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REECOL Ecological rehabilitation and long term monitoring of post mining areas

Deliverable 3.2

Identification of post-mining rehabilitation schemes regarding future land uses and affordability of the solutions

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1. INTRODUCTION

The REECOL project deals with the **reclamation of coal regions in Poland, the Czech Republic, Slovenia, Greece and France**. The partner countries of the project have a long tradition in **surface and deep mining of brown coal** and are currently solving various mining problems due to the gradual decline in mining.

Task 3.2 characterizes the **different approaches to post-mining reclamation** that have been used **in the project's partner countries** in terms of **Identification of reclamation practices with regard to further land use**.

Reclamation procedures and methodologies in the individual countries of the project are not yet coordinated and differ considerably. Therefore, the individual chapters of this report characterize the **situation in individual countries**.

When choosing a suitable case area in the **Most Basin and its surroundings**, the history of reclamation research, the geological and pedological diversity of the reclaimed soils and the planned reclamation use of the area were considered. The application of **various reclamation methods**, including **natural succession**, the **occurrence of areas not yet reclaimed**, the **presence of long-term monitored experimental areas** and **possibilities of ecological use of the site** were important. The **Radovesice - Střimice spoil heaps complex** was selected as **the Czech main case study area**.

There are **two main case study areas in Poland**. **Silesian post-industrial and postmining areas** present unique challenges and opportunities for sustainable development and land reclamation. There are two main case study areas. The **Konin Lignite Basin**, located **in the Greater Poland Voivodeship**, is a significant area in the Polish mining and energy industries, playing a crucial role in supplying energy resources for decades.

The issue of reclamation of **Slovenian** mining sites is specific. **It** is the only partner of the project, where only underground brown coal mining is carried out. It is mainly about hydraulic recultivation of subsidence basins. Due to the operational power plant, the products of lignite combustion are common materials.

PPC lignite mines in West Macedonia Lignite Centre (WMLC) and **Megalopolis Lignite Centre (MLC)** provide lignite for power generation, the most important energy source for the Greek economy. Lignite is mined by the PPC exclusively in opencast mines. It has operated mines in **Western Macedonia in the Ptolemais area** (Main Field, South Field, Kardia Field) and **Florina** (Amyntaio Field).

The **French** case study is a basin beneath an old coal mine (**Dump 49**) located **in Mazingarbe**, a city of the **Pas-de-Calais** department (62) and the **Hauts-de-France** region (previously North-Pas de Calais region). It is situated in the **watershed of Le Surgeon, La Fontaine de Bray, La Loisne** and **Le Fossé d'Aisnes et d'Auchy**.

2. CZECH REPUBLIC SITUATION

2.1. Czech case study

The wider case study area will be **the Most basin**, individual characteristic areas will be selected for the main part of the research.

When **choosing a suitable case area in the Most Basin and its surroundings**, the **history of reclamation research**, the **geological and pedological diversity** of the reclaimed soils and the **planned reclamation use** of the area were considered. The application of **various reclamation methods**, including natural succession, the **occurrence of areas not yet reclaimed**, and the **presence of long-term monitored experimental areas** were important.

After applying the research methodology, 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 areas** (2 reclaimed, 2 left to natural succession) and on the **Střimice spoil heap there are 2 areas** (1 reclaimed, 1 left to natural succession).

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 **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. **4 long-term monitored experimental areas** were established **on this spoil heap**.

2.2. Main types of reclamation used in Czech coal regions areas

There are **3 coal regions in the Czech Republic**: the **Moravian-Silesian Region** and the **Ústí Region** and the **Karlovy Vary Region** (together they form the Northwest Region). The Most basin is situated in the Northwest region, which is the largest coal deposit in the Czech Republic and was chosen for the solution of the project.

Currently, **reclamation in** the conditions of the **Czech Republic** can be defined as **a summary of interventions that are intended to eliminate unwanted anthropogenic interventions in the landscape**. **Most often**, the subject is **recultivation of the territory affected by the extraction of mineral resources** (residual pits after surface coal mining, landfills, excavated sand pits, quarries, pinnacles). The **result of reclamation** can be the **transformation** of excavated areas **into fields and forests**, the **construction of recreational facilities** in urban agglomerations or successional areas.

2.2.1. Differentiation of recultivation according to stage

Technical reclamation

The **goal** of the technical phase of reclamation is **to model the new terrain**. Heavy equipment is used (dozers, bulldozers, ditch ploughs, cutters). **The process of reclamation is usually as follows**: the mining layers or floors begin to be covered, the places for water management reclamation begin to be isolated, the terrain begins to be modelled. The **work includes** moving soil, depositing, spreading, compacting, bringing in topsoil. It is already necessary to know the future use of the terrain at this stage. This has an **effect on the choice of rocks** that will be used **to cover the** individual **areas**. **Topsoil will be brought** to the places where there will be fields or orchards (the law imposes an obligation to selectively remove topsoil and use it again for land reclamation).

Biological reclamation

After the creation of the terrain, the biotechnical stage begins, which has the task of **revitalizing the new territory**. This phase **includes** the **adjustment** of the **physical and chemical properties** of the soils (acidity, structure), fertilization and the supply of nutrients to the soils. They are **followed by agrotechnical measures** (loosening, skidding, rolling) and the **cultivation of suitable crops**. A special **sowing cycle begins in the fields to fertilize the soil**.

2.2.2. Differentiation of reclamation according to use

Agricultural reclamation

In the process of agricultural reclamation, fields, meadows, vineyards or orchards are established. It begins with the **application and spreading of organic matter**, followed by **ploughing**, **dragging**, **skidding**, **sowing of preparatory crops**, their **ploughing**, **fertilizing**, and then the **cultivation of target crops or grassing**.

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Forest reclamation

The result of forest reclamation is the **creation of new forests**. Different types of habitat and **geographically native trees** are used for planting. This type of reclamation leads to the creation of a **new ecological stability of soils** and **landscapes** and leads to **soil consolidation**.

Hydric reclamation

Hydraulic reclamation mainly covers the **heating of excavated quarries**, as well as the **restoration of river ecosystems**, modification and improvement of the **water balance**.

Natural succession

The essence of reclamation close to nature is to **leave the course of natural succession**. Instead of the expensively created and maintained recreational forest or forest park, a "new wilderness" can then emerge. **Nutrient-poor soils** (typically landfills) **often develop communities of rare plant** and **animal species** that have been displaced from fertile, fertilized agricultural landscapes (Vojar 2012).

Other reclamation

This includes the **construction of roads**, **purpose-built buildings**, **recreational areas**, **golf courses**, **airports**. A reclamation lake often becomes **the centre of a recreation area**.

The following table No. 1 shows the **percentage representation of individual types of reclamation** in the Most basin area.

Table 1. Percentage representation of individual types of reclamation in the Most basin area.

Type of reclamation	% representation
Agricultural reclamation	40
Forest reclamation	43
Hydric reclamation	8
Natural succession	3
Other reclamations	6

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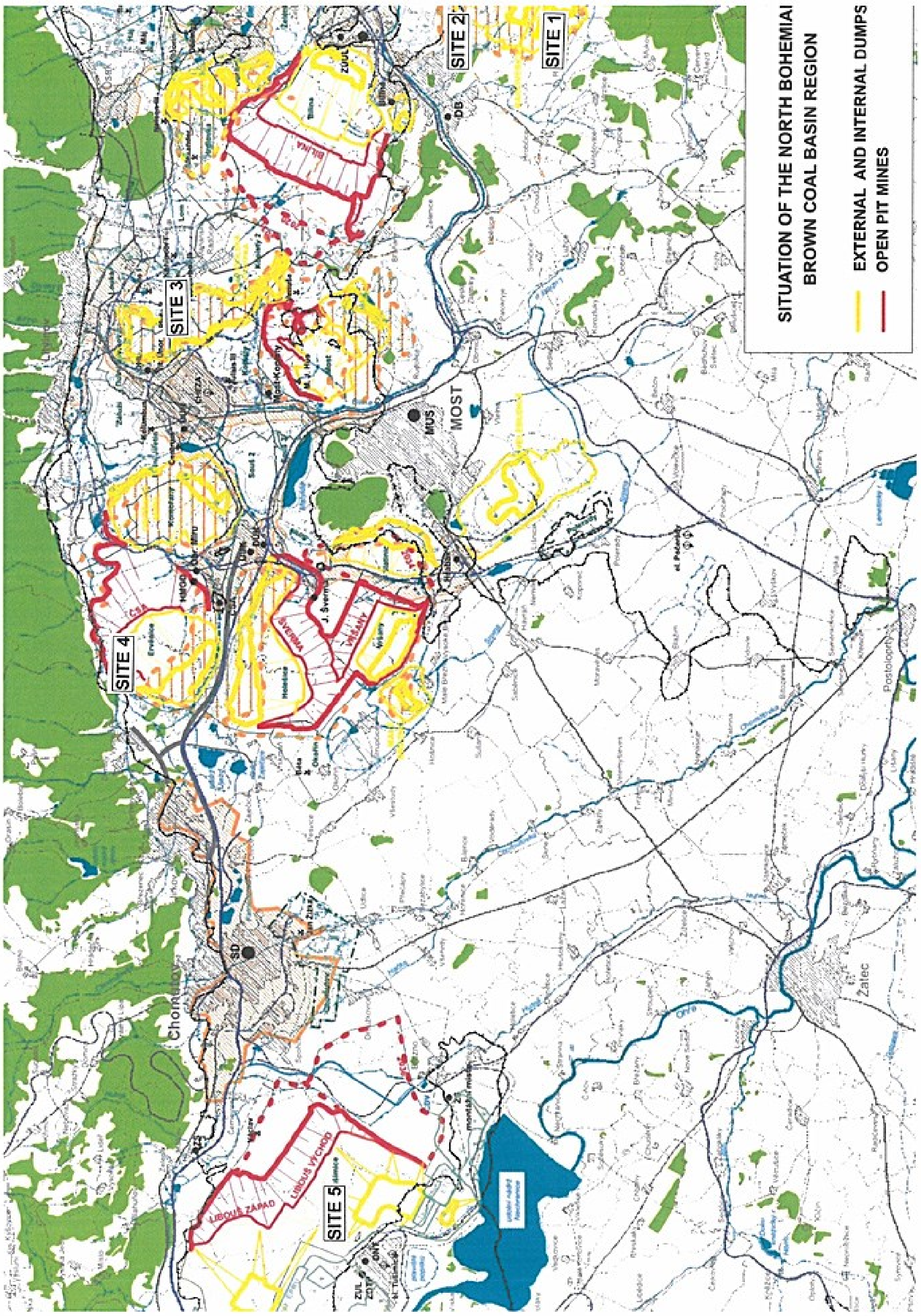

Figure 1. Situation of open pit mines and spoil heaps in NW Bohemia

2.3. Legislative and financial framework of reclamation

All types of reclamation described above (including the establishment of succession areas) **must** first of all **be in accordance with** the **applicable legislation** in accordance with the **approved spatial planning activity** (valid spatial plan), however, it is most **influenced by the approach of nature and landscape protection authorities** and their setting of conditions in their decisions, which are the basis for permitting mining activities and these conditions are binding for mining organizations.

Part of the mining activity permit according to the Opening, Preparation and Extraction Plan according to § 10 of Act No. 61/1988 Coll., on Mining Activity, Explosives and State Mining Administration, as amended, based on the **decision of the regional mining office** (hereinafter referred to as "**OBÚ**"), there is also the approval of the creation of a financial reserve for remediation and reclamation and mine damage. The **opening, preparation and mining plan** (hereafter referred to as "**POPD**") also **includes the Comprehensive Remediation and Reclamation Plan**, which **addresses the implementation of biological and technical reclamation**, in an appropriately chosen relief (remediation) of the affected area, including the financial balance of individual works and the costs of the necessary resources.

The mining **organization is obliged**, either continuously or once, to **deposit the approved amount of funds** into a special escrow account in the bank **according to the valid decision of the OBU**, from which the **mining organization will draw** the necessary amount of **funds for individual rehabilitation and reclamation activities based on the permission** of the relevant **OBU**.

In the documentary part of the **POPD**, **consent** is required **for the removal of the affected land by mining from the agricultural land fund (ZPF)** and **land intended for the fulfilment of forest functions (PUPFL)** according to Act No. 334/1992 Coll., on the protection of the agricultural land fund, as amended, respectively Act No. 289/1995 Coll., on forests, as amended. Withdrawal can be **temporary or permanent**. In case of **temporary** withdrawal, the mining organization pays **annual levies** in the amount specified in the decision on withdrawal. This decision also sets out the conditions under which the competent authority will terminate the payment of the temporary levy - usually after carrying out remediation and reclamation, or after returning the land to ZPF or PUPFL. The issued **consent to withdrawal from the ZPF** also **addresses**, among other things, the **future method of recultivation of the affected areas** and is accepted within the framework of SPSaR.

The price of individual types of reclamation in Czech crowns per hectare is given in the following table No. 2.

Table 2. Price/ha of individual types of reclamation in the Most Basin area

Type of reclamation	Price/1ha (CZK)
Agricultural reclamation	100 000 – 300 000
Forest reclamation	400 000 – 600 000
Hydric reclamation	1 900 000 – 7 800 000
Natural succession	0 – 100 000
Other reclamations	Different by type

2.4. Applied research methodology

The methodology of the recultivation survey is given by **working methodologies approved by the Ministry of the Environment of the Czech Republic**.

2.4.1. Methodology of field work

The **terrain survey was based on** geological mapping and sampling of overburden rocks in the open pit mines, experimental application of fertilizable soils, foundation of areas retained to natural succession, as well as on long-term sampling and sample analyzes in the experimental areas.

On-site mapping using a soil probe was carried out in all areas, as well as **sampling from test pits** at selected sites. The soil sampling was performed from the **exposed side of the soil probe** and only from **horizons** that were **macroscopically different** (in grain size, color). The **amount of soil** collected for **one sample was 1-1.5 kg**. If the **soil skeleton** was **above 20%**, it **increased to 3-5 kg**. The **sampling points** were recorded in the **working map**.

2.4.2. Recommended laboratory testing

The **selection of laboratory tests and analyzes** of their results were **determined in the range of proven methods** used for **reclamation** activities **in the Most Basin on a long-term basis** [8]. For each sample, grain-size determination, mineralogical composition evaluation using the Siemens x-ray diffractometer, determination of soil response, determination of $CaCO_3$ content, determination of content and quality of oxidizable carbon and humus, determination of nitrogen content, determination of sorption capacity and determination of acceptable nutrient content according to the Melich III methodology were performed.

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The content of sulfur, organic (coal) mass, soil reaction and the content of selected hazardous trace elements were determined by **comparing the content of contaminants in the soil in the individual areas**.

All performed laboratory analyzes were **performed at the test laboratories of the Brown Coal Research Institute (VUHU)** and the **Research Institute for Soil and Water Reclamation (VÚMOP)**, accredited by the Czech Accreditation Institute (ČIA), according to ČSN (Czech National Standard) **EN ISO/IEC 17025,** based on **internal methodologies** and based on **relevant standards**.

2.5. Main types of reclaimed soils

The **reclamation work methodology** in the **North Bohemian Basin** is, above all, **determined by the properties of overburden rocks**, which occur in the top horizon of the reclaimed sites. The **research of the soils reclamation properties** dealt with four current mining localities in the central part of the basin. It **concerned the mine Bílina**, **Libouš**, **Vršany** and **ČSA**. This chapter states the stratigraphic status properties of these sites with respect to reclamation availability (Ondracek 2003é.

In the area of **Bílina mine**, there are **quaternary rocks well usable for reclamation**. It concerns topsoil, loess and loess loams, which are selectively mined and used as fertilizable rocks. **Grey kaolinite and illite clay stones**, which form the top horizon in a part of the area, are also usable. Deeper deposited **rocks of the delta sandy formation** representing the biggest volume of overburden rocks **are not usable from the reclamation** perspective and the coal clay stones from the seam formation can be rated as phytotoxic. In the forefront of the **Vršany mine**, there are also **quaternary rocks usable for reclamation**. **Topsoil** and mainly very abundant and good quality reserves of **loess** are selectively mined and **used as fertilizable rocks**. However, the **yellow clay** of the overburden formation, as well as the **sands and sandy clay stones** of the upper inter deposit **cannot be used for reclamation**. Furthermore, the **coal clay stones** from the bottom inter deposit are virtually **phyto-toxic**. A better situation is in the other two mining localities. In the **ČSA mine**, **quaternary rocks** are almost depleted, **grey clay stones** of the overburden massif are, with the exception of siderite horizon above the head of the coal seam, well **usable for reclamation** (the mining of overburden rocks finished here, but the restoration of ČSA internal dump continues. **In the mine Libouš**, **quaternary topsoil** is selectively mined and deposited. **Grey clay stones** of the overburden massif are **well usable for reclamation**. The horizon of a heavy clays structure on the head of the tertiary is the only exception.

The evaluation proves that **the mines Bílina and Vršany** have a **similar** pattern **in terms of the availability for reclamation perspective**, with rocks not very suitable for reclamation and that the **mines Libouš and ČSA** have **better conditions**. The reason for this is the type of settlement during the time of coal seam depositing and later on. The **mines Libouš and Bílina** have the **biggest reserves of topsoil,** and **the best quality deposits of loess** occur in the **forefront of the mine Vršany**.

The **solution to the research task** included the **detection of the petrographic and mineralogical properties of stratigraphic horizons** laying in the procedure of the opencast mines in the **North-Bohemian Basin**. The results are stated in the table No. 3. **Loess**, **loess loams**, **alms** and **bentonites** are used **for the technical reclamation of the dumps** of the upper horizon, which is formed by phyto-toxic rocks and rocks with bad usability for reclamation (see table No. 3). The **application of bentonites was stopped** due to a **high** market **price of the material**.

Table 3. Mineralogical composition and restoration usability of typical overburden soils

Location	Stratigraphic horizon	Type of the Rock	Restoration Usability	Mineralogy
Bílina mine	Quaternary deposits	top soils, loess loams, loams, gravel sands	**perfect**	quartz, kaolinite, illite, dash of anorthoclase, calcite and montmorillonite
	„Libkovice“ overlying strata	grey k.-i. clays	**good**	quartz, kaolinite, illite, dash of siderite
	sand-clay strata	sandy clays, sands	**bad**	quartz, dash of kaolinite, illite, siderite
	overburden rocks of coal bed	sandy clays, sands, coal	**phytotoxic**	quartz, kaolinite, illite, dash of coal and siderite

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Table 3. cont. Mineralogical composition and restoration usability of typical overburden soils

Location	Stratigraphic horizon	Type of the Rock	Restoration Usability	Mineralogy
Vršany mine	Quaternary deposits	top soils, loess loams, loesses, loams, gravel sands	perfect	quartz, kaolinite, illite, dash of anorthoclase and calcite
	Overlying strata	yellow plastic clays	bad	quartz, kaolinite, illite, dash of siderite and goethite
	overburden rocks of upper coal bed	sandy clays, sands	bad	quartz, kaolinite, illite, dash of siderite and dolomite
	overburden rocks of main coal bed	sandy clays, sands, coal	phytotoxic	quartz, kaolinite, illite, dash of coal and siderite
ČSA mine	Quaternary deposits	loams, clay loams, gravel sands	good	quartz, kaolinite, illite, dash of anorthoclase
	Overlying strata	grey k.-i. clays	good	quartz, kaolinite, illite, dash of siderite
Libouš mine	Quaternary deposits	loams, clay loams, gravel sands	good	quartz, kaolinite, illite, dash of anorthoclase and montmorillonite
	Overlying strata (top of the strata)	yellow plastic clays	bad	quartz, kaolinite, illite, dash of montmorillonite, calcite and siderite
	Overlying strata	grey k.-i. clays	good	quartz, kaolinite, illite, dash of siderite

2.6. Current methodology of implementation of individual types of reclamation

The **optimum methodology of different spoil heaps restoration in the Most basin** is one of the most important results of the project solution areas. Coal mining and **reclamation works** proceed **in four considerably different geological areas**. In case of the **Bílina and Vršany open pit mines** the main issue is the occurrence of **extremely acid phytotoxic areas** with **high contents of coal and sterile sand**, in the case of the **Libouš and ČSA open pit mines** the main issue is the occurrence of **sterile areas** with **high content of physical clay**. The presented methodology was suggested after long term survey of research areas soil profiles.

2.6.1. Methodology of forest reclamation

The forestry reclamation methodology has several **variants depending on the properties of the spoil heap soils**.

Methodology of the forest restoration of the phytotoxic areas

The **surface** of these areas **consists of coal strata overburden rocks**. It is **heterogeneous mixture of sands** and **sandy clays with high content of coal** (more than 5 %), **siderite**, **pyrite**, **marcasite** and **sulphur** (3 – 5 %).

