criteria were based on the potential to facilitate the development and testing of innovative land reclamation solutions and monitoring methodologies.
   - The case study areas include the Amynteon and Ptolemais lignite mines in Greece, the mining areas of PGG in Poland, the Velenje Mine in Slovenia, the Radovesice and Strimice dumps in the Czech Republic, the Konin Brown Coal Mine in Poland and former Mazingarbe coal mining site in France.
3) **Basis for Future Research:**

   The insights gained from the current state analysis of these case study areas are crucial for the next phases of the REECOL project:
   - **WP4 - New Rehabilitation Solutions:** WP4 will focus on developing and implementing novel rehabilitation techniques tailored to the specific conditions and needs identified in each case study area. The tasks within WP4 will involve developing and testing new rehabilitation solutions in selected post-mining areas, specifically targeting the unique challenges and opportunities present in these regions. Key activities will be carried out in the mining areas of PGG in Poland, the Konin Brown Coal Mine in Poland, and Mazingarbe in France.
   - **WP5 - Short and Long-term Monitoring Solutions:** WP5 will establish robust monitoring frameworks to assess the effectiveness of the rehabilitation solutions applied. This will involve the use of advanced remote sensing technologies, landscape indicators, and geotechnical assessments to continuously evaluate the progress of reclamation efforts and ensure their long-term sustainability.

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