We recommend **two variants**:

- The **application of fertilisable rocks marl and bentonite** is the **first variant of phytotoxic areas restoration**. In this case these rocks are applied in the amount 2500-3000 $m^3.ha^{-1}$ with the cross ploughing from 0.5 to 0.6 m. The application of organic substances (composts) with the adjusted ratio C : N (25) in the amount 200 $t.ha^{-1}$, embedded into 0.20-0.30 m reclaimed surface of the area and the follow-up two-year preparatory agricultural cycle (growing plants for green manure) is requested as an additional measure. The **optimum dump slope incline** is 16 % (1:6).
- The **application of loess to the surface of the area before restoration** in the amount about 0,5m **without ploughing** is the **second variant of the phytotoxic areas restoration**. The application of organic substances (composts) with the adjusted ratio C : N (25) in the amount 200 $t.ha^{-1}$, embedded into 0.20-0.30 m reclaimed surface of the area and the follow-up two-year preparatory agricultural cycle (growing plants for green manure) is requested as an additional measure. The **optimum dump slope incline** is 16 % (1:6).

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Methodology of the forest restoration of the heterogeneous sandy areas

The **surface** of these areas **consists of another overburden rocks**. These rocks are **clays**, **sandy clays**, **sands** and **mixture of these rocks**. The main **problems** of these areas are **erosion effects and relatively bad chemical properties**. Application of fertilizable rocks (bentonites, marls or loess) is not necessary, but we recommend it in the case of occurrence more than 50 % of sands in the petrologic content. In this case these rocks are applied in the amount 1500-2000 $m^3.ha^{-1}$ with the cross ploughing from 0.4 to 0.5 m. The application of organic substances (composts) with the adjusted ratio C : N (25) in the amount 200 $t.ha^{-1}$, embedded into 0.20-0.30 m reclaimed surface of the area and the follow-up two-year preparatory agricultural cycle (growing plants for green manure) is requested as an additional measure. The **optimum dump slope incline** is 16 % (1:6).

Methodology of the forest restoration of the clayey areas

The **surface** of these areas consists of the **brown kaolinite** – **illite clay** with **very good pedological properties**. Application of fertilizable rocks is not necessary in this case. The application of organic substances (composts) with the adjusted ratio C : N (25) in the amount 200 $t.ha^{-1}$, embedded into 0.20-0.30 m reclaimed surface of the area and the follow-up two-year preparatory agricultural cycle (growing plants for green manure) is requested as an additional measure. The **optimum dump slope incline** is 16 % (1:6).

Methodology of the forest restoration of the clayey areas with plastic clays

The **surface** of these areas consists of **yellow, viscous clay with very fine granularity**. The **other pedological properties are good**. These rocks are quite rare in the Most Basin area. **Restoration** of these areas (change of granularity) is **very difficult and expensive**.

Research of sand and power plant ash is going on these days (see chapter No 5.2). Present methodology consists in the application of organic substances (composts) with the adjusted ratio C : N (25) in the amount 200 $t.ha^{-1}$, embedded into 0.20-0.30 m reclaimed surface of the area and the follow-up two-year preparatory agricultural cycle (growing plants for green manure) is requested as an additional measure. The **optimum dump slope incline** is 16 % (1:6). **Long term care of plants is necessary**.

Figure 2. Forest reclamation (Radovesice spoil heap)

2.6.2. Methodology of agricultural reclamation

The restoration methodology is **very simple** in this case. The **application of 0.5 m of topsoil to the surface** of the area is necessary **according to the Czech law**. The follow-up two-year preparatory agricultural cycle (growing plants for green manure) is requested as an additional measure. The **optimum dump slope incline** is 3 - 8 %.

2.6.3. Methodology of hydric reclamation

The best example is restoration of the Ležáky/Most open pit mine. This **methodology will be used in further hydric reclamations** in the area of the **Most Basin**. Restoration works of the mine slopes started after the decision about reduction of the brown coal mining in 1995. These works were accelerated after the end of coal mining in 1999. It was **technical restoration** of future lake slopes and **mineralogical sealing of the lake bed**. Three strata of clays (thickness 280 mm, 280 mm and 560 mm) were compacted here (thickness after compaction 200 mm, 200 mm and 400 mm). Total thickness of mineralogical sealing is 800 mm. The technical restoration of lake cost, its compaction and the construction of peripheral main road 4 m in width finished in 2008.

The **second step of works** was the **restoration of the coast and slopes of the lake**. These areas are the continuation of the agglomeration of **the Most city** and **the Litvínov city**. The Most Lake is sensitively integrated into reclaimed dumps of the open pit mine Ležáky/Most. The **southern and south eastern slopes** are **selected for commercial and recreational utilization**. The beach and the sporting ships port are situated here. Parks, sport organizations and pubs will be situated in south eastern part of this area. **Forest restoration of the other slopes under the lake coast started**.

The **running water to the former mine** started on 24.10.2008. The **main source of the water** is the **river Ohře**. The water is brought by industrial water pipeline from the pump station Stanná near the Nechranice dam. The power of this source is 0,6-1,2 m^3 of water per second [4]. The **second permitted source** is the **mine water** from the **former coal pit Kohinoor**. The **third source is** the **natural water basin of the lake Most**. The water running will finish in 2014. The area of the lake is 311 ha the maximal depth is 75 m. The **total volume** of the water is 68,9 mil. m^3, the sea level of the water surface is 199 m.

2.6.4. Methodology for establishing areas left to natural succession

The **application of fertilizable rocks** is the **prevailing restoration method in the Most Basin** area because of **bad pedological properties of dump rocks**. The **natural succession areas founding is recommended** in the case of **favourable conditions**.

Figure 3. Succession area (Radovesice spoil heap)

The location of the areas left to **undergo natural succession** should be **determined on the basis of systematic research of each locality**. It is necessary to proceed from the **soil pedological characteristics**, the **morphology of the terrain**, and in the older areas, **to prefer habitats** where **functional ecosystems have already spontaneously started to develop** under specific conditions.

It is also suitable **to found geological parks** in situ **to preserve mostly small-scale habitats**, where the protection and research of some biological, geological and paleontological phenomena is necessary. The **second possibility** is the **rescue and relocation of unique samples from the mine area** (a typical example is the preservation and relocation of unique petrified trees from the open pit mine Družba).

2.6.5. Methodology for the areas contaminated by salinity

The problem was discovered in 2016, when the cause of the **excessive death of trees was investigated on a number of areas**. The **overlying clays** of the locality are **pedologically quite homogeneous** and their **soil properties** (with the exception of too fine grain composition) are **very favourable**. Practically **the only explanation for the death of woody plants** was thus **a soil reaction**. The results, despite the large differences between the individual probes, confirmed the **highly alkaline soil reaction of the soil** (it ranged from 7.11 to 8.05 and usually exceeded the value of 7.5).

The **alkaline soil reaction of the soil** (pH approx. above 7.5) actually has **major negative consequences for most tree species**. Blockage of nutrient uptake (especially Mg) and disruption of the photosynthesis process is particularly significant. In general, **woody plants tolerate slightly acidic soils rather than alkaline ones**. The **presence of salts** (attested gypsum) in the seasoning horizon makes the **situation even worse** and is clearly negative. Bonding to water (gypsum) dries the surface.

After evaluating the results, a **trial application** of selected **additives suitable for moderate soil acidification** on selected areas **was recommended**. After considering individual options, the **application of ammonium sulphate was proposed**. Due to the **high content of ammonium nitrogen**, it is a **long-acting nitrogenous fertilizer**, particularly **suitable for spring fertilizing of soils**. **Ammonium sulphate slightly acidifies the soil**, so it is used **for all plants** grown **on neutral and alkaline soils**. It is incorporated into the soil after spreading it evenly. It is well soluble in water. The **physiological acidity** of this fertilizer also partially **contributes** to the **better release of phosphorus and some mineral compounds in the soil**. The **recommended dosage** of ammonium sulphate is approx. 3 – 4 kg / 100 m^2.

Table 4. Soil reaction of the soils of selected areas before and after sulphate application ammonium

Area	pH before application (2016)	pH after application (2017)	pH before application (2018)	pH after application (2010)
Březno XV	7,49	6,92	7,30	**6,72**
Březno XVI	8,05	6,72	7,11	**6,33**
Březno XVII	7,85	6,92	7,45	**6,90**
Březno XVIII	7,40	6,69	7,19	**6,58**
Merkur XIX	7,57	6,70	7,76	**7,21**
Merkur XX	-	-	7,15	**6,88**
Merkur XXI	-	-	7,76	**7,21**
Libouš I	-	-	7,48	**7,15**

The results of the analyses (see table No. 4) demonstrate the co**nsiderable effectiveness of the application of ammonium sulphate**. The work to date shows the **likely need for application i**n an **interval of 2 years**.

2.7. Some practical results of recommended methodology – application of fertilisable soils

Application of **fertilisable soils** is the **most important restoration method** used nowadays. The main usable **raw materials** are **topsoil**, **loess**, **loess loam**, **marl** and **compost**. The most important dumps with application of this methodology are the **Radovesice dump**, **Střimice dump**, **Bílina internal dump**, **Braňany dump** and others. **Restoration of the Střimice dump** is an **example of a successful application of bentonite** (Řehoř 2018).

Střimice spoil heap restoration – application of bentonite

The **Střimice spoil heap** reclamation was **the first large reclamation event** using **modern reclamation processes**. The dump is located to the Southeast from the town of Most. It was formed in the years 1959-1973.

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The surface of the crown is 160 ha and the elevation reaches 330 meters above sea level. The original **forestry reclamation** took place **in 1967**. With regard to **severe changes of the surface zone** in the dump, **the planting virtually died out**. At the same time, a **great impact** of **erosion effects** became **evident**. **Bentonites** from the Black Hill mine were **used for technical reclamation**. The layer of the brought bentonite rocks was defined to 50 cm. This was **followed by agricultural reclamation** of the dump plain with the total surface of 89 ha.

The **success rate of the selected method was tested** in co-operation with the **Bílina mine and** the **VUHU**. By **sampling and analysing the samples** from the Střimice spoil heap, the creation of a **new soil profile was identified** (see figure No 4). The **profile is divided into** an **upper layer** consisting of topsoil (or the mixture of topsoil and bentonite), a **middle layer** consisting of bentonite (or the mixture of clay and bentonite) and the original material of the dump.

The **upper layer** consists, from the mineralogical point of view, of **quartz**, **kaolinite**, **illite**, **montmorillonite**. A **mixture of spars** and sometimes **muscovite** are present. The **chemical status** is **quite friendly**. The **soil reaction** is **indifferent**; the **T absorption** is **medium to high** (according to the bentonite content) and the **content of calcite varies**. The **content of nitrogen** is **low** and the **content of humus** is **medium**. The **content of acceptable sustenance is low for phosphorus** and **medium to high for magnesium and potassium**. Regarding the **grain size**, the soils are **quite coarse**, **sandy to loamy**. They are **suitable for reclamation**. The **middle layer** mostly consists of **bentonite**. In the mineralogical composition, it corresponds to a greater amount of montmorillonite. The **soil reaction** is **lightly alkaline**, the **T absorption is high** (with growing amount of montmorillonite) and the **content of calcite is growing**. The **content of nitrogen and humus** is **low**. The **content of sustenance is slightly growing** against the upper layer. From the **grain size** point of view, the samples are **lightly coarse**. The original material of the dump consists of **yellow clays with pieces of coal**. These soils are **extra severe for reclamation**.

The **results prove success in** the selected method of the Střimice spoil heap **reclamation**. It is shown in the table No. 5. With respect to the **current market price of bentonite**, it is **not possible to apply** this type of reclamation **nowadays**.

Table 5. Chemical-pedological properties of the soil from the experimental area Střimice II – long-term development

S1 probe -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		
1992										
[1]0.00-0.50	0.05	1.2	1.0	6.7	8	240	215	15	15	100
[2]0.50-0.90	0.04	0.9	8.6	8.4	3	260	986	32	32	100
[3]pod 0.90	0.01	2.4	0.5	4.2	1	100	190	3	8	39
2010										
[1]0.00-0.50	0.07	1.4	1.9	6.9	9	185	200	16	16	100
[2]0.50-0.90	0.07	0.7	9.9	8.2	3	215	939	31	31	100
[3]pod 0.90	0.05	2.9	0.2	4.5	1	101	299	4	8	50
2016										
[1]0.00-0.50	0.05	1.5	1.0	6.8	8	240	215	15	15	100
[2]0.50-0.90	0.04	1.0	8.6	7.8	3	260	986	32	32	100
[3]pod 0.90	0.01	2.4	0.5	4.8	1	100	190	3	8	39
2022										
[1]0.00-0.50	0.08	1.8	1.0	6.8	8	268	222	16	16	100
[2]0.50-0.90	0.04	1.1	8.0	7.1	4	262	983	28	28	100
[3]pod 0.90	0.01	2.3	0.5	4.9	1	106	199	4	8	50

The Střimice spoil heap reclamation has been completed. At the crown of the dump, an **airport** with ca 90 ha surface, surrounded with **agricultural reclamation** serve the Most town citizens. On the slopes of the dump forestry reclamation with **tourist trails were built**.

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Figure 4. Soil profile with bentonite application - Střimice spoil heap

2.8. Conclusion and lessons learnt - the Czech Republic

Today's **reclamation scheme** is **greatly influenced by the "Czech Reclamation School"** founded at the end of the 1950s. This is based on the **principle of restoring the landscape to the state before the start of mining activities**. The **main and traditional methods** of reclamation are **agricultural**, **forestry** or **hydraulic**. Their **goal** is the creation of **areas usable for agriculture and forestry or** flooding the mine with water and **creating a lake.** This procedure **has long been highly regarded** and achieved **considerable success**.

The **reclamation scheme given by the legislation corresponds to** this: Plan for remediation and reclamation of the mining site - survey of individual areas and areas according to recommended methodologies - determination of the reclamation methodology of a specific area - implementation of reclamation - subsequent care of the area.

This scheme **is still the most used**, but it is **starting to run into certain limits**. These are mainly the **cost of implementation** and **problems with biodiversity**. Therefore, the **use of spontaneous and controlled succession methods** in the recultivation of land after mining is **starting to be applied more**. This provides the prerequisites for the creation of a colourful **landscape with exceptional species diversity**, **high ecological resistance**, which is even **more valuable for recreational use**.

Another trend in reclamation is perhaps indicated by the **planned reclamation of the ČSA surface mine area**, where mining ends in June 2024. The territory will consist of 3 main areas. On areas that are already partially reclaimed today, the reclamation will be completed in its current form. **Development for business and housing**, as well as **energy use in the form of photovoltaics**, is expected in locations where the technical background of the quarry is today, and **in less valuable reclaimed areas**. **Roughly a quarter of the total area** (11 km2) will be **left to natural development**. **Including the lake**, which in this locality **will be filled naturally** - from streams from the mountains and from groundwater directly in the location of the current open pit mine. At the same time, the **plan contains a territorial reserve for the possible future construction of a pumping station**.

3. POLAND SITUATION

3.1. Silesian Voivodeship Case Study

Poland's post-industrial and postmining areas **present unique challenges and opportunities** for sustainable development and land reclamation. The decline in coal mining has left **significant areas requiring rehabilitation and revitalization**.

The **economic and social transformations related to** the process of a **just transition** have led to **increased awareness and demand for requirements** concerning **post-industrial and post-mining areas**. The issues of deindustrialization, such as structural unemployment, the decapitalization of technical infrastructure, economic recession, and the closure of entire industrial centres, most often **affect post-industrial zones** located **in heavily urbanized areas** and **create crisis situations** in spatial, economic, social, and environmental spheres. In **most European countries**, **efforts** have been **implemented for years to restore degraded areas to local communities**. Their **revitalization involves transforming** these areas **into modern economic**, **residential**, **cultural**, or **recreational spaces**. **Efforts** aimed at **spatial and functional transformation** of post-industrial areas were **undertaken in Western Europe** as early as the **1970s and 1980s**. In the case of **Central European** countries, post-industrial revitalization projects have been **carried out since the 1990s** and, **in recent years**, **have become** one of the **most important factors** in the **development and revitalization of cities** (Domański, 2009).

One of the **critical regions is the Silesian Voivodeship**, which has the **largest number of post-industrial** and **postmining lands** in the country. These areas **face issues** such as **structural unemployment**, **decapitalization of infrastructure**, and **environmental degradation**. **Efforts** have been made **to transform** these zones **into modern economic**, **residential**, **cultural**, or **recreational spaces**, which is **essential for sustainable urban development** and avoiding urban sprawl (Pactwa, 2021)

3.1.1. About Silesian Voivodeship

The **Silesian Voivodeship** has **the largest amount of post-industrial and postmining areas in the country**, which **until now** were **not perceived as attractive** for creating new locations and activities. **PGG's statutory activities** related to deep underground hard coal mining are also **concentrated in this province**.

Their **number and area** will continue to **increase due the just transition process**. These areas usually cause **spatial degradation**, which negatively affects the region's image and competitive position. The **revitalization** of post-industrial areas, including **post-mining areas**, is an **opportunity** to give them **new social and economic functions**, **improve** their **aesthetics**, and **quality of life**. The revitalization of post-industrial areas plays an **important role not only in Poland but also in Europe**, as it **helps avoid urban sprawl** and **improves** the **quality of the urban environment**. Thus, **revitalization creates** the **conditions** necessary **for sustainable development** (Kaźmierczak, 2014).

The **revitalization** of post-industrial areas **requires** an **efficient and effective management process**, whose key element of success is the **planning of land use**. Such planning should be **preceded by** the **identification of these areas** and **their valorisation**, including an **assessment** of the **developmental potential** of a given area. The development of the Silesian Voivodeship is **significantly influenced by traditional industries**, primarily **coal mining and metallurgy**. The restruct**uring processes in coal mining and metallurgy** initiated a period of **substantial changes in the economic sphere of individual cities** within the Silesian Voivodeship, which are currently continued as part of the just transition process (WWF, 2021). This has resulted in the **liquidation processes within coal mining**. The **concentration of industry** in such a small area has contributed to **significant transformations of the natural environment**, resulting in **extensive industrial heaps**, **pits**, and **sinkholes**. **Environmental threats** also include **saline mine waters discharged into surface waters**. Practically **every city in the Upper Silesian Coal Basin has areas** within its boundaries directly or indirectly associated with mining activities, which **require revitalization** and **transformation** towards **new economic activities** or the **provision of ecosystem services** (CEC, 1990).

There is a **lack of** a **comprehensive**, **systematic**, and **publicly available valorisation of degraded areas**, containing information about their value for the economic sector, whose identification could realistically change and accelerate their economic reuse. A **serious barrier to the revitalization** of these sites is the **dispersed information**, which is **also held by private entities**. From this perspective, the **full utilization of the potential of post-industrial areas** in Silesia will **require the implementation of a long-term investment policy**, **sustainable space management**, and an **appropriate data-based system** for the **distribution of funds** to restore their functions (Program, 2008). Therefore, it is crucial to undertake **actions** and provide **appropriate tools** equipped with data **to support** the process of **bringing post-industrial sites back into economic circulation** while **preserving and enhancing their value in terms of infrastructure**, **space**, **environment**, and **culture**.

According to data published by the Ministry of Agriculture and Rural Development (GUS, 2019), **in 2018**, there were **5269 hectares of devastated and degraded land** in the Silesian Voivodeship, accounting for **approximately 0.43% of the voivodeship's area**, and **in 2020**, this percentage slightly decreased to about **0.40%** (GUS, 2020). Nationwide, this percentage is more than twice as low. In terms of the total area of land requiring reclamation, the Silesian Voivodeship ranks third in the country. This area has been increasing at least since 2010, while on a more general, national level, a decline can be observed. The **primary cause of land degradation and devastation** in the region **remains mining**, especially coal mining, which is responsible for almost the entire increase in the area of land requiring reclamation.

3.1.2. Assessment method for mining areas

Most of post-mining area, e.g. inactive waste heaps, levelled/buried tailings, closed shafts, and mines are **suitable for industrial and residential redevelopment**, Also **still active mine tailings storage areas** and **areas of operating coal mine** after closure and removing useless infrastructure **will be suitable for redevelopment proposes**. **Term BROWNFIELD** is often used for **post-industrial land that is abandoned**, **or underutilized due to loss of their function due to transformation processes**. In the case of **the active coal mine whose operations will be extinguished shortly** the term **PRE-MINING BROWNFIELD** could be set. This particular area relates to a **mining plant industrial site at the surface**, with possible objects, buildings, shafts, and infrastructure or contaminated areas, which were used in the past in the production chain in the coal mine. Due to the transformation of mining areas lost its function will appear soon.

Land use planning should be performed **as early as possible** to choose **appropriate reclamation activities** for mining areas that have lost or will soon lose their functionality. **Despite of high redevelopment potential**, due to the large supply of devastated and degraded land, the **most of mining area will be not reused in the near future**. At the terrain which was not revitalized the **spread of invasive plants and dense tree** cover development are observed. These processes **decrease the economic value of wasteland terrains**.

To support **land use planning decisions** within post-mining areas and the selection of the **most effective rehabilitation methods, evaluation redevelopment potential** of post-mining and active mines areas have been **applied for selected sites** owned by PGG .

The **complexity of processes** and **constraints associated with the revitalization** of post-industrial and degraded areas necessitates the provision of appropriate, up-to-date, and easily accessible **information to enable investors to make informed decisions** when **reusing post-industrial lands**. **Recently**, two major **projects concerning the valorisation of post-industrial areas** and their description methods have been conducted – one **in Poland** and the other **in England**. In both cases, research was carried out to determine the factors that investors consider when redeveloping degraded areas and selecting locations for investment sites.

In Poland, the **project** was **implemented** by the Central Mining Institute – National Research Institute in Katowice **for the Silesian Voivodeship** in southern Poland (**System OPI TPP 2.0**), while **in England**, it was conducted **for the Black Country region** by the University of Wolverhampton (BRIC Index). The **OPI TPP 2.0** system evaluates three aspects – **investment attractiveness**, **reclamation costs**, and potential for **providing ecosystem services** – and is mainly aimed at urban planners, urbanists, and entities supporting the region's transformation. The **English approach** adopted **a mixed methodology**, using both qualitative and quantitative approaches, which planners consider when making decisions about redeveloping post-industrial areas. The **primary users** of the system are **developers**. **Both systems** are **GIS-based** and facilitate the monit**oring of degraded areas**, **evaluate locations** based on **specific criteria**, and help **identify risks** associated with post-industrial lands.

In **describing post-industrial areas** considered **in** the **REECOL Project**, the **BRIC Index method was used** as it is more general and requires less data, with greater availability. The table below compiles the parameters, their definitions, and the assessment method for post-industrial areas used in the BRIC Index method.

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Table 6. Criteria and assessment method for post-industrial areas (BRIC Index method)

Criterion	Definition	Assessment Method
Land Condition	Level of current investment	Degraded areas already been built
		Completely vacant land
		Partially developed land
Land Origin	Type of land use based on historical development since the beginning of the 20th century	Category A land: Small industrial facilities, mines or heaps, factories and plants, sites with very small or small fuel tanks
		Category B location: Garages, workshops, mines, railway lines, textiles, small-scale wood processing, wastewater treatment plants, small chemical production, sites with small and medium fuel tanks
		Category C land: Metal processing, scrap yards and shipyards, paint and solvent production, small gasworks/gas storage, smaller power plants, railway bases (maintenance and refuelling), sites with large fuel tanks
		Category D location: Large gasworks, iron and steel mills, large chemical plants, refineries and major fuel depots, ship dismantling and construction, larger power plants, sites with large fuel tanks
Future Land Use Plans	Planned future use of the land	Production or commercial activities with limited "soft landscape," business parks, and data centres
		Open public space. Residential buildings without private gardens (apartments), schools, colleges
		Residential buildings with private gardens. Schools for younger children with playgrounds and sports fields, plots, and cultivation areas
Water Hazards	Environmental hazards related to water, including the impact of land contamination on water quality	Isolated aquifers in an environment with low sensitivity to pollution. No surface water on the site or no direct contact with surface water within 250 m from the site. Channelized river, canal not directly connected to groundwater
		Water protection zones. Shallow aquifers. Surface waters on or near the site and connected to shallow groundwater aquifers. Existing pollution migration paths
Location	Proximity to city centre	Over 5 km
		Between 2-5 km
		Below 2 km
Accessibility	Access to highway or city centre	Poor access; over 5 km from highway junction, over 2 km from city centre
		Average access - one of the good access conditions is met
		Good access; less than 5 km from highway, less than 2 km from city center
Neighborhood	Types of land use adjacent to the analyzed area	Industrial / green
		Commercial / retail
		Residential
Infrastructure	Presence of drainage systems, power grids, and other utilities in the vicinity that can be utilized	No infrastructure
		Access to specific types of infrastructure
		Well-developed infrastructure network
Pre-Project Work	Scope of acquired agreements for new land use	No agreements
		Some agreements acquired
		All agreements acquired

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As part of the work **in the REECOL project**, **the method was modified** to consider the **specifics of Polish post-mining areas** and the typical challenges faced by investors in the Silesian Voivodeship. The **valorisation** was conducted with **three main future land use directions** in mind:

- **Industrial Production**. This scenario likely focuses on transforming post-mining landscapes into zones suitable for industrial activities. This could involve the construction of factories or other facilities that contribute to the economic revitalization of the area while considering environmental constraints and the availability of local resources.
- **Residential Areas**. In this scenario, the post-mining areas are envisaged as potential sites for residential development. This involves converting previously industrial or undeveloped land into habitable spaces, ensuring that they meet the living standards and infrastructure needs typical of residential neighbourhoods.
- **Green Spaces or Renewable Energy Production**. This scenario focuses on ecological restoration and renewable energy projects. It could include creating parks, conservation areas, or installations of renewable energy infrastructure like solar panels or wind turbines. This aligns with global and regional sustainability goals, offering environmental and social benefits to the local communities.

For **each direction**, **all factors were considered**, but depending on the future land use, appropriate weights were given.

Active coal mines in Upper Silesian Coal Basin which **in the next 10 years** are planned **to be closed down**, were selected as **case study areas to define redevelopment potential**.

Three active coal mines are operated by PGG: KWK Bolesław Śmiały, Łaziska Górne (B1), Ruch Wujek, Katowice (W1), and KWK Sośnica, Gliwice (S1)

The area of one active (Sośnica) (S2), one reclaimed haste heap (Skalny) (B2), and one non-operational tailings (W2) I, which are located near evaluated active mines were also analysed.

Table 7. Valorisation criteria for Silesia postmining areas and weights according to development scenario

Indicator	Evaluation	Description of the assessment	Weight		
			production direction	housing direction	green or RES direction
Scale of soil contamination	1	Natural content, increased content	0,5	1	0,3
	2	Poorly polluted, moderately polluted			
	3	Heavily polluted, very heavily polluted			
Exposure of water bodies	1	Isolated aquifers, no surface water in the area	1	0,5	0,3
	2	Isolated aquifers, surface water contained in sealed channels			
	3	Water conservation zones, shallow groundwater levels, surface water on the site			
Annual average air quality	1	Air Quality Index: AQI < 50	0,3	1	0,3
	2	Air quality index: 50 < AQI <300			
	3	Air quality index: AQI > 300			
Water hazards	1	Outside the flood or water hazard zone	1	1	0,3
	2	In the vicinity of a flood and waterlogging hazard zone with potential impacts on the site			
	3	In the risk zone for flooding or waterlogging			
Geological hazards	1	Outside the zone at risk of landslides, submergence, sufosion	1	0,7	0,3
	2	In the vicinity of the landslide hazard zone, submergence, sufosion with potential impacts			
	3	In a zone at risk of landslides, submergence, sufosion			

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Table 7. cont. Valorisation criteria for Silesia postmining areas and weights according to development scenario

Indicator	Evaluation	Description of the assessment	Weight: production direction	Weight: housing direction	Weight: green or RES direction
Noise exposure	1	>5 km from airports, motorways and motorways, industrial zones	0,2	1	0
	2	2-5 km from airports, motorways and motorways, industrial zones			
	3	<2 km from airports, motorways and motorways, industrial zones			
Risks related to mining activities	1	Outside the mining area, thermally active area, shallow mining area	1	1	0,2
	2	Outside the mining area, a thermally active area. In the shallow mining area			
	3	On a mining site or in a thermally active area.			
Accessibility - expensive	1	Connection to national road, expressway or motorway <2 km	1	0,7	0,3
	2	Connection to national road, expressway or motorway 2-5 km			
	3	Connection to national road, expressway or motorway >5 km			
Accessibility - public transport	1	Connection to railway station, bus station <250 m	0,7	1	0
	2	Connection to railway station, bus station 250 - 500 m			
	3	Connection to railway station, bus station >500 m			
Site genesis	1	Small industrial sites, mines or heaps, factories and plants, sites with very small or small fuel tanks	0,7	1	0,3
	2	Garages, workshops, mines, railway lines, textiles, small-scale woodworking, sewage treatment plants, small-scale chemical production			
	3	Large iron and steel mills, large chemical plants, fuel depots, larger power plants, sites with large fuel tanks			
Location in relation to dense residential areas	1	distance from site < 1 km	0,5	1	1
	2	distance from site 1-3 km			
	3	distance from site >3 km			
Location in relation to compact industrial and commercial areas	1	distance from site < 1 km	1	0,7	0,5
	2	distance from site 1-3 km			
	3	distance from site >3 km			
Access to the infrastructure network	1	Available > 3 network types	1	1	0
	2	2-3 network types available			
	3	Available < 2 network types			
Building facilities	1	No building facilities	1	1	1
	2	Building facilities in good condition and adaptable			
	3	Buildings to be demolished			
Presence of conserved sites	1	Protected facilities in good technical condition, adaptable No conserved sites	1	0,5	1
	2	Protected facilities in poor condition or difficult to adapt			
	3	Protected facilities in poor condition and difficult to adapt			

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Table 7. cont. Valorisation criteria for Silesia postmining areas and weights according to development scenario

Indicator	Evaluation	Description of the assessment	Weight		
			production direction	housing direction	green or RES direction
Ownership structure	1	Municipality or Treasury Ownership of public entities or ownership of private entities	1	1	1
	2	Municipality and Treasury Ownership of public and private entities			
	3	Private ownership Unregulated ownership structure			
Investment areas	1	Location in an economic/investment zone	1	0,7	0
	2	Municipal investment area			
	3	Outside investment areas			

3.1.3. Results

As part of the preliminary work in the REECOL project, a total number of **six sites were selected to test the land valorisation method**, which served as the **basis for choosing the direction of reclamation**. **Active coal mines** in Upper Silesian Coal Basin which in the next 10 years are **planned to be closed down**, were selected **as case study areas** to define redevelopment potential. **Three active coal mines are operated by PGG**: KWK Bolesław Śmiały, Łaziska Górne (B1), Ruch Wujek, Katowice (W1), KWK Sośnica, Gliwice (S1)

The area of **one active** (Sośnica) (S2), **one reclaimed** haste heap (Skalny) (B2), and **one non-operational** tailings (W2) l, which are located **near evaluated active mines were** also **analysed**.

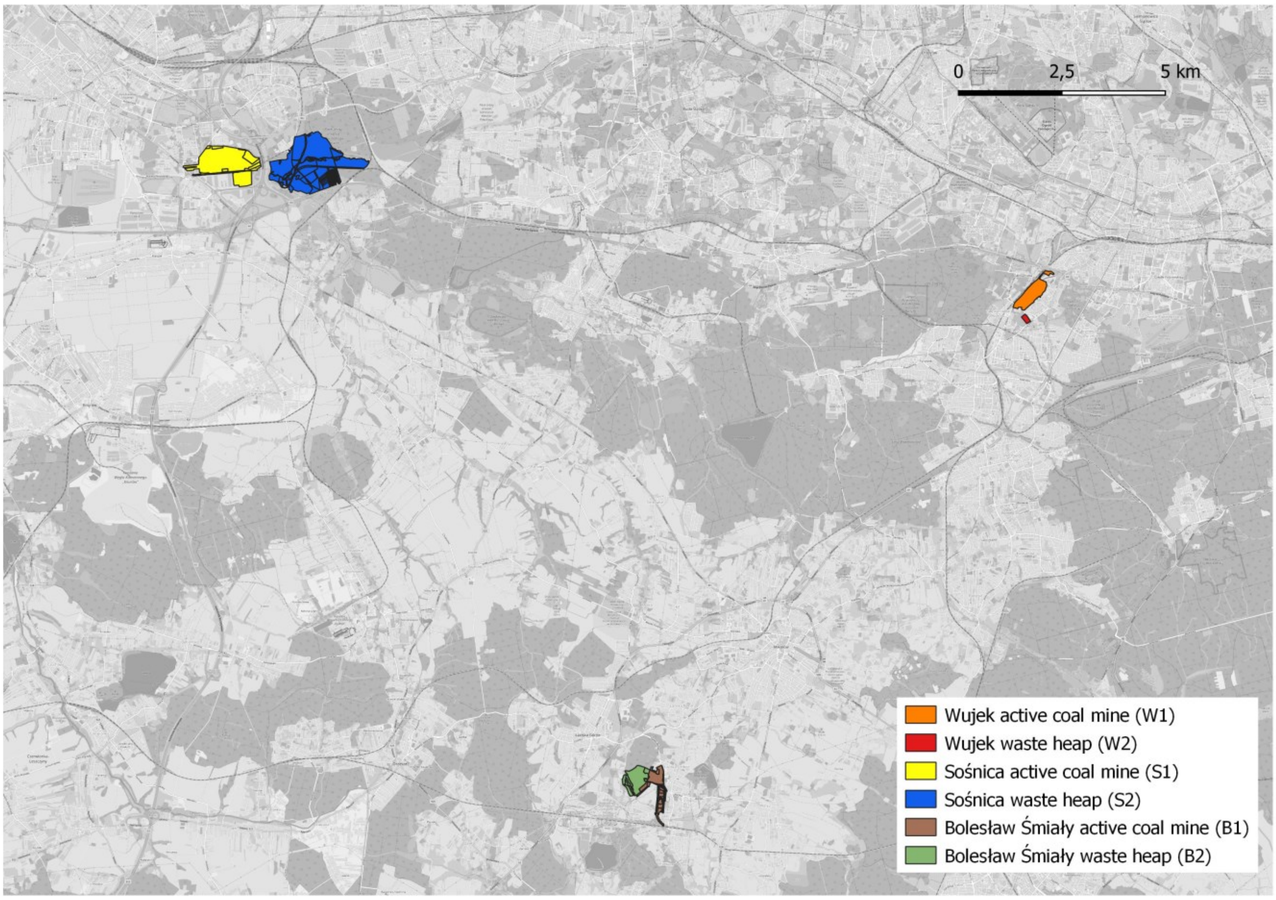

Figure 5. Sites used in assessment of valorisation method

The tables below present the **assessment results for individual areas** divided into directions of future development.

Table 8. Site assessment result for industrial production scenario

Indicator	S1	S2	W1	W2	B1	B2
Scale of soil contamination	1,0	0,5	1,0	1,0	1,0	1,0
Exposure of water bodies	2,0	1,0	2,0	2,0	2,0	1,0
Annual average air quality	0,6	0,3	0,6	0,6	0,6	0,6
Water hazards	1,0	1,0	1,0	1,0	1,0	1,0
Geological hazards	1,0	1,0	1,0	1,0	1,0	3,0
Noise exposure	0,6	0,2	0,6	0,6	0,6	0,6
Risks related to mining activities	3,0	1,0	3,0	3,0	3,0	3,0
Accessibility - expensive	1,0	1,0	1,0	1,0	1,0	1,0
Accessibility - public transport	0,7	0,7	0,7	0,7	0,7	2,1
Site genesis	1,4	0,7	1,4	1,4	1,4	0,7
Location in relation to dense residential areas	0,5	0,5	0,5	0,5	0,5	0,5
Location in relation to compact industrial and commercial areas	1,0	1,0	1,0	1,0	1,0	1,0
Access to the infrastructure network	1,0	1,0	1,0	1,0	1,0	1,0
Building facilities	3,0	1,0	3,0	1,0	3,0	1,0
Presence of conserved sites	1,0	1,0	1,0	1,0	1,0	1,0
Ownership structure	1,0	1,0	1,0	1,0	1,0	2,0
Investment areas	3,0	1,0	3,0	1,0	3,0	3,0
TOTAL SCORE	22,8	**13,9**	22,8	18,8	22,8	**23,5**

Table 9. Site assessment result for housing scenario

Indicator	S1	S2	W1	W2	B1	B2
Scale of soil contamination	2,0	2,0	2,0	2,0	2,0	2,0
Exposure of water bodies	1,0	1,5	1,0	1,0	1,0	0,5
Annual average air quality	2,0	2,0	2,0	2,0	2,0	2,0
Water hazards	1,0	2,0	1,0	1,0	1,0	1,0
Geological hazards	0,7	2,1	0,7	0,7	0,7	2,1
Noise exposure	3,0	3,0	3,0	3,0	3,0	3,0
Risks related to mining activities	3,0	3,0	3,0	3,0	3,0	3,0
Accessibility - expensive	0,7	0,7	0,7	0,7	0,7	0,7
Accessibility - public transport	1,0	1,0	1,0	1,0	1,0	3,0
Site genesis	2,0	1,0	2,0	2,0	2,0	1,0
Location in relation to dense residential areas	1,0	1,0	1,0	1,0	1,0	1,0
Location in relation to compact industrial and commercial areas	0,7	0,7	0,7	0,7	0,7	0,7
Access to the infrastructure network	1,0	1,0	1,0	1,0	1,0	1,0
Building facilities	3,0	1,0	3,0	1,0	3,0	1,0
Presence of conserved sites	0,5	0,5	0,5	0,5	0,5	0,5
Ownership structure	1,0	1,0	1,0	1,0	1,0	2,0
Investment areas	2,1	1,4	2,1	0,7	2,1	2,1
TOTAL SCORE	25,7	24,9	25,7	**22,3**	25,7	**26,6**

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Table 10. Site assessment result for green or RES scenario

Indicator	S1	S2	W1	W2	B1	B2
Scale of soil contamination	0,6	0,6	0,6	0,6	0,6	0,6
Exposure of water bodies	0,6	0,9	0,6	0,6	0,6	0,3
Annual average air quality	0,6	0,6	0,6	0,6	0,6	0,6
Water hazards	0,3	0,6	0,3	0,3	0,3	0,3
Geological hazards	0,3	0,9	0,3	0,3	0,3	0,9
Noise exposure	0,0	0,0	0,0	0,0	0,0	0,0
Risks related to mining activities	0,6	0,6	0,6	0,6	0,6	0,6
Accessibility - expensive	0,3	0,3	0,3	0,3	0,3	0,3
Accessibility - public transport	0,0	0,0	0,0	0,0	0,0	0,0
Site genesis	0,6	0,3	0,6	0,6	0,6	0,3
Location in relation to dense residential areas	1,0	1,0	1,0	1,0	1,0	1,0
Location in relation to compact industrial and commercial areas	0,5	0,5	0,5	0,5	0,5	0,5
Access to the infrastructure network	0,0	0,0	0,0	0,0	0,0	0,0
Building facilities	3,0	1,0	3,0	1,0	3,0	1,0
Presence of conserved sites	1,0	1,0	1,0	1,0	1,0	1,0
Ownership structure	1,0	1,0	1,0	1,0	1,0	2,0
Investment areas	0,0	0,0	0,0	0,0	0,0	0,0
TOTAL SCORE	**10,4**	9,3	**10,4**	**8,4**	**10,4**	9,4

The **assessment** was carried out **on six selected sites**, **evaluating** them for **their suitability for industrial production**, **residential use** and **green or renewable energy sites**. Scores were calculated based on **criteria** such as **soil contamination**, access to **infrastructure** and **environmental risks**, providing a comprehensive **framework for future development planning**. The **site labelled S2** (Sośnica_2) appears to be **the best option for the industrial and residential scenario**. In contrast, the **sites marked as S1, W1**, **B1 scored highest** for the **green or RES scenario**.

3.1.4. Conclusions and lessons learnt

In the case of **mining areas owned by PGG**, the **applied method** of **assessing the reclamation potential supports** the **decision-making** process regarding the **selection of the optimal reclamation direction**. This **increases the chances of utilizing the land according to the potential** shaped by the characteristics of both the land itself and its surroundings. The determination of the **target land use direction** must be **agreed upon with the municipality**, as it is responsible for shaping spatial order. Defining the **optimal land use method at an early stage of reclamation** (preferably before the land loses its current functionality) allows for the **planning of appropriate reclamation activities** that will enhance or maintain the identified potential for reuse. The reclamation of land after mining activities **aims to restore degraded areas to a usable or natural state**, benefiting the environment, local community, and economy. This process **requires a comprehensive approach**, including **technical**, **ecological**, and **economic analysis**, as well as active **cooperation with local authorities**. Early **identification of optimal actions** allows for **more effective resource management** and **minimization** of the **negative impacts of mining**, leading to **sustainable development of post-mining areas**.

3.2. Konin Basin Case Study

3.2.1. Main types of reclamation used in the Konin Basin

The **Konin Lignite Basin**, located in the Greater Poland Voivodeship, is a **significant** area **in the Polish mining and energy industries**, playing a crucial role in **supplying energy resources for decades**. It covers an **area around the cities of Konin and Turek** and encompasses the **Adamów Brown Coal Mine**, the **Konin**

Brown Coal Mine, the **Pątnów-Adamów-Konin power plant complex**, and various **associated facilities**. This region is characterized by **rich lignite deposits**, which formed the foundation of industrial activity and significantly influenced its economic development throughout most of the 20th century. Currently, **ZE PAK S.A.** is **responsible for** the operations of both the **Adamów and Konin mines**.

However, the **intensive exploitation of lignite** deposits has led to **substantial environmental degradation**, highlighting the **need for effective reclamation** actions following the cessation of mining activities. This chapter will present both the **general principles** and **goals of reclamation in the Konin Lignite Basin** and specific **examples of actions** taken **to restore ecological balance** in the region, such as the **reclamation efforts at the Jóźwin Open-pit**.

The **Adamów Brown Coal Mine** has a rich history of brown coal extraction, beginning in April 1959 when overburden removal and external dumping commenced at the Adamów open-pit mine. Over the years, lignite mining activities expanded to include three additional open-pit mines: Bogdałów, Władysławów, and Koźmin. Together, these operations have spanned an area of over 100.46 km², significantly influencing the region's industrial and economic landscape (Orlikowski, Szwed, 2011). The last functioning open-pit mine within the Adamów Brown Coal Mine was the Adamów open-pit, which ceased extraction in 2021. The extent of the open-pit areas included in the Adamów Brown Coal Mine is shown in Figure 6.

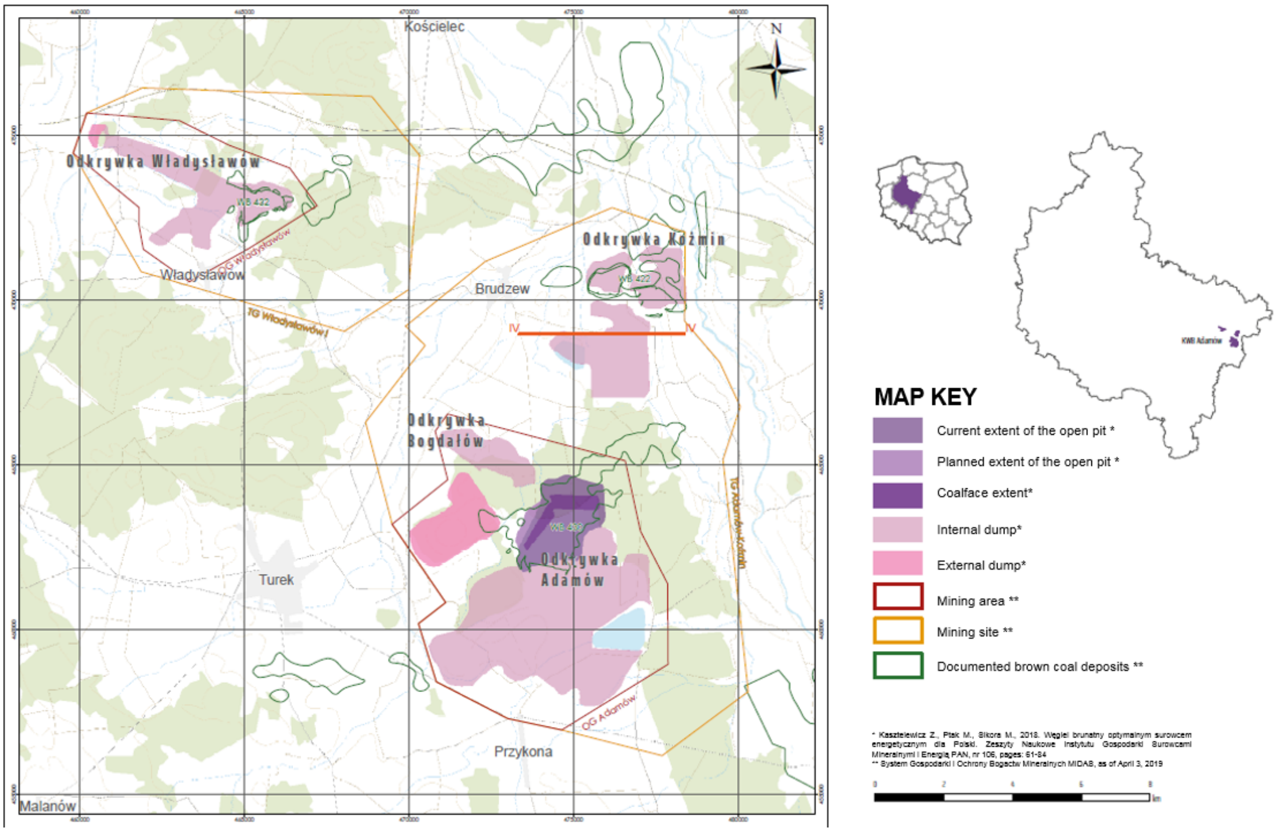

Figure 6. Extent of Open-Pit Areas in Adamów Brown Coal Mine (Kasiński J.R., et. al, 2019)

The **Konin Lignite Mine**, operated by KWB "Konin" in Kleczew SA, has a long history, having commenced operations in 1945. In 1999, the state-owned enterprise KWB Konin was transformed into a wholly state-owned company, which in 2012 became part of the ZE PAK S.A. Group. Over the decades, the Konin Brown Coal Mine has expanded its lignite mining operations across several open-pit mines, significantly impacting the region's industrial landscape. The chronological order of exploitation and closure of these pits is presented in table 11. Currently, open-pit lignite extraction is being conducted at the Tomisławice pit, with plans to conclude operations at this last pit by 2024.

Table 11. Open-Pits of Konin Lignite Mine Timeline (ZE PAK materials)

Open-Pit Mine	Start of Operation	End of Operation
Niesłusz	1945	1953
Gosławice	1953	1961
Pątnów	1958	1974
Kazimierz	1962	2001
Jóźwin	1965	2011
Lubstów	1971	1999
Jóźwin IIB	1982	2009
Drzewce	1999	2023
Tomisławice	2005	2023
Niesłusz	2010	2024

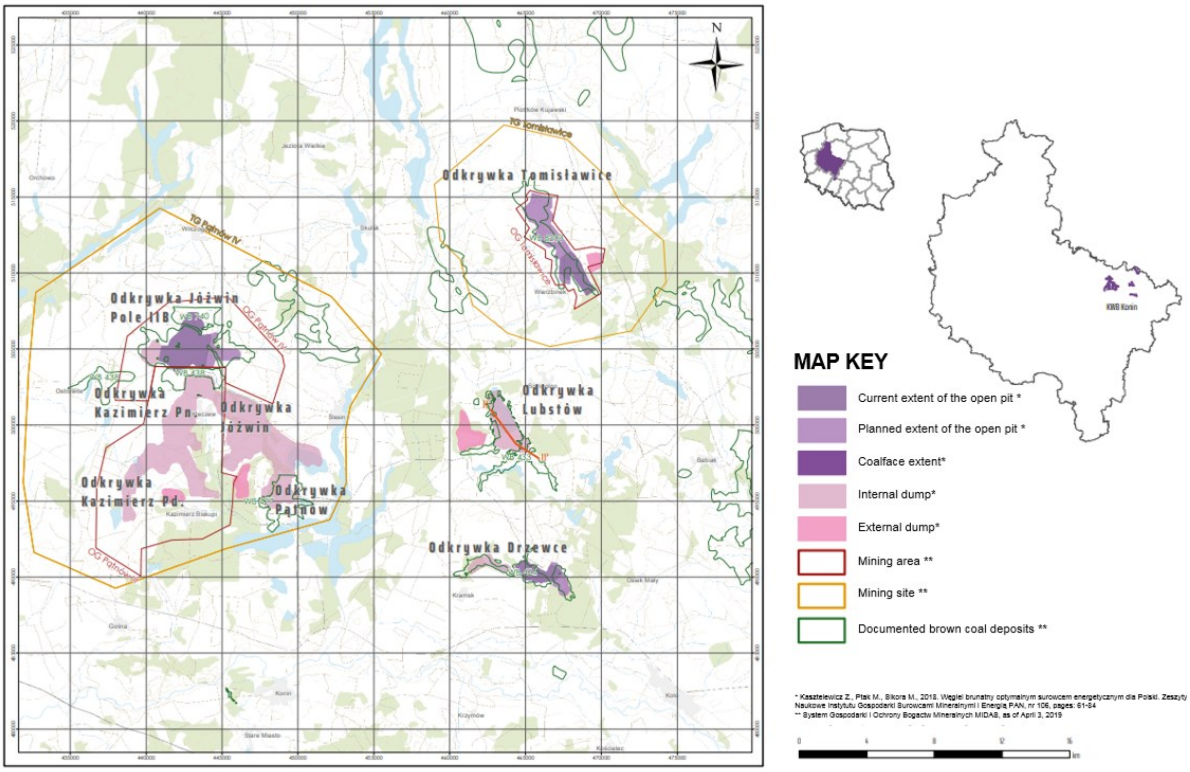

Figure 7. Extent of Open-Pit Areas in Konin Brown Coal Mine (Kasiński J.R., et. al, 2019)

The **main directions of reclamation** in the Konin Lignite Basin are diverse, aiming **to restore the land to various productive and sustainable uses**. These **primary reclamation directions** include **agricultural**, **forestry**, **water**, **recreational**, and other purposes. The **approach** to reclamation is **tailored to the specific characteristics and potential of the land**, ensuring that it can be **effectively repurposed** for future use.

As of **June 30, 2020**, a total of **1,155 hectares** of land has been **successfully reclaimed** in the **Konin and Adamów lignite mining areas**. The below chart illustrates the percentage share of each reclamation type among the reclaimed lands. The data indicates the **dominant share of agricultural reclamation**, followed by forestry and water reclamation. Recreational and other types of reclamation occupy smaller percentages.

There are **plans to reclaim an additional 5,617 hectares** of land across various types of reclamation. This includes the **reclamation activities scheduled for each mining site**, focusing on **transforming the post-mining landscape** into **productive and sustainable land uses** (Figure 7.).

To provide a **comprehensive view of the overall reclamation activities,** the combined areas of reclaimed and planned reclamation lands are presented below.

In summary, the **total land already reclaimed is 1,155 hectares**, while an additional **5,617 hectares are planned for reclamation**, bringing the **total to 6,772 hectares**. This extensive reclamation effort reflects a **systematic approach to addressing the environmental impacts of lignite mining** in the Konin Basin. The ongoing and planned reclamation activities encompass a variety of land uses. This **comprehensive strategy** not only **aims to restore ecological balance** but also to **ensure** that **reclaimed lands** can provide **sustainable benefits** for the local communities and ecosystems. The scale and diversity of these reclamation projects highlight the importance of coordinated efforts and long-term planning in mitigating the adverse effects of mining and promoting land recovery and productivity. The following sections of this chapter are dedicated to **detailed descriptions of the individual reclamation directions** utilized in the Konin Lignite Basin.

AGRICULTURAL RECLAMATION

In the **mid-1970s**, a **comprehensive approach to agricultural** and **forestry reclamation** was **developed**, known as **the Bender's target species concept or the PAN Model**. This method involves **introducing crop plants or forest species to post-mining lands** immediately after the surface leveling phase of technical reclamation. **Ensuring** these **plants grow and thrive** necessitates **correcting the soil's chemical properties** through **appropriate mineral fertilization**, tailored to the soil's characteristics and the nutritional needs of the plants.

Improving the **soil's physical properties** is equally **critical**. This is achieved **through mechanical cultivation**, which **enhances weathering** and **homogenizes the diverse soil mixture** present **in the region**. The **soil** here **consists of glacial loams** from the Warthe and Vistulian glaciations, **Quaternary sands**, **Poznań clays**, and **occasionally Miocene sands**, typically found in the overburden of the lignite deposits in the Konin-Turek Basin (Gilewska, Otremba, 2018).

When these **conditions are met**, crop **plants or forest species can effectively drive the soil formation process**, enhancing the **productivity of new ecosystems on reclaimed lands**. The concept supports the use of **various pioneer plants**, including **cereals**, **rapeseed**, **alfalfa**, and **forest species** like oak, ash, larch, and pine. However, **not all species are suitable for stable yields and desired growth**, hence the **selective use of certain plants**. **Post-mining soil** begins its **cultivation phase immediately following technical reclamation**. Through strategic reclamation practices, anthropogenic factors—key in this model—help adapt the soil to crop requirements, achieving dual objectives: transforming soil-rock into productive soil and producing valuable biomass. Initial **agricultural reclamation often results in crop yields** comparable to those from third-class agricultural soils. Figure 8 illustrates Bender's target species concept graphically (Gilewska, Otremba, 2018).

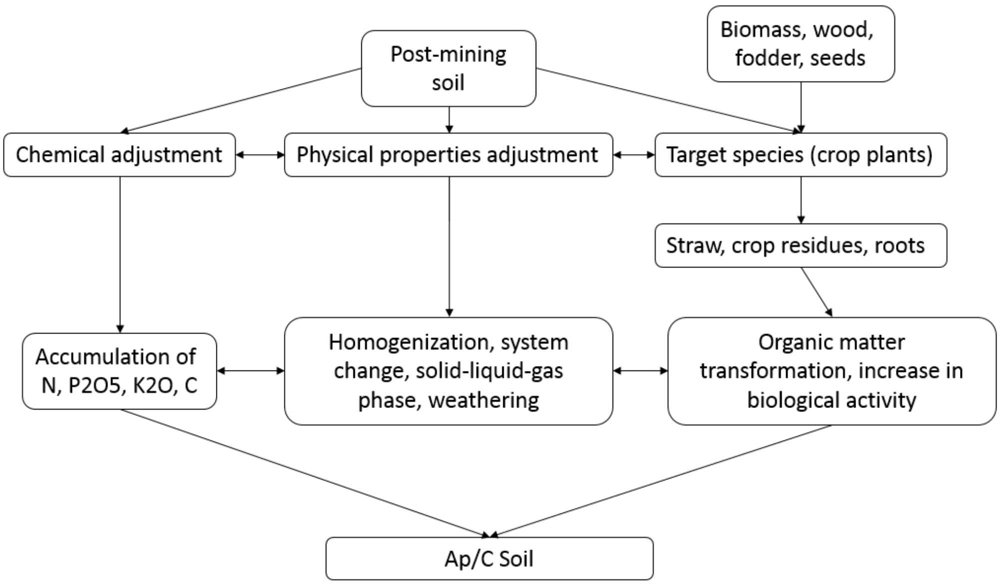

Figure 8. Scheme of Concept Ground Reclamation by Bender (Gilewska, Otremba, 2018)

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Agricultural reclamation in the Konin Basin is **one of the predominant methods**. This approach follows the **technology developed by Bender** and relies heavily on **human intervention** to **select and apply reclamation treatments effectively**. Over a period of **about 10 years**, the **extracted and deposited overburden**, consisting of materials from various geological epochs, **transforms into new, fertile soils**. These **reclaimed soils often surpass the quality of pre-mining soils**, which were primarily sandy. The **mining areas of Konin and Adamów** are **unique in Poland**, where agricultural landscapes dominate, with **alfalfa** being a **significant crop** in the region's **planting structure**.

FOREST RECLAMATION

The **basis for forest reclamation on post-mining lands in the Konin-Turek Lignite Basin** was established in 1976 with an **experiment on the internal spoil tip slope of the Kazimierz open-pit**. The **experimental plantings included** target species directly, bypassing the pioneer vegetation stage. The **selection of species considered soil properties**, **habitat requirements**, and **cultivation needs**. The **main** species included **European larch**, **pedunculate oak**, **Norway maple**, **sycamore maple**, **red oak**, **European ash**, and **small-leaved lime**. Additionally, **common beech and hornbeam** were included as **accessory species**, and **various shrubs** were used in the undergrowth (Gilewska, 2010).

The study aimed to **observe the development and success of these plantings** under **different mineral fertilization combinations**. Key **findings** from the research include (Gilewska, 2010):

- **Importance of Mineral Fertilization:** The study highlighted that adequate mineral fertilization, termed chemical adjustment, is crucial for the successful growth of trees and shrubs. Different combinations of fertilization were tested, including control (0 NPK), 1 NPK (200 kg N·ha-1, 100 kg P2O5·ha-1, 50 kg K2O·ha-1), and 2 NPK (400 kg N·ha-1, 200 kg P2O5·ha-1, 100 kg K2O·ha-1). Fertilization was applied over four years to ensure the development of a dense tree canopy and self-sustaining ecosystem within ten years.
- **Assessment of Plantings:** Evaluations conducted five years after planting showed a high success rate (approximately 93%) for most species, although European larch and pedunculate oak had lower success due to animal damage. Trees planted under 1 NPK and 2 NPK conditions exhibited the best growth, indicating the positive impact of mineral fertilization on tree development.
- **Species-Specific Observations:** The study found that while most species thrived, European ash (Fraxinus excelsior) showed poor performance and was prone to decline, likely due to its high nutrient and water requirements. Consequently, the proportion of ash in future reclamation projects was reduced from 40% to 10%. Preferred species for these projects now include pedunculate oak, red oak, European larch, and small-leaved lime.
- **Long-Term Outcomes:** Observations over 23 years indicated that the reclaimed land developed into a habitat similar to fresh forests with a mix of larch. The predominant forest-forming species were pedunculate oak, sycamore maple, European larch, and common beech. This mixed forest type sets a clear direction for future forest production and management, enabling the planning of cultivation activities throughout the production cycle.

The **forest reclamation** efforts in the Konin Basin **underscore the importance of species selection** and **mineral fertilizati**on. Adequate **nutrient supply promotes the growth** and **resilience of trees** and **shrubs**. On **clay-rich** post-mining **soils**, the resulting **habitat resembles fresh forests with European larch**. The **main forest-forming species** include pedunculate **oak**, **sycamore maple**, **European larch**, and **common beech**. **Establishing the forest type guides** the **overall forest production process** and serves as a **foundation for planning cultivation** activities, determining the composition of the tree stand, and scheduling silvicultural treatments.

WATER RECLAMATION

Water reclamation in the Konin Lignite Basin is a **crucial aspect** of post-mining land restoration, focusing on **transforming final pits into valuable water reservoirs**. This approach not only **addresses environmental concerns** but also creates **recreational and ecological assets for the region**.

The **process begins with** the **technical reclamation of reservoir slopes**, forming and profiling them to specific gradients to ensure stability and usability. The shoreline is designed with varied features such as small bays and shallows to create habitats for waterfowl. The **slopes undergo natural erosive processes** influenced by factors like lithology, slope gradient, wave intensity, and wind exposure, particularly from the dominant western winds. **To mitigate erosion**, particularly on eastern slopes, **biological reinforcement with erosion-resistant vegetation** is employed.

Flooding the final pits is one of the most **significant challenges**. It **involves several strategies** to ensure **effective water management** and **slope stabilization**. The process includes **maintaining a barrier of deep wells** for a period after the sump pump is decommissioned to reduce water pressure. **Vegetation** is used **to bind the soil and prevent erosion**, enhancing slope stability. During this phase, **water from ongoing deep drainage systems** is directed **into the pits to accelerate flooding**. This method is effective until the wells start drawing water from the forming reservoir. Afterward, the **process relies on rainwater and limited groundwater inflow**.

Reservoirs in regions with higher groundwater flow can fill relatively quickly, within a few years. Examples include Zatorze Lake (18.5 ha), Czarna Woda Lake (32.5 ha), Kozarzewek reservoir (65 ha), and Honoratka reservoir (360 ha). However, **filling large-capacity reservoirs** in watershed areas **can be prolonged**. Solutions include **diverting water from neighboring active pits**, as seen with the Bilczew field of the Drzewce open-pit, which was filled in a few years. The **Kazimierz Północ open-pit** was **filled in 11 years using water from the Jóźwin IIB pit**, **creating** the 522 ha **Kleczew reservoir**. **Similar techniques** were applied to the **Lubstów open-pit,** using **both deep well water** and **surplus water from the Noteć River**, achieving rapid filling of the 480 ha, **137 million m³ reservoir** (Nowak et al., 2024).

The **current challenge** is **flooding the Jóźwin IIB open-pit,** closed in 2023. Located in the watershed area of Biskupia Struga and Ostrowo-Gopło Canal, this pit has the **largest parameters among all Konin Basin pits** (840 ha, 240 million m³, and 68.7 m maximum depth). It **lies within the broadest depression zone of all exploited pits in the basin**, making its **reclamation a significant undertaking** (Nowak et al., 2024).

Table 12. Status and Characteristics of Post-Exploitation Reservoirs in Adamów and Konin Mines

Reservoir	Flooding status	Area at max. filling [ha]	Reservoir depth [m]
Adamów Mine			
Janiszew	Completed	60,0	
Głowy	In progress	91,5	24,5 - 40,5
Koźmin	Completed	121,0	4,0 - 10,0
Koźmin Końcowy	Completed (acceptance by the end of 2023)	131,0	31,8 - 45,8
Władysławów	In progress	109,0	39,0
Adamów Pośredni	In progress	105,0	28,7 - 37,0
Adamów Końcowy	In progress	309,0	24,5 - 37,5
Konin Mine			
Kleczew	In progress	550,0	63,7
Roztoka	In progress	19,0	9,0
Jóźwin	Planned	750,0	40,3 - 68,7
Lubstów	In progress	480,0	63,0 (S) - 55,0 (N)
Bilczew	Completed	41,0	21,5
Drzewce	Planned	160,0	19,0 - 41,0
Tomisławice	Planned	290,0	48,0

RECREATIONAL RECLAMATION

The **recreational reclamation** of post-mining areas has emerged as a **relatively new but rapidly growing approach**, **often integrated with water reclamation**. This trend has seen increasing interest from local municipalities, **leading** to the **development of various recreational projects** tailored to community needs.

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One **prominent example** is the **transformation of the Jóźwin IIA mine into a recreational center**. At the request of the Kleczew municipality, this area was developed into **the Park of Recreation and Physical Activity**, centered **around a water reservoir**. This park features **numerous facilities** aimed at **promoting active lifestyles** among residents.

Another significant project is the **water reservoir and its surroundings** on the **western side of Kleczew**, developed **from the final pit of the Kazimierz Północ mine**. This area is being prepared to serve both recreational and water-related activities.

The **Kazimierz Południe mine** has been **repurposed to include a sports field and a shooting range**. Part of this revitalized area has been taken over by the Konin Aero Club, which uses the favorable conditions for gliding and parachuting, highlighting the **diverse recreational opportunities that can arise from post-mining land**.

In the **former Morzysław mine area**, the **Park of the 700th Anniversary has been established**. This park, featuring **a small lake**, now includes **tennis courts,** a **sports hall**, a **playground**, and a **popular zip line**. These developments underscore the potential of post-mining areas to be repurposed into vibrant community hubs, providing various recreational amenities and contributing to the **overall well-being and quality of life** of the **local population**.

3.2.2. Legislative and financial framework of reclamation

Material production, which underpins the economic and civilizational development of societies, necessitates the use of resources, notably mineral resources provided by the mining industry. However, the **extraction, processing, and refinement of minerals** have **significant negative impacts on the environment**. The mining industry is therefore obligated to **undertake preventive measures to minimize these impacts** and remedial actions to **restore degraded and devastated areas** to their previous state or to repurpose them for new uses.

In Poland, a **comprehensive system of legal and financial regulations has been established** to ensure the **mining industry's compliance with environmental protection** and **remediation obligations**. The primary legal document governing these issues is the Geological and Mining Law of June 9, 2011 (Dz. U. 2011 No. 163, item 981), with subsequent amendments.

Mining activities are **also regulated by various other laws** that address the broad scope of **environmental** interactions, including the Environmental Protection Law, Nature Protection Law, Water Law, and laws on the protection of agricultural and forest lands, waste management, and the management of extractive waste. These regulations not only **define procedures** but also **secure the financial means to fund environmental protection and remediation projects** resulting from mineral extraction activities.

The **use of agricultural or forest lands for mining purposes** is strictly regulated by the Law on the Protection of Agricultural and Forest Lands of February 3, 1995 (Dz.U.1995.16.78 with amendments). This law imposes a range of **administrative conditions** and **financial compensations** for the conversi**on of biologically active lands to non-agricultural or non-forestry uses**. Annual fees for the exclusion of agricultural lands from production contribute to the voivodeship budget and are accumulated in a dedicated bank account. These **funds** are **used to protect, reclaim, and improve the quality of agricultural lands**, prioritizing projects in municipalities where the revenues are generated.

In addition to the aforementioned fees, **mining companies are legally required to restore or repurpose lands degraded or devastated by their activities**, i.e., to reclaim them. **Ongoing reclamation** is a part of **mining operation costs,** and **after mining activities cease**, the liquidation of the mine and the reclamation of remaining areas are **funded by resources accumulated during the mine's operation**. The legal and financial guarantee for fulfilling reclamation obligations is the mine closure fund (Naworyta 2013).

The Geological and Mining Law outlines **several forms of financial security** to cover the **costs of environmental remediation** resulting from mining activities:

- Securing claims that may arise from conducting activities covered by the concession.
- Providing security in case of non-performance or improper performance of concession conditions.
- Establishing a mine closure fund.

Additionally, the Act on Extractive Waste of July 10, 2008, requires entrepreneurs planning to construct **Category A waste disposal facilities** to provide a **financial guarantee or its equivalent to cover the costs of closing and reclaiming these facilities**. These financial securities must be available when obtaining the concession or the decision to build the waste disposal facility, except for the mine closure fund, which is accumulated systematically in relation to mineral extraction.

Negative impacts of mining on the environment can be **temporary or permanent**, with permanent changes typically manifesting as **land surface transformations**. The extent and scope of these **impacts vary depending on the extraction method**, with the **largest** typically occurring **in open-pit mining**. The Geological and Mining Law and the Act on the Protection of Agricultural and Forest Lands impose on entrepreneurs the **obligation of systematic reclamation of lands that become unnecessary for mining activities**. Final remediation of the impacts of mineral extraction is stipulated by Article 129(1) and (2) of the Geological and Mining Law, which mandates that **entrepreneurs must**:

- Secure or eliminate mining workings and installations.
- Undertake necessary measures to protect neighboring mineral deposits.
- Undertake necessary measures to protect the workings of neighboring mines.
- Undertake necessary measures to protect the environment and reclaim lands after mining activities.

The Geological and Mining Law of 1994, amended by the Act of July 27, 2001, introduced a **requirement for mining entrepreneurs** to **accumulate financial resources specifically for the closure of mining operations**. Prior to this amendment, the existing regulations did not adequately ensure the financial means for closing mines and remediating environmental impacts of mining activities. Both domestic and international practices have shown that this process is lengthy and costly, sometimes comparable to the investment required for building a similar mine. In a market economy, the unexpected need to close mines due to loss of profitability often left bankrupt enterprises without the necessary funds for closure. To prevent such situations, the requirement to accumulate financial resources in a special fund was introduced (Articles 128 and 129 of the Geological and Mining Law).

Currently, **lignite mining companies operating open-pit mines in the Konin Basin** are **required to allocate not less than 10% of the due exploitation fee for their open-pit operations**. The funds are accumulated in a separate bank account in the form of money, treasury bonds, or bonds issued or guaranteed by the State Treasury, and are increased by interest.

The **allocation of funds begins from the date the exploitation fee is due** and **ceases on the day the mine closure starts**. It is possible to create a fund for more than one mine (applicable to multi-mine enterprises). These funds are considered revenue costs under income tax regulations and can only be used to cover the costs of closing the mine or its parts, as well as unnecessary installations, facilities, or workings of the mine. Disbursement from the fund starts after the approval of the closure plan of the mine or its designated part.

The **introduction of the financial accumulation requirement** in the 2001 amendment **was not fully satisfactory** because it **began only from the extraction period and accumulated systematically throughout the exploitation period**. This approach would be justified if there were no cases requiring mine closure before the depletion of resources. In Poland, an additional reclamation fund has been created by some mines to address these needs. For example, lignite mines such as Konin and Turów, finding the 10% exploitation fee insufficient, established additional reclamation funds (Uberman, Nawrota, 2015).

To illustrate the financial commitment to reclamation, from January 1, 2010, to June 30, 2020, ZE PAK S.A. spent a total of 56,105.60 thousand PLN on reclamation activities, with 23,057.00 thousand PLN allocated to PAK KWB Adamów and 33,048.60 thousand PLN to PAK KWB Konin.

Additionally, in 2023, **ZE PAK S.A. announced an increase in the reclamation reserve**. This reserve pertains to the mining segment and is associated with the exploitation of lignite open-pits and the estimated costs of reclaiming post-exploitation areas. The **basis for increasing the reserve is** a report prepared by an independent advisor on the costs of reclamation and land use after mining operations. This reserve ensures that funds are available to cover the costs of reclamation for areas that have completed or will soon complete mining operations.

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3.2.3. Main types of reclaimed soil

In the **Konin Basin**, the **extraction of brown coal** through open-pit mining **results in significant soil disruption**. This process involves **establishing a drainage barrier at least two years before excavation begins.** The **overburden covering the coal** is then **removed and deposited next to the excavation**, forming an **external spoil tip**. As mining progresses, **subsequent overburden layers** are typically **deposited in previously excavated pits**, creating **internal spoil tips**. The **final pit in a sequence** is usually **repurposed as a water reservoir for tourism and recreation**. Occasionally, **ash clarifiers from power stations are placed in these end pits** (Mocek-Płóciniak, 2016).

The **spoil tips in the Konin Basin** primarily **consist of a mixture of Quaternary and Neogene bedrocks**, including **glacial loams** from the Warthe stage and Vistulian glaciation, **Quaternary sands**, and **partially Poznań clays and Miocene sands**. These **diverse geological materials** result in **post-mining soils** that **typically exhibit favorable granulometric and mineralogical compositions**. Additionally, the **soils** possess an **alkaline or neutral pH** due to the **presence of calcium carbonates**, and **average potassium levels**. The **unique organic matter** contributed by the **admixture of brown coal further enhances soil quality** (Gilewska, 2008; Otremba and Gilewska, 2013).

3.2.4. Current methodology for the implementation of individual types of reclamation in Jóźwin Open-pit

Reclamation activities conducted as part of the **closure of PAK Kopalnia Węgla Brunatnego Konin S.A. – Jóźwin open-pit** provide a **significant example of the reclamation** processes managed **by ZE PAK**. The areas designated for reclamation are highlighted in Figure 9, illustrating the scope and organization of the reclamation efforts.

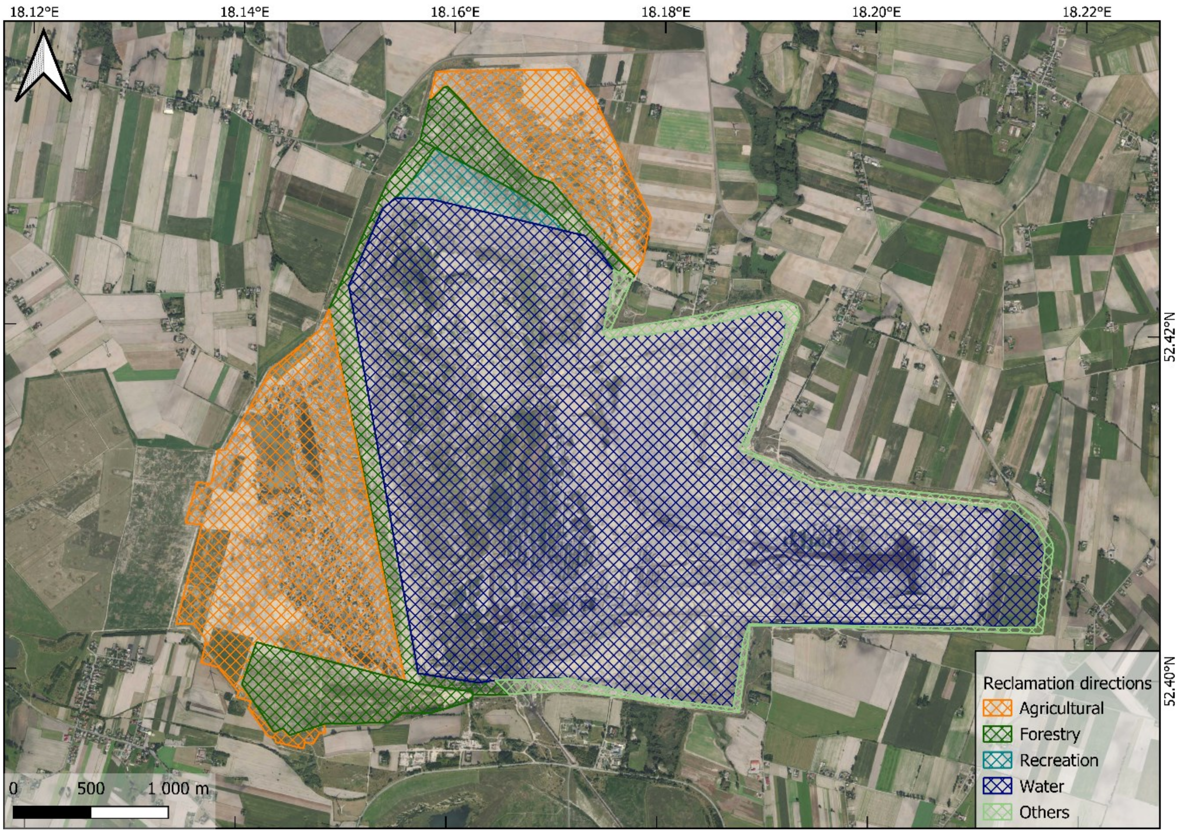

Figure 9. Reclamation Directions for Jóźwin Open-pit Area

3.2.4.1. Technical Reclamation

Technical reclamation involves mining operations such as **moving earth masses and profiling the internal spoil tip** to match the surrounding, undisturbed terrain. It also includes **shaping and profiling the slopes** of the final pit for the projected Jóźwin water reservoir. **Specific tasks** include:

- Moving earth masses on the internal spoil tip.
- Profiling the internal spoil tip.
- Shaping and profiling the final pit slopes.
- Constructing reclamation access roads to agricultural reclamation fields.
- Building forest tracks for reclamation purposes.
- Creating perimeter ditches to channel rainwater to existing receivers.
- Constructing perimeter ditches around the reservoir and outflow ditches to direct rainwater to the pit as needed.
- Building a reclamation road around the pit.
- Conducting earthworks on undisturbed areas adjacent to the internal spoil tip and final pit.
- Additional tasks include building access roads to the internal spoil tip, restoring existing and creating new perimeter and drainage ditches, providing technological equipment for biological reclamation, and rebuilding municipal roads.

3.2.4.2. Biological Reclamation

Biological reclamation **focuses on restoring the land to productive and sustainable uses**, encompassing **agricultural, forestry, recreational, and water purposes**. Each type of reclamation is **tailored to** the specific **characteristics and potential of the land**.

Agricultural reclamation aims to convert former mining areas into fertile fields, **forestry reclamation involves** planting trees to create forests, **recreational reclamation prepares** the land for leisure and sports activities, and **water reclamation transforms** pits into reservoirs for various uses, such as recreation and water management.

AGRICULTURAL RECLAMATION

Agricultural reclamation involves **agro-technical procedures** and **sowing of mineral fertilizers** and **seeds of grasses** and **leguminous plants**. Activities include:

- Medium plowing.
- Cultivation or loosening with a heavy disc harrow.
- Sowing mineral fertilizers (160 kg N/ha, 140 kg P2O5/ha, 100 kg K2O/ha).
- Harrowing with a heavy harrow.
- Sowing grass and leguminous plant seeds (5 kg/ha cocksfoot, 30 kg/ha alfalfa).
- Harrowing with a light harrow.
- Removing stones from the sown area.
- Rolling with a light roller.

FORESTRY RECLAMATION

Forestry reclamation involves **afforestation of the internal spoil tip** and **designated final pit slopes by planting forest-forming tree** and **shrub species**, such as:

- European larch.
- Scots pine.
- Pedunculate oak.
- Sessile oak.
- Small-leaved lime.
- Sycamore maple.
- Common maple.
- Beech.
- Hornbeam.
- Silver birch.
- Black locust.

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- Black alder.
- Blackthorn.
- Myrobalan plum.

Mineral fertilization and maintenance work is carried out over four years.

RECREATIONAL RECLAMATION

Recreational reclamation also involves **agro-technical procedures** and **sowing of mineral fertilizers** and **seeds of grasses and leguminous plants**, similar to agricultural reclamation. Specific procedures include:

- Medium plowing.
- Cultivation or loosening with a heavy disc harrow.
- Sowing mineral fertilizers (160 kg N/ha, 140 kg P2O5/ha, 100 kg K2O/ha).
- Harrowing with a heavy harrow.
- Sowing grass and leguminous plant seeds (5 kg/ha cocksfoot, 30 kg/ha alfalfa).
- Harrowing with a light harrow.
- Removing stones from the sown area.
- Rolling with a light roller.

WATER RECLAMATION

Water reclamation involves the **formation of the Jóźwin water reservoir**. Key parameters of the reservoir include:

- An average water level of approximately +93 m above sea level.
- Water surface area of about 840 hectares.
- Depths ranging from 43 to 69 meters, depending on the final pit bottom contour.
- Capacity of around 240 million cubic meters.

Various **options for filling the final pit with water** are being **considered to** ensure **optimal and efficient use of the reclaimed area**. These methods **aim to balance** environmental, practical, and economic factors to achieve the best outcome for the Jóźwin water reservoir.

- **Variant I:** Natural filling from the reservoir's own catchment area, including infiltration of groundwater and surface runoff.
- **Variant II:** Using deep drainage water from the Jóźwin pit, previously applied in the Lubstów reservoir.
- **Variant III:** Water transfer from the Warta River via Gosławskie Lake, reducing the filling time from 35 to about 10 years.

Combining all three methods **may reduce the filling time to approximately 8 years**.

Agro-technical procedures are carried out **on areas designated for seeding and turfing** to **protect slopes against erosion**, including:

- Cultivation or loosening with a heavy disc harrow.
- Sowing mineral fertilizers (160 kg N/ha, 120 kg P2O5/ha, 90 kg K2O/ha).
- Harrowing with a heavy harrow.
- Sowing a mix of grasses and leguminous plants (25 kg/ha red fescue, 20 kg/ha reed fescue, 25 kg/ha perennial ryegrass, 20 kg/ha white clover, 10 kg/ha alfalfa).
- Harrowing with a light harrow.
- Removing stones from the sown area.
- Rolling with a light roller.

During reclamation, **mine water is used** to fill the final pit of the Jóźwin open-pit. **Excess mine water** is **directed through ditches to surface watercourses** and further **to Konin lakes or nearby rivers**. **Continuous monitoring** of the water environment is maintained, with data compiled annually in a hydrological-meteorological yearbook.

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3.2.5. Evaluation of current reclamation schemes in the Konin Basin

The Konin Lignite Basin, a **crucial area in the Polish mining and energy industries**, has **undergone extensive reclamation efforts** to **mitigate the environmental impacts of lignite extraction**. The reclamation activities have been **systematically planned and implemented** across various sites within the basin, covering agricultural, forestry, water, and recreational reclamation.

Agricultural reclamation in the Konin-Turek Lignite Basin has **proven to be highly effective**. This method has primarily focused on **converting** post-mining lands **into fertile agricultural fields**. The **introduction of the Bender's target species concept** has played a significant role in this process. The use of **appropriate mineral fertilization** and **mechanical cultivation** has **transformed** overburdened lands **into productive soils within a decade**. The **reclaimed soils** often **surpass the quality of pre-mining soils**, which were **predominantly sandy**, demonstrating the success of this reclamation approach.

Key **achievements in agricultural reclamation** include:

- High crop yields comparable to third-class agricultural soils.
- Successful introduction of various crops enhancing biodiversity.
- Effective soil transformation through the integration of glacial loams, sands, and clays, improving soil structure and fertility.

However, continuous **monitoring and adaptive management are essential** to **maintain soil health** and **productivity**, especially in the face of changing climatic conditions and evolving agricultural practices.

Forestry reclamation has also been a significant focus. This method aims **to establish stable forest ecosystems on post-mining lands**. The experiment initiated in 1976 at the Kazimierz open-pit provided valuable insights into the selection of tree species and the importance of mineral fertilization. The **high success rate of tree plantings, particularly** under **optimal fertilization** conditions, **underscores the effectiveness of this approach**.

Key findings from forestry reclamation include:

- High survival rates (approximately 93%) for most tree species.
- Enhanced growth and development of trees under mineral fertilization regimes.
- Establishment of mixed forests resembling natural fresh forests, contributing to long-term ecological stability.

However, species-specific challenges, such as the **poor performance of European ash**, highlight the **need for careful species selection** and ongoing **research to optimize forest composition and health**.

Water reclamation has **transformed** several final pits **into valuable reservoirs**. These water bodies serve **multiple purposes**, including **ecological restoration**, **water management**, and **recreational uses**. The **technical reclamation** of reservoir slopes, **combined with biological reinforcement**, has ensured the **stability and usability** of these areas.

Key outcomes of water reclamation include:

- Successful creation of reservoirs like the 522 ha Kleczew reservoir and the 480 ha Lubstów reservoir.
- Development of varied shorelines to support waterfowl habitats and enhance biodiversity.
- Implementation of effective flooding methods, such as using deep drainage water and diverting water from neighboring active pits, to accelerate reservoir filling.

Despite these successes, **challenges remain in managing erosion**, ensuring **water quality**, and maintaining **ecological balance**. **Continuous monitoring** and **adaptive management** strategies are essential to address these challenges and optimize the benefits of water reclamation.

Recreational reclamation, though a newer approach, has shown **promising results**. This method focuses on **transforming** post-mining landscapes **into areas suitable for recreational activities**, benefiting local communities and enhancing the quality of life.

Key achievements in recreational reclamation include:

- Development of parks and recreational facilities, such as the Park of Recreation and Physical Activity at Jóźwin IIA.
- Creation of sports fields, shooting ranges, and other amenities on former mining sites.
- Integration of recreational and water reclamation, providing multifunctional spaces for community use.

These projects have **successfully repurposed degraded lands** into **vibrant community hubs**. However, ongoing **maintenance**, **community engagement**, and **adaptive management** are crucial to ensure the long-term sustainability and success of recreational reclamation projects.

4. SLOVENIA SITUATION

4.1. Slovenia case study

Case study areas of Slovenia are linked to **gradually closed mining areas**. The gradually closed **Velenje mine** is a source of **brown coal for the Šoštanj power plant**. It is a **deep mine**, which leads to **different reclamation problems than in other case areas**. The area of interest is a large part of the **Šaleška valley** exposed to **extensive terrain subsidence**. These declines are of varying intensity due to the different mining methods and the size of underground spaces. So far, the **level of the bottom of the Šaleška valley** has **fallen by up to 100 m** in the most threatened areas. A **large part** of the sunken area was **flooded with water**, thus **creating three lakes** of the Šaleška valley with levels at different altitudes. This situation places **high demands on rehabilitation, recultivation** and **revitalization works**.

4.2. Main types of reclamation used in Slovenia coal regions areas

Despite there where several mines in Slovenia in the past we can basically talk about **two main regions** which are still today **affected by recultivation and rehabilitation of degraded areas**.

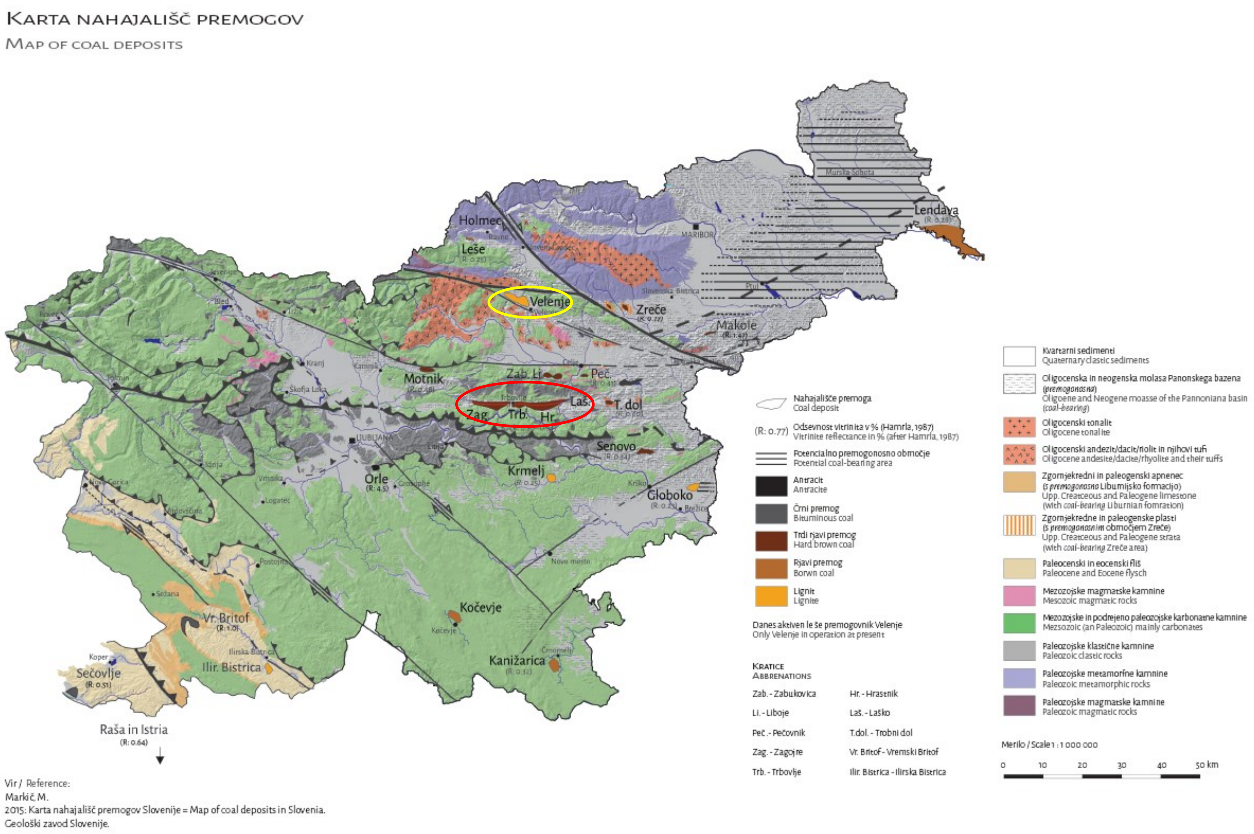

Figure 10. The two main regions where rehabilitation and reclamation of mine surfaces are carried out: Zasavje Coal Region-red ellipse and Šaleška Velly Region-yellow ellipse; Map of coal deposits in Slovenia; (M.Markič, GEOLOGICAL SURVEY OF SLOVENIA, 2015)

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One is Zasavje Coal Region. The exit from coal has started in 1999 when referendum results did not support the construction of the third unit of Trbovlje Thermal Power Plant (hereafter: TET). As the business logic of the near-by Trbovlje-Hrastnik coal mine (hereafter: RTH) was closely connected with TET, the decision to close the mine was made. At the request of the Government of the Republic of Slovenia, the leadership of RTH published a study, which estimated the costs of closing the RTH by the end of 2015. The **assessment** was **based on** the conceptual designs of **existing methods of mine closing** and **ecological and spatial remediation of the surface**. In 2000, the **Act of Regulating Gradual Closure of Trbovlje-Hrastnik Mine and Economic Restructuring of the Region was adopted** (and later amended). In 2005, the closure works started and in 2013, the mining activities stopped. Shortly after, the TET closed as well.

In **2020**, all necessary **closure and rehabilitation works** were carried out. Due to a larger than foreseen scope of works and costs in the medium-term program, some less-necessary closure and rehabilitation works have remained - mainly in the field of infrastructure renovation. Open cave areas (approximately 10 km) will remain open even after the mine is cleared. In addition to the basic purpose (drainage), remaining open underground mine spaces can also be used for other economic purposes (e.g., tourism). **Technical monitoring of the remaining parts of the mine and surfaces** is currently being carried out, and maintenance of the rehabilitated mine surfaces is also underway. The same applies to other mine-related facilities, which have been placed in spatial planning documents of the local government. There are still **regeneration and repurposing of land activities needed** which include mostly:

- decontamination of areas, which were degraded in the coal mining activities, and
- rehabilitation of those locations, to make them ready for future brownfield development on the locations.

Rehabilitation methods and approaches was **mostly** carried out by **levelling degraded** (subsidence, cracks) **terrain**, **greening with plants** and building **water infrastructure for drainage**.

We need to **consider the geotechnical characteristics and stability** of these areas

The second mining region is Šaleška Valley region (hereafter: SA) where U/G **coal mine Premogovnik Velenje** and nearby **power plant TEŠ** are still operating.

At SA respectively Velenje case, we need to highlight that the lignite extraction technology in the Velenje 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 the trenches**. Due to the large number of excavation floors (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** and **over a long period of time**. **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**. The area of active **ongoing subsidence rehabilitation** (PSU) 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) in construction projects**.

In the mining area, we have **three artificial** (caused by mining) **lakes**, which are **Lake Škale**, **Lake Velenje** and **Lake Družmirje** (Šoštanj). Whole area of lakes is **approximately 290 hectares** which is **26 % of mining area**. **Rest** of the surface of mining area are mostly **farming land and forests**. Operation of coal mine is technically drafted until year 2047 but by national strategy end year of coal production is scheduled by end of 2033.

4.2.1.1. Differentiation of recultivation according to stage

Technical reclamation

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 o**f 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**. Security measures include **maintaining the level of the terrain** in the **area between Lake Velenje and Družmirje Lake at a sufficient average terrain angle**, constant **monitoring** of the situation in the form of **daily patrols**, physical **closure of degraded areas if necessary**, and a **system to act in case of possible dangers** is also in place.

Temporary recultivation

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**.

Biological reclamation

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.

4.2.1.2. Differentiation of reclamation according to use

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** (hereafter: **PSU**), 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**.

Area of subsidence's between lakes (PSU)

The **PSU area**, where **remediation** is carried out by **pre-filling the terrain** and fillin**g in the resulting subsidence by incorporating the by-products of electricity production in TEŠ**, is located **between Lake Velenje and Lake Družmirje** and measures around 50 hectares.

The **area** is **located above the still active part of the Pesje pit**, where lignite mining causes **surface subsidence** (up to 8 meters per year) and the appearance of cracks. By filling the subsided areas, **the initial elevation of the terrain is maintained** and thus **prevents the PSU terrain from sinking below the level of the Lake Velenje**, whose lake level is at an angle of +366.5 m above sea level. This als**o prevents the merging of two lakes** that have a surface at different altitudes. The difference in lake levels is 6.5 meters.

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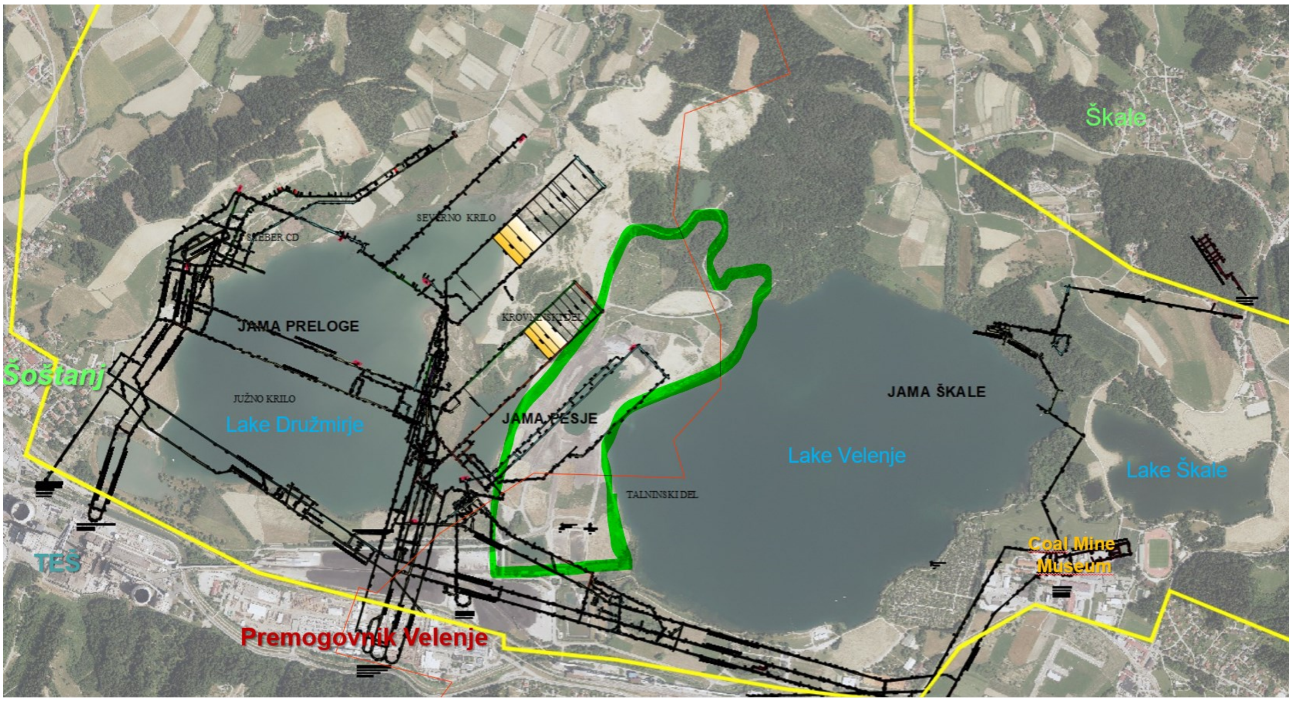

Figure 11. Subsidence remediation area PSU-within the green polygon. Black lines are underground mining objects. (Original PV archive)

Filling subsidence at PSU area **wastes from nearby power plant are used** which is **called Stabilizer** and is a **by-product from power plant TEŠ**. Stabilizer is a **composite of fly-ash**, **slag**, **gypsum** and **various sludges** as a construction composite for backfilling mining subsidence. **Small amount of other material** mostly from mine and nearby construction sites (e.g. roads, tunnels building) are **also installed at PSU** and are:

- inert materials in coal extraction,
- earth excavations from construction works,
- artificially prepared soils,
- fillers during the construction of buildings and
- other building materials.

To maintain the western sealing dyke, **clay material is installed in layers**, which is transported from other parts of the mining area.

Surfaces that sink and are filled in and access routes must be **wetted with water** to such an extent that **dusting** of the surroundings is **prevented**. Wetting of surfaces is **carried out with cisterns** and/or **using a pipe irrigation system**. Dusting prevention is **also caried out by seeding grass** where suitable.

Subsidence's are **daily filled with materials** as **subsidence**, **cracks** etc. are continuously occurring due to excavating coal in Velenje Coal Mine in pits under PSU – mine faces. This will not change until the mine is operating.

Agricultural reclamation

After technical remediation parts of degraded surfaces **that do not have fertile soil on top** are **covered with** at least 20 cm of **fertile soil**. These areas are **sown with grass**, **native shrubs** and **trees are planted**, in **accordance with the planting plan**, which brings its final appearance as close as possible to the original condition and surroundings.

Forest reclamation

Rehabilitated areas, on which there **was a forest before the intervention** (the impact of mining), are generally established (where the areas were not flooded, and lakes formed) **into forest areas**. Based on the municipal zoning acts, which are drawn up for the mine area in cooperation with Velenje Coal Mine, **the intended use after**

mining is completed is also **determined** based on **the mining rehabilitation and recultivation project**. Thus, **forest areas can** also be **recategorized into another purpose**.

Hydric reclamation

Watercourses that are **under the influence of mining** are maintained to such an extent that they **merge as much as possible with the surroundings and other parts of the watercourses**. **Before** the subsided part of the terrain **is flooded by the water of the lake**, the **fertile upper layer of the soil is removed**, which is **used for rehabilitation in other parts** of the mine area. **Streams and lakes in the mine area** are **maintained** in accordance with the **guidelines of the water management community and spatial acts**.

Natural succession

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**.

Other reclamation

Other examples of remediation are the **remediation of damage to residential buildings** on the outskirts of the mining area. Renovation mainly covers **minor repairs** (fixing of minor cracks on the building or minor rehabilitation of the building structure) on buildings.

4.3. Legislative and financial framework of reclamation

The Mining Act and The Concession (mining) Contract **oblige The Velenje Coal Mine to carry out rehabilitation** while excavating coal and **final rehabilitation** where feasible.

The **handling of materials used for the rehabilitation of mine surfaces** is elaborated in more detail in the Rules of Procedure on the handling of materials in the rehabilitation of subsidence areas, issued by Velenje Coal Mine and Thermal Power Plant Šoštanj and mining projects for the rehabilitation of mine surfaces.

Mining regulations require that **where possible initial state before mining** is established.

Influence to **recultivation and its framework** has also so called **Municipal Spatial Plan (OPN)** which can be basic one or detailed one. It consists of requirements and approval of different **affected parties such as agriculture and farming, forestry, fishing etc**. In several cases there are also requirements that **associated infrastructure must be established** (e.g. access roads). OPN can also be changed where most usually municipalities are trying to implement their demands and they set future use of land. The price of individual types of reclamation in Velenje Basin per hectare is given in the following table.

Table 13. Price/unit of types of reclamation in the Velenje (Šaleška) Basin

Type of reclamation	Price/unit (EUR)
Filling subsidence with by-products and Earth excavation material – temporary reclamation	1.200.000 – 1.800.000 annually 23.000 – 35.000 EUR/1ha
Temporary reclamation and terrain maintenance	500.000-600.000 annually
Final reclamation	50.000-100.000 annually

4.4. Applied research methodology

Methodology of field work

The **PSU area** (in the Figure below), where **temporary reclamation** is carried out **by pre-filling the terrain** and **filling emerging subsidence** by incorporating by-products of electricity production in TEŠ and other materials, is located **between Velenje and Družmirje lakes**. The PSU area lies within the extraction (mining) area of PV on an area of approximately 50 hectares. The area is located **above the still active part of the Pesje PV pit**, where due to the underground mining of lignite, **the surface is subsiding** (up to 9 meters per year), and **cracks are appearing**. By **filling in the sunken areas**, the **initial elevation of the terrain is maintained** and thus **prevents** the PSU **terrain from sinking below the level of the Lake Velenje**, whose lake level is at +366.5 m above sea level.

Figure 12. Subsidence remediation area of PSU (area of filling subsidence with stabilizer and other suitable materials - within the green polygon. Surface area approx. 50 hectares. (Source archive PV)

In accordance with the **Slovenian mining legislation**, the **concessionaire** is obliged to **ensure and carry out reclamation of the degraded area of the mining area** at the same time as coal mining and **parts where mining is finished final reclamation must be done**. The coal extraction technology in PV is carried out using the Velenje Mining Method[1], which results in **the settlement of the overlying layers** and thus the **formation of surface subsidence**. In **flat areas**, the resulting **subsidence is flooded by water** in such a way that these areas are **permanently excluded** in the sense of primarily **agricultural or other land use**.

The total amount of material for filling subsidence at PSU is up to approx. 700.000 m^3 annually.

With the **stabilizer**, we **make embankments** and **access roads** and **fill the resulting subsidence** or **upgrade** (raise the terrain level) **areas that will subside later**. The stabilizer is installed **in accordance with the requirements of the Slovenian Technical Agreement (STS)**, the technological study prepared by the contractor and the mining project for the rehabilitation of subsidence at PSU. The process of loading, transporting, installing stabilizer and other materials into subsidence on the PSU and other works related to the ongoing rehabilitation of the PSU are process related. Subsidence filling **areas** at the PSU, which are **not filled in or are not exposed to the destructive influence of coal mining for a long time**, are generally **covered with soil and grassed**. Where it makes sense, we also **plant shrubs and trees** with the aim of **preventing dust from rising** and arranging the space on the fly.

Temporary and final **reclamation of other parts** (**other than PSU area**) of the PV mining area covers a wide range of several **different types of work, including**: removal and maintenance of vegetation including the removal of invasive alien plants, removal and deposition of humus soil, leveling of terrain, grading of degraded land, rehabilitation of cracks, loading, transportation and grading of excavated soil, machinery excavation of ditches, construction and maintenance of drains, arrangement and maintenance of access routes and

[1] Special method of long wall top coal caving

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watercourses, installation of material in cracks and depressions, temporary rehabilitation of cracked surfaces, rehabilitation and maintenance of roads and paths, liquidation of communal lines, removal of buildings and infrastructure, etc.

Maintenance in the form of mowing, **care of plants**, especially shrubs and trees, as well as maintenance of **watercourses**, **roads**, **paths and drainage** is carried out on the **surfaces under which mining has been completed**.

4.5. Main types of reclaimed soils and methods of their reclamation

TEŠ stabilizer

The basic building block for filling subsidence and for pre-filling PSU is Stabilizer TEŠ. **Stabilizer TEŠ** (hereinafter Stabilizer) is a **mixture of products from the production of TEŠ**, determined by the Slovenian technical consent **STS-07/031: "Composite from electro filter ash, slag, gypsum and various silts - as a construction composite for backfilling when filling mine subsidence"**. **Ash** is a product of **coal combustion**, and **gypsum** is a product of **flue gas desulfurization in TEŠ**. The annual available amount of this material, which will need to be installed on the PSU in one year, amounts to approx. 400,000 tons.

Other materials

The following **materials can also be used in the PSU area** to **rehabilitate subsidence** by filling the subsidence and before backfilling:

- inert mining materials,
- excavations from construction works,
- artificially prepared soils,
- fillers in the construction of buildings and
- other suitable construction products as needed.

The **material for reclamation of other parts** (other than PSU area) of the PV mining area is **mainly the parent soil**.

Methodology of forest reclamation

Forest areas, where they **were before the felling of trees and** the **removal of vegetation due to mining**, are **restored to forest areas** by **planting native species**, in accordance with the **reforestation plan**, which is part of the mining rehabilitation project.

Methodology of agricultural reclamation

Damaged agricultural land that is **not flooded with water** is **rehabilitated** by **leveling cracks** and **depressions**. The **parent soil is used** for this.

Methodology of hydric reclamation

Watercourses are rehabilitated in such a way that they **come as close as possible to the previous and surrounding condition** of the watercourses.

Methodology for establishing areas left to natural succession

Natural succession is **hardly used in Slovenia**.

4.6. Some practical results of recommended methodology – application of fertilisable soils

In the past, depressions created **by mining and flooded with water** were **filled with fly ash**.

The oldest one, the **Škale lake** came into existence at the beginning of the 20th century. Due to **a lot of pollution sources** in the watershed in the past (mostly organic pollution) the **lake is meromictic**. The lowest (hypolimnic) water layer of the lake never mixes, and it contains H2S and that is why in the summer oxigene layer is only 6 m thick. In scope of **recultivation sewage system** in the **watershed was build**, landfarming on the lake shore become less intensive and the communal waste landfill pollution was reduced to minimum. **Today** lake is used **mostly for fishing purposes**.

Figure 13. The Škale lake today

Velenje lake, which is the **biggest one by surface**, came into existence after WWII. **At the beginning** of its existence, it was used as a **reservoir for ash and ash transport water from the Šoštanj thermal power plant**. The **pH of transport water** was **approx. 12** and so was **pH of the lake**. Therefore, **lake was "dead"** as **none of organisms could survive** in such an alkaline environment. In the **early 80s** ash landfill was build but transport of **water run was still pumped into the lake** and its **pH still remained 12**. Finaly closed loop system for the fly ash was built in 1994. In only three years the **lake quality has almost been normalised**. What stayed, was **too many nutrients entering into the lake**. In **next year's lake stabilised** and **today** this is **one of the best onshore swimming resorts in Slovenia**. Today the lake covers an area of **approximately 1.4 square kilometres**.

Figure 14. Velenje lake in the past (filled with fly ash and had high pH)

Figure 15. Velenje lake today

Figure 16. Spreading of stabilizer in layers

Figure 17. Filling sinkholes with fly ash

Figure 18. Maintenance of the irrigation system

Figure 19. Rehabilitation of the western sealing dam

4.7. Conclusion and lessons learnt

The reclamation of Slovenian localities is specific, it is always **reclamation after deep mining of brown coal**. The described **reclamation schemes and the achieved results confirm their success**. Based on the solution of the REECOL project, **the implemented methodologies will be supplemented with ecological aspects** and **the effects of climate change**.

5. GREECE SITUATION

5.1. Main types of reclamation used in the Greek coal regions areas

The PPC is **the leading power generation and supply company in Greece**, and it is engaged in **generating**, **distributing**, and **selling electricity to consumers**. PPC **lignite mines in West Macedonia Lignite Centre** (WMLC) and **Megalopolis Lignite Centre** (MLC) provide **lignite for power generation**, the most important energy source for the Greek economy. **Lignite** is mined by the PPC **exclusively in opencast mines**. It has operated **mines in Western Macedonia in the Ptolemais area** (Main Field, South Field, Kardia Field) and **Florina** (Amyntaio Field). PPC also has an **opencast site in the Peloponnese region of southern Greece**, in the **Megalopolis Field** (Public Power Corporation, 2021).

Amyntaio Lignite Field is located in **Florina Prefecture in Western Macedonia**, North Greece. Public Power Corporation **(PPC) has exploited three lignite deposits** in this area, **Anargiroi**, **Amyntaio** and **Lakkia**. **Amyntaio** deposit was **the largest** among the three, with exploitable reserves of 200 million tonnes and supported a 600 MW lignite-fired power plant for about 30 years. **Amyntaio Lignite Field** is currently **an exhausted mine** and many **geotechnical and hydrogeological parameters affect the** specific **area**. **Due to the** exhausted **mine geometry**, there is an **extended and deep area** which is about **to be filled with water during the development of the lake**. At the early stages of the lake's first phase development, the lake's surface expands rapidly, while in the last phase it expands very slowly. There is a **necessity for the gradual rehabilitation of the mine slopes and the surrounding area during the lake development** in the following years (Public Power Corporation, 2021).

In the framework of **mines' rehabilitation**, the following **actions** have **already** been **employed**:

- 112.5 ha at the Ptolemais and Amyntaio mines were planted with trees in 2021.
- Completion of landscaping works at the Amyntaio mine for soil reclamation to help prepare sites for the installation of photovoltaic parks of ~940 MW.
- Ratification of the Framework Agreement of Article 155(4) of Law 4759/2020 covering 9,700 hectares to be reclaimed by PPC to the Greek State by 2025 - ~40% of the hectares will be handed over by the first half of 2023 for new uses.
- The Framework Agreement of Article 155(3) of Law 4759/2020 was signed; PPC undertook to implement the relevant contractor selection procedures to prepare the special urban planning schemes based on guidelines and specifications of the Ministry of Development and Investments.

As part of the **lignite phase-out strategy**, **PPC is committed to rehabilitating and reclaiming** ~ 23,700 ha of former lignite mines. These areas will be **transformed into a diverse range of new uses**, including **lakes**, **forests**, **industrial zones**, **agricultural**, **leisure zones**, and **solar parks**, demonstrating the versatility and potential for sustainable development (Public Power Corporation, 2021).

The **actions taken by PPC for soil rehabilitation** are described by LCWM, 2018:

- Shaping of the surface and slopes. Measures for the avoidance of landslides.
- Mixing ash with the remaining infertile materials and depositing it in mines, according to the approved Extractive Waste Management Plan.
- Intermediary materials, rich in organic content, are sent to the upper layer of the deposition.
- Preservation of soil material (soil for plants) and laying of soil material on final surfaces, where necessary, for the support of the intended land use.
- Cultivation of saplings for environmental rehabilitation, for wood production and for the formulation of livestock zones.
- Construction of fencing.
- Creation of 2,200 ha, till 2018, cultivated with forest species.
- Creation of 1,500 ha for agricultural use, of which the 500 ha are rented by local cultivators and the rest are available for other uses (e.g. Photovoltaics, Integrated Waste Management System of Western Macedonia, cultivation of aromatic plants, moto-cross track)
- Management of an experimental orchard.
- Areas for beekeeping

Reforestation with Acacias

For the reforestations are usually used **acacia species** (Robinia pseudoacacia), since according to studies is the **most appropriate** option **due to its properties**. It **reduces erosion**, has a **high degree of planting success** (90%), an impressive **ability to exploit infertile soils** and has **no need of special care**. Also, there is the **possibility of producing wood fuel** as well as in the flowering period it **supports beekeeping**. In the wider area there are at least 15,000 acres of acacia that consist of **the largest forest of acacia species in our country**.

Reforestation with Other Tree Species

First, it is **examined the phytosociology of the area** and then a big number of **deciduous and evergreen saplings is planted in a sparse grid** so that their growth will **not prevent farmers from using the land**. The

tree species that have been **planted** are **Arizona Cupressus**, **cypresses**, **pines**, **leylands**, **cataplas**, **Fraxinus**, **birches** and **maples**.

Cultivations-Field Rentals

The fields that were **formed in the horizontal parts of the deposition area** are **rented to farmers** at a low cost. The **most common** cultivation is **cereals**, and according to a study carried out by the School of Agriculture of the Aristotle University of Thessaloniki in these areas can thrive **species like edible legumes**, **vines** and **aromatic** and **leguminous plants**.

Shaping of the Surface and Slopes

The **laying and smoothing of the final surfaces** are necessary in order **to be completely covered any topographical abnormalities** that have arisen from the way the materials have been deposited by the depositor. The layered surfaces allow the surface water to runoff to a certain direction. The **inclinations of the slopes are smoothed** in order to have a **slight inclination** so as to **prevent any erosion and sliding problems**, as well as to **maximize water retention**, which **contributes to the rapid growth of vegetation**.

Ash Management

The **mix of ash with other infertile materials improves** physical and mechanical characteristics, as well as compressive strength, plasticity and grading, and it is **deposited inside the mines**. The **intermediate infertile materials**, which are **rich in organic content**, are **sent to the upper layer of deposition**.

Preservation of Soil Material

The existence of a **suitable and fertile soil substrate** is an important factor for the efficiency and development of plant material. Therefore, **the soil material is preserved** in order **to be used as a final layer in the depositions** where necessary, **depending on the intended land use**.

Construction of Fencing

Fencing is **selectively placed on the surfaces** where are going to be **planted the forest species** so as **to prevent grazing problems**, **damages** and **trespassing**.

Orchards

An **experimental orchard** of 62 acres **with pilot cultivations of pear trees**, **apple trees**, **cherry trees**, **quince trees**, **quince trees** and **vineyards** (Figure 20). The orchard has been **existing since 2001** according to the principles of systematic agriculture. The **fruits** are **distributed to** institutions, local bodies and employees of the **Lignite Centre of Western Macedonia**.

Figure 20. Orchard in already reclaimed lands in North Field of Ptolemais mining area (photo taken by PPC authors, on 11th April 2023)

Experimental Greenhouse

The **experimental greenhouse of hydroponic cultivation** of 1 acre **operated for twelve years** (from2000 to 2012), producing various kinds of vegetables, as well as flowers on a perlite substrate. Its aim was **to highlight the possibility of using rehabilitated land with cultivation techniques** that are **not directly related to the soil** and **take advantage of the low-cost energy of district heating**.

Aromatics Plants

In recent years, the **cultivation of aromatic plants** has been **developed in the rehabilitated deposit of the Main Field Mine**. The **cultivated species** that are tested are **lavender** and **lemon balm**.

Apiculture (Beekeeping)

In rehabilitated areas have been **planted acacias and conifers**, and these areas are **fenced for the support of beekeeping**. **Apiculture** (beekeeping) is an **agricultural occupation**, which plays an **important role in the rural economy at a global level**. The exploitation of the **bees of the acacia forests of the Lignite Center of Western Macedonia** creates a significant prospect of **support for the organic beekeeping**, which explains the increased **interest of beekeepers for the exploitation of the flowering acacia**.

Energy Crops

Energy crops are **plants grown exclusively for the production of green energy**. More specifically, **energy crops** are cultivated species, which **produce biomass** as a main product, which **can be used for various energy purposes**. It has been **implemented a pilot cultivation of energy crops** such as the **sunflower**, **cardoon** and **oilseed rape**.

Pilot Cultivation of Paulownia

There is **a pilot cultivation of Paulownia for the production of biomass**. The produced biomass will be used for the unit that has been constructed by PPC Renewables in the area of Amyntaio. Moreover, **Paulownia** is a **very good plant for bees** since it gives honey of excellent quality.

Soil Fertility

In order to be determined that **the soil fertility requirements are met**, the Environmental Unit**, if necessary,** will take **steps in order to keep Ph in normal limits, develop proposals** for the **appropriate land use** of this area and take action for the **improvement of the soil fertility**. All the **necessary data** for this purpose are **measured by PP**C or a **collaborating laboratory**. In **collaboration with the Technological Educational Institute of Western Macedonia**, it is carried out a **research program** for the **implementation and evaluation of soil improvers** (e.g. zeolite).

Search for the Further Development of Ecosystems

After the rehabilitation, **it is observed**, on a continuous basis, the **environmental restoration** so as to check the success of the goals and the PPC's commitment to the stakeholders. More specifically, it is carried out **an annual audit for the environmental rehabilitation process** in order to be taken **the necessary corrective measures**.

Composting

Composting is a natural process, which **converts organic materials into a rich in nutrients dark substance**. This **substance** is **called compost** or **soil improver**. Composting is a very direct and important **way of recycling** and the most **environmentally friendly**. The production of compost is **in a pilot level**. The produced material **will be used as a soil improver in planting**.

Forestry Park

It has been created a **forestry park**, where visitors have the opportunity to be informed about the flora of the area, since in this park **all kinds of forest trees thriving in northern Greece are planted**.

Wildlife Conservations

There are some **areas**, which have been **formed in breeding and adaptation places for small animals and birds**, having as a **goal** the **wildlife enrichment of the rehabilitated areas**. In these areas, in cooperation with hunting associations, it is carried out the **breeding and adaptation of small animals**. There is a **permanent**

prohibition on hunting throughout the year **in the whole area of the Lignite Center of Western Macedonia**, making it the largest sheltered 24-hour protection zone in Greece.

As for the latest data, until 2023, **the already reclaimed areas are presented in Table 1 with analytical data** for each PPC's mine (Public Power Corporation, 2024 a,b,c). The graded areas constitute the areas that have been **suitably configured in order to host future land use**, which could be **either forest or agricultural land use** or even **PV parks**. In contrast, the **graded PV areas** have been **configured accordingly to host PV parks**. The former differs from the latter because the reclamation type has not yet been decided for the former areas. As can be seen from the table, the **land use types** in the PPC mines **focus on the ecological reclamation of the mining areas and renewable energy sources**.

Figure 21 depicts the **spatial configuration of the Amyntaio mines** extending from SW to the NE along the four natural lakes shown in the figure, within the environmental permitting limit as well as the inside and outside dumping areas.

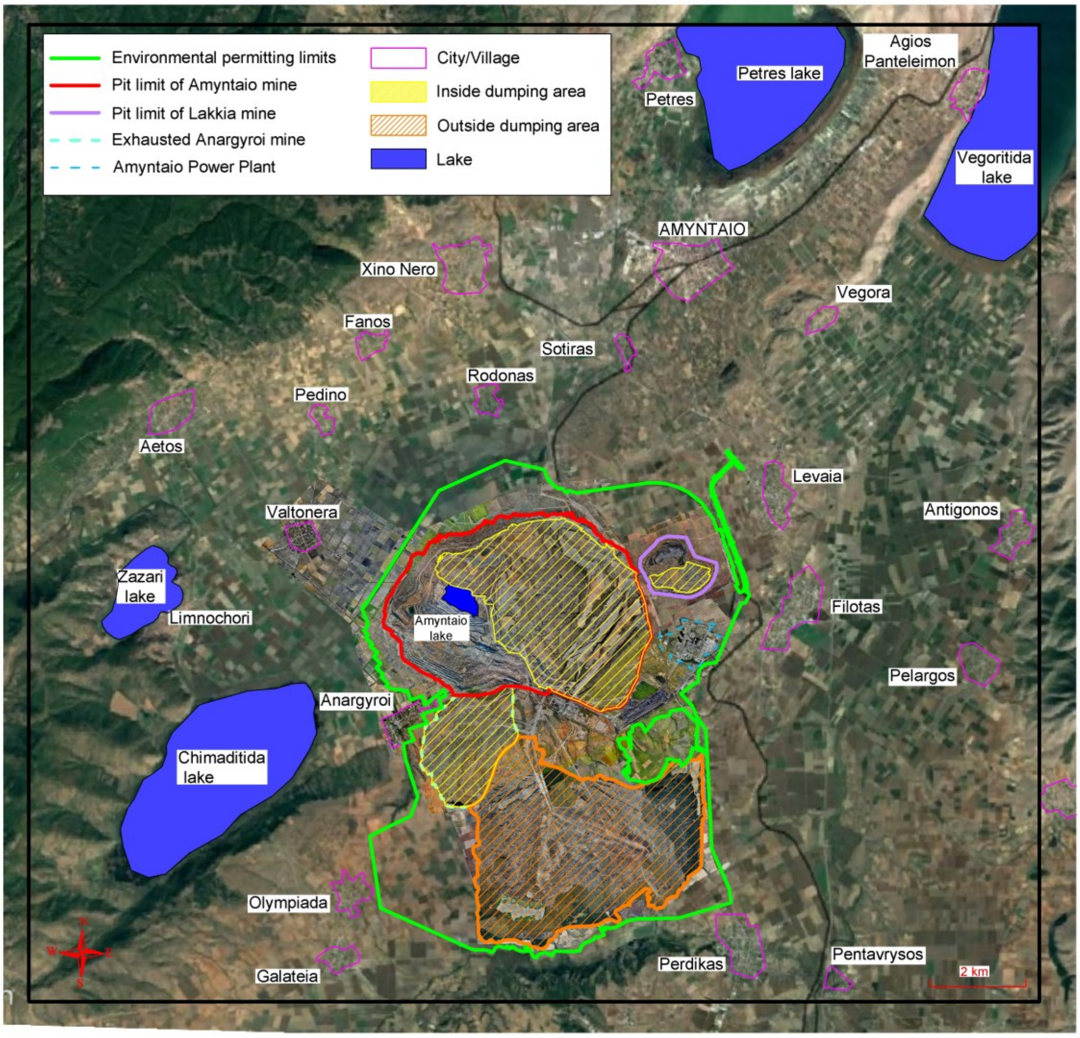

Figure 21. Plan of the Amyntaio area mines (Anargyroi, Amyntaio, Lakkia) (December 2021) (Kavvadas et al. 2022)

Table 14. Reclaimed areas (hectares) in the PPC lignite mines until 2023

	Forest use (ha)	Agricultural use (ha)	Graded areas (ha)	Graded areas for PV (ha)	Lake (ha)	TOTAL (ha)
AMYNTAIO	899.5	82.5	752.7	1,412.5	82.0	**3,229.2**
PTOLEMAIS	1,762.8	323.2	224.9	1,327.8	4.0	**3,642.7**
MEGALOPOLIS	450.0	300.0	0.0	450.0	115.0	**1,315.0**
TOTAL	**3,112.3**	**705.7**	**977.6**	**3,190.3**	**201.0**	**8,186.9**

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5.2. Legislative and financial framework of reclamation

Officially, the **lignite phase-out period in Greece began in December 2019**, with the updated **National Energy and Climate Plan** (NECP) (Hellenic Republic Ministry of the Environment and Energy, 2019) publication proposing the **withdrawal of all lignite power plants by the latest 2028**. However, **around 2010**, the **gradual reduction of lignite production from PPC mines** had already **started** due to the **systematic integration of renewable energy sources into the interconnected system**. Subsequently, an **updated long-term mining and closure planning was prepared** according to the **requirements of the NECP**. The **Just Transition Plan** (JTP) (Hellenic Republic Ministry of the Environment and Energy, 2020) **followed the new NECP**, which, among other things, proposed **new land uses for the post-lignite areas**, based on which the **Environmental Impact Studies** (EIS) for the exploitation of PPC SA's lignite mines **were updated**. The proposed reclamation of the lands included in the EIS was under the proposed land uses of the JTP. The **implementation of mine closure** is **governed by specific laws that the Greek government** has **defined**:

1) Law 4759/2020 (Modernization of Spatial and Urban Planning Legislation) designated the **Regional Units of Kozani and Florina in the Region of Western Macedonia**, and the **Municipality of Megalopolis in the Region of the Peloponnese**, as "**Decarbonization Zones**" (D.Z.) under Article 155. Additionally, the **corresponding lignite fields** and **PPC S.A. power plant areas** within these zones were defined as "**Decarbonization Cores**". PPC S.A. was assigned the responsibility to: a) conduct tenders for the preparation of Special Spatial Plans (SSPs) (Politis, 2020) within the D.Z. (ar. 155, par. 3) and b) implement the new land uses and upgrade the post-mine areas (ar. 155, par. 4).
2) Law 4872/2021 significantly impacted post-mine land use by amending ar. 155 of Law 4759. It introduced the **concept of the 'Post Mine Land Uses Sector'** and **delineated the process of its separation from PPC S.A**. Additionally, it **established an anonymous company**, METAVASI S.A., to which the **sector's assets would be transferred**. This transfer marks a **substantial shift in the management and utilization of these lands**, entrusting METAVASI S.A. with their future development.
3) Law 4956/2022 ratified the Agreement outlined in paragraph 4 (Agreement 4, ar. 155, Law 4759/2020), which **specified the lands to be transferred to the Greek Public** (METAVASI S.A.) and established **a schedule for their availability**. Concurrently, the Agreement in paragraph 3 (Agreement 3, ar. 155, Law 4759/2020) was signed. Tenders were conducted based on technical specifications set by a Ministry Decision for the preparation of SSPs, which are currently awaiting approval. These agreements and tenders are **critical for the land transfer process and the planning of post-mine land use**.

The **prices of individual reclamation types** are presented in Table 15 according to the reclamation works already done. The reclamation cost **for the lakes is not presented** in this table as it is **not a standard price** and is dependent on several financial factors. The reclamation works for the lake development include the configuration (removing the excavated materials) and reclamation (shaping the pit slopes) of the mine pit void.

Table 15. Price/ha of individual types of reclamation in the PPC mines

Type of reclamation	Price/1ha (EUR)
Agricultural – Industrial reclamation	6,500, 12,500, 21,000 three categories depending on the scope of the works
Forest reclamation	5,000
Recreation parks (lakes)	9,000

5.3. Applied research methodology

The methodology for the environmental reclamation of the mining areas is **not a one-size-fits-all approach**. It is **based on the international and national experience in the environmental reclamation** which is in force, but it also **takes into account the unique local conditions** of each mining area. **The main pillar** of the reclamation works is the **planning of realistic and effective interventions** which will **comply with the broader natural** and **socioeconomic environment** of the area.

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Methodology of field work

Based on the applied methodology of reclamation in the PPC mines, **soil sampling for laboratory tests should be employed** to **check the soil fertility of the dumps' surfaces** and the **final pit slopes**. Depending on the soil fertility check, **the necessity of the following actions will be checked**:

- Grading land in the final dumping surfaces with planting land of a thickness suitable for the fast development of vegetation in the lands that will be available for agricultural cropping.
- Soil enrichment with organic matter (interburden barren materials including thin lignite beds) or chemical lubrication
- Chemical or mechanical weed control.

Recommended laboratory testing

The following **laboratory tests** are employed in the **selected soil samples** for the **calculation of the parameters** which define the **soils fertility**:

- Soil texture
- Ph
- Electrical conductivity
- Content in CaCo3
- Content in organic matter
- Content in nutrient elements: P, K, B, Ca, Mg, Mn, Zn, Fe, Cu
- Content in heavy metals: Cd, Co, Ni, Pd

5.4. Main types of reclaimed soil

The main types of reclaimed **soil in the mining dumps** of PPC are **consisted of** gravels, marl, clay, conglomerates, clastic and sandy clays, calcareous marl.

5.5. Current methodology for the implementation of individual types of reclamation

The **methodology** for the reclamation of the mining areas is **based on the Just Transition Plan**, according to which the areas inside the decarbonization core and the undisturbed areas will be **suitably configured depending on the proposed land uses**. The reclamation plan for the areas related to mining activities will be **employed in consecutive annual phases**. **Each phase starts after the release of the mining area** and is **completed within two years**. The **reclamation stages** are **adjusted depending on the intended land use** for each under-reclamation area. The methodologies followed for individual types of reclamation are described according to the **Environmental Impact Assessment Study of Ptolemais and Amyntaio-Lakkia mines**, **2024**.

Methodology of forest reclamation

Forest-vegetated areas are **created aiming at wood production**, the **creation of livestock zones**, and the **reclamation of areas with forest kinds**. These areas, which are configured **in inclined areas**, are developed **mainly in the perimeter of the dumps** and **planted with kinds that thrive in the area**. The **afforestation with forest species** that **exhibit adaptability to the soil** and **climatic conditions** of the area is carried out **using the following techniques**:

- Using the conventional manual technique. By using this technique, 300,000-450,000 trees are planted every year in the Lignite Centre of Western Macedonia, which correspond to an area of 250 ha.
- Using the ripper method (soil ripper). This method is based on creating of a groove using a ripper pulled by a tractor or the tines of a bulldozer, followed by the placement of seedlings in the furrow by a crew following these machines' path.
- By transplanting. By applying this method, the transfer of developed trees is employed from site to site, mainly wherever there is a direct need to upgrading the aesthetics of the space.
- Root system transfer. This method allows the utilization of roots located in areas that are going to be excavated, and as such, the fertile soils are not destroyed but transferred to areas that are ready for reclamation.

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The **selection of the most suitable forestation method** is elaborated considering **the following criteria**:

- The ripper method is employed for planting in loose soils with mild inclinations. This method presents higher percentages of success due to the higher moisture retention. However, it should be ensured that the grooves are parallel to the contour lines and not vertical, as the soil erosion hazard lurks.
- In the medium to high inclinations, the creation of a groove is proposed of dimensions analogous to the plant size that will be planted.
- In eroded surfaces or higher-inclined surfaces, the Coutourier planting could be applied (side planting in small levels of width 20cm which are created manually).

Methodology of agricultural reclamation

The **arable lands** are configured in planar or semi-planar areas with prevailing mild slope inclinations (Servou et al. 2023). **After** the **systematic and gradual completion of the reclamation** interventions, these lands are **leased to local farmers** at a low cost and are **almost entirely cultivated with durum wheat**. In the future, **provided that irrigation infrastructure is developed around the lakes** that will be **formed in the final excavations of the mines**, it will be **possible to cultivate** annual or perennial **crops** with **higher yields per hectare** on the above lands.

Methodology of recreation parks (lakes) reclamation

The **final pits** will remain after the mining exploitation works are completed. After the pumping cessation, they are expected to be **filled with water from rainfall or surface runoff**, as well as the **aquifer of the area's overburden**. Figure 22 presents the **future pit lakes in the Lignite Centre of Western Macedonia**.

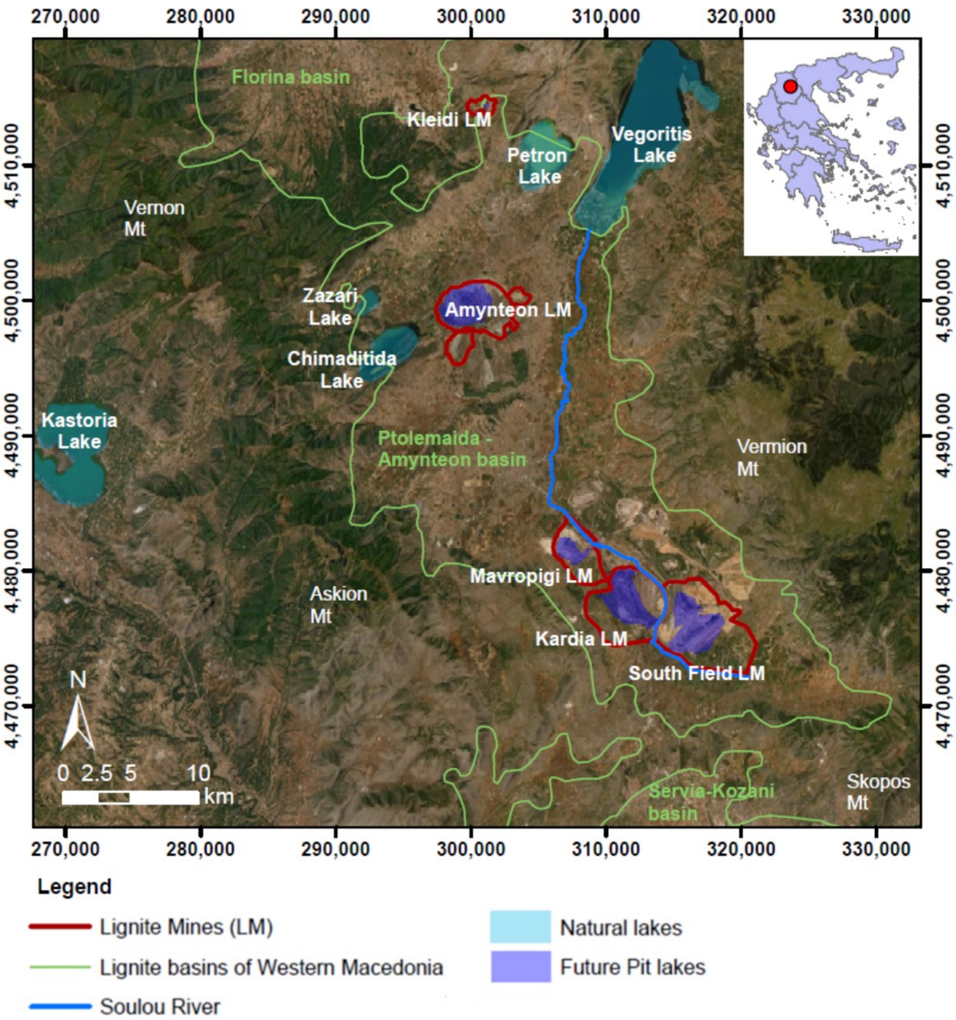

Figure 22. Spatial configuration of natural and future pit lakes within the broader area of Lignite Centre of Western Macedonia (Louloudis et al. 2022)

The **main stages of reclamation** which are considered for the protection of lake ecosystems **are the following**:

- Mechanisms of water level monitoring
- Slope stabilization
- Tree planting
- Interventions in landscape aesthetics
- Monitoring of the water quality of the lake ecosystem and
- Taking measures for the protection of the water quality

A characteristic **case of lake reclamation** in PPC **lignite mines is the Amyntaio lake** which is **depicted in** Figure 23.

Figure 23. Panoramic view of the Amyntaio lake (photo taken on 6th July 2023 by PPC authors)

5.6. Conclusion and lessons learnt

Greek **lignite mines in West Macedonia Lignite Centre** (WMLC) and **Megalopolis Lignite Centre** (MLC) provide **lignite for power generation**, the most important energy source for the Greek economy. Lignite is **mined by the PPC exclusively** in **opencast mines**. It has **operated mines** in **Western Macedonia** in the **Ptolemais** area (Main Field, South Field, Kardia Field) and **Florina** (Amyntaio Field). PPC also has an **opencast site in** the **Peloponnese region of southern Greece**, in the **Megalopolis**. The described reclamation schemes and the achieved results confirm their success. Based on the solution of the REECOL project, **the implemented methodologies will be supplemented with ecological aspects** and **the effects of climate change**.

6. FRENCH SITUATION

6.1. French case study

At the **end of the 1970s** the **French state launched a specific development program** of the **main urban** centres of the **mining basin of the North-Pas de Calais region**. The state has also **invested in** the **conversion of** a dozen **heavily degraded coal mining sites**, representing nearly 1500 hectares of wasteland, **into parks**. **Since 1984**, the **newly created Region** has been **pursuing these development programmes** in partnership and in favour of exemplary landscaping public spaces of mining municipalities. From **1984 to 2006**, **according to the successive State-Region Plan Contracts**, the **policy of massive and quantitative treatment of stigmas** («large industrial wastelands» 1989-1993) and **greening of spaces awaiting future use** («environmental wastelands» 1994-1999) has gradually **evolved into an integrated policy**, serving urban renewal, major economic projects of regional interest and ecological treatment and opening to the public, **within the framework of the Green and blue Frame** («reconquest of degraded spaces» 2000-2006). The **NPC Public Land**

Establishment (EPF NPDC) has **participated in** the **conversion of a good part of these coal wastelands**. The **network of former mining railways** is gradually being **converted into walking and hiking routes**. The **subsiding ponds** become sometimes **leisure bases**, sometimes **protected faunal and floristic reservoirs**, such as the **200 dumps that still punctuate the territory**. **Local authorities** have **devised recreational projects** that are sometimes original: artificial ski slope, leisure base, environmental education centre, mining history museum, etc. **In total**, over a **period of 30 years**, more **than 8,000 hectares of brownfield land** have been **reclaimed**.

The **French case study** is a **basin beneath an old coal mine** (Dump 49) located **in Mazingarbe**, a **city of the Pas-de-Calais department** (62) and **the Hauts-de-France region** (previously North-Pas de Calais region). It is situated in the watershed of Le Surgeon, La Fontaine de Bray, La Loisne and Le Fossé d'Aisnes et d'Auchy. The old coal mine is issued from the development of a large industrial complex based on carbochemistry with coking plants and basins (1897 – 1984), nitrogen fertilizer production (1922 - 1988) and ethylene production (1953 – 1965). The coal extraction was carried out from 1860 to 1963. In 1977, the well was backfilled and the headframe and part of the installations were destroyed leading to a dump of 60 m high and composed of black shales (approximately 1 million m3) on 7.3 ha. Until recently, the **wasteland basins consisted of two parcels:** the former «west» settling basin and the former "north" tailings pond (Figure 24). **One** of these **parcels** was the subje**ct of a management measure by phytomanagement** (i.e. Miscanthus x giganteus and a biochar produced from miscanthus; MisChar research project https://mischar-43.webself.net/). On **the other part** of the site, **natural vegetation developed and cover the site**. The EPF NPDC was the owner of the site until recent years. This site, **candidate to consolidate a urban green belt** is currently managed by a company **to flatten the basins beneath the dump** and **find a solution to cancel the presence of an invasive species that has entirely colonized the basins**. The dump, where there is no alien species, will stay as it is, being part of the cultural heritage of the city. Contrary to dumps, the basins show contamination, in particular by metals, due to previous industrial activities. The city which is the future owner of the site will only allow its use on walking trails that will surround the site.

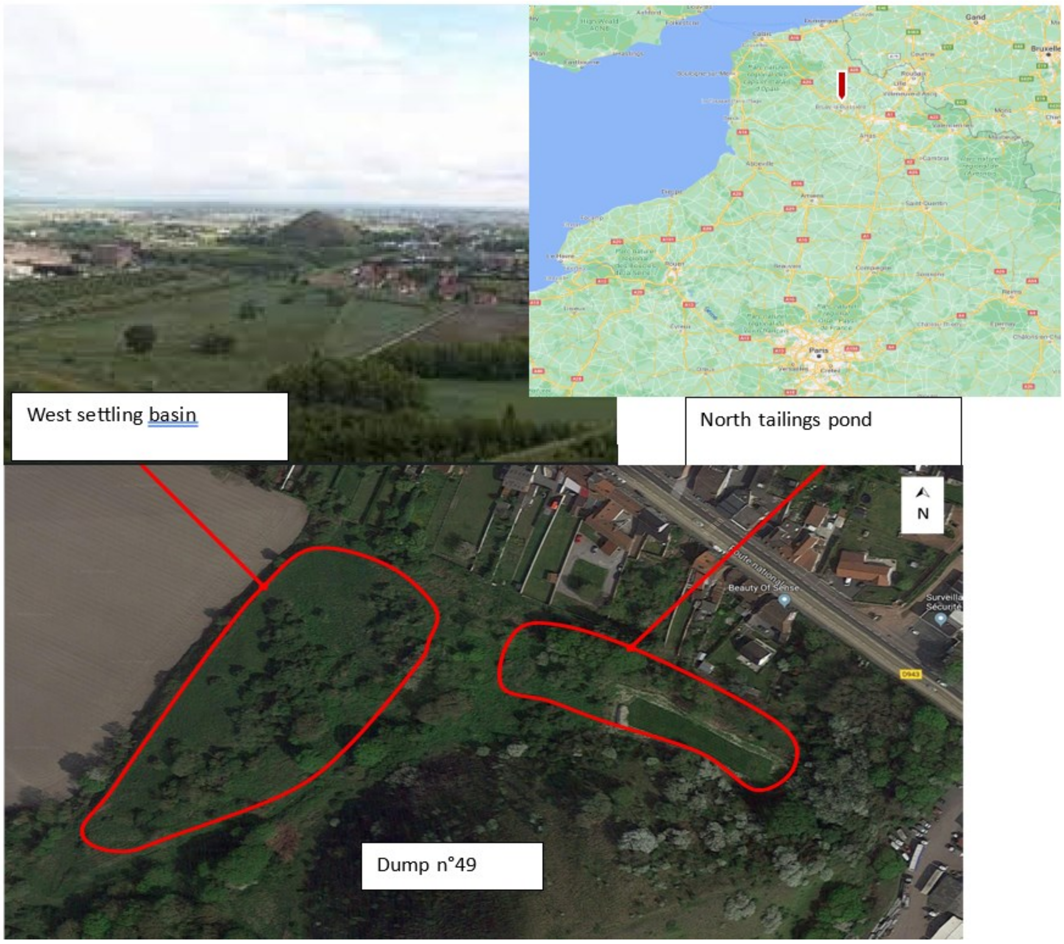

Figure 24. Location of the French case study and satellite views of the case study

6.2. Main types of reclamation used in French coal regions areas

The "**Commitment to Revitalize the Mining Basin"** (ERBM; L'Engagement pour le renouveau du bassin minier) is an ambitious **program** that aims to **achieve the transformation of the territory of the mining basin over a ten-year period**. It involves **the state and local authorities**: the **Hauts-de-France region**, the **departments of Nord and Pas-de-Calais**, as well as **eight intercommunalities**, **from Béthune to Valenciennes**. **In total**, the commitment concerns **250 municipalities** in the mining basin and **1.2 million inhabitants**. The Commitment to Revitalize the Mining Basin deploys a cross-cutting **programme to sustainably transform this territory**: housing and eco-construction, heritage, transport, economic attractiveness... The aim is **to remove obstacles to mobility and employment** and **strengthen support** for the **most vulnerable populations**, particularly for their **heath**. The programme is **based on** the **following strategic axes**: Accelerate the pace of housing rehabilitation to create jobs and innovation; Strengthen urban centres; Facilitate the mobility of goods and people; Promote the development of economic activities; Support the population in their social, economic and civic development; Improve the health of residents; Develop the uses of digital technology; To cultivate the image of a territory with attractive landscapes; Enhance the value of mining, historical and cultural sites of memory; To soothe the wounds of the past (reclaiming wastelands, soil treatment, risks in fragile areas...); Support the recompositing of management and project territories. The **improvement of the living environment of people** is notably **reached by the reclamation of dump and their surrounding** into **walking** and **hiking routes**, **leisure bases**, **recreational** projects and **faunal and floristic reserves**.

6.3. Legislative and financial framework of reclamation

The state has committed to mobilise its intervention credits as a priority, for example with an increased effort of 4.5 million euros each year in favour of economic activity. It will also provide an additional €100 million over the entire duration of the programme for the energy rehabilitation of housing and improvement of living conditions. The **Hauts-de-France region** is has also committed itself to mobilise a specific envelope of 3 million euros per year over ten years for the rehabilitation of social housing stock in mining towns and 39 million euros for the **New National Urban Renewal Program**. The **Pas-de-Calais County Council** will invest 20 million euros over ten years. All the communities involved are mobilizing their public policies and investments in this territory.

6.4. Applied research methodology

On most contaminated parts of the wasteland basins where the **Caucasian hogweed (alien species) was present**, the company mandated by the city brought materials from various construction sites and cover the alien species with 3-4m of them. This **reclamation strategy** would definitively **remove the presence of the alien species** while **protecting the dump from contaminated dust blowing** and the **new environment** that will develop from contaminant transfer **making a barrier** to **avoid direct contact with the contamination**. This **reclamation action started in December 2023** (figure 25).

On **a small part** kept by the company, a **field trial** was set up **to precisely characterize the contamination** and **physic-chemical**, **ecotoxicological** and **ecological properties** of the **soil covered by the Caucasian hogweed**. **The same characterization** is performed on a **soil nearby covered by** another type of **vegetation without the alien species**. The **comparison of both soil characteristics** will **inform** us **about differences** which can be used **for the reclamation of the soil with the alien species**.

Figure 25 includes views of the **site after soil levelling** and **covering the Caucasian hogweed with 3-4m of construction materials** (left) and the **field trial beneath the dump** (right). On the **left**, pictures were taken in **February 2024** and on the **right** in **December 2023**. Pictures below show the **Caucasian hogweed the native plant species on the site before management** and **on the field trial in April and July 2024**, respectively.

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Figure 25. On the field trial, top-soil and plant sampling

On the field trial, **top-soil and plant sampling** (green leaves and dry stems of Caucasian hogweed) was performed in **November 2023 to characterize** the **properties of the metal soil-plant transfer and soil properties**. In **April 2024**, **soil sampling** was performed **on a plot with the alien species** and **on a plot nearby without the alien species** as well as **a botanical survey**. **PAHs and PFAS analyses** in the soil samples **are in progress** to characterize the **soil contamination**. In **July**, **soil was sampled again**, the **samples were prepared in composites**, stored at -20°C for **future extracellular soil enzymes** (C, P, N et S cycles) analysis whereas **others were sent to Valorhiz and BRGM for future analyses** (Rockeval, TypoSoil, pH, rapport C/N, CEC, % clay, % silt, % sand, % CaCO3, basal respiration, microbial biomass and diversity). In addition, **Arrhenathrum elatius** the dominant species **on the nearby plot** was **sampled to analyse the metal soil-plant transfer**.

6.5. Some practical results of recommended methodology

The **efficiency of the reclamation strategy** on the main part of the basins on the cancellation of the alien species **will be monitored** over the project timeline, **expecting** that the **plant species will not be observed anymore**.

On the field plot, **preliminary results are summarized in the table** 16. Excessive total trace element (TE) concentrations were evidenced in the top-soil of the field trial (As, Cd, Cr, Cu, Hg, Pb, Se, Zn) besides extractable concentrations of these TE were very low which is in agreement with the pH result. These **results confirm** the **need to avoid the direct contact with the soil** and to implement risk reduction **measures to avoid soil contamination dispersion** in the **environmental compartments** and **human exposure**. Results in the **alien species do not evidence metal transfer in its above ground parts**. As the **plant does not accumulate metal**, it is not an issue for the food chain in case of consumption.

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Table 16. Trace element total and extractable (NH4NO3 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 is 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.

	Soil		Leaves		Stems	
Conc. (µg/g)	Mean	SD	Mean	SD	Mean	SD
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				

6.6. Conclusion and lessons learnt

The **monitoring of the main parts of the basin** in the timeframe of the project will **confirm the reclamation strategy** set up by the company to eradicate the Causasian hogweed. The **ongoing analyses** will inform on the **different physical**, **chemical** and **biological properties of the soil** with and without the alien species and **help to propose relevant reclamation strategy** complementary to the one proposed by the company to reduce environmental and human exposure to contamination and eradicate the alien species.

7. CONCLUSIONS

Task T3.2 deals with the **current state of reclamation schemes in coal regions in Poland, the Czech Republic, Slovenia, Greece and France**. The **partner countries of the project** have a **long tradition in surface and deep mining of coal** and are currently solving various mining problems due to the gradual decline in mining. This task **characterizes** the **different approaches to post-mining reclamation** that have been used **in the project's partner countries** in terms of identification of **reclamation practices** with regard to **further land use**. It concerns forestry, agricultural and hydraulic reclamation, spontaneous succession, solving the problem of soil degradation, climate change and other problems.

Reclamation procedures and methodologies in the individual countries of the project are **not yet coordinated and differ considerably**. Therefore, the individual chapters of this **report characterize the situation in individual countries.**

In each partner country, the characteristics of the case areas, the main reclamation methods used, legislative and economic evaluation of reclamations, field and laboratory research methodology, characteristics of reclaimed soils and materials, characteristic examples of realized reclamations and a summary of the status of reclamation schemes are **briefly summarized**.

Based on the results of the T3.2 task, it will be **possible to**:

- Compare reclamation methods in individual mining regions,
- Adopt successful reclamation methods from partner countries,
- Use this evaluation of the current state of reclamation in the development of a new reclamation methodology in other research packages of the REECOL project.

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