Mine rehabilitation in Germany Example LMBV

1. Country Overview of Mining Activities

Key mining sectors

The Federal Republic of Germany is one of the largest consumers of raw materials in the world, especially with regard to mineral resources. Primary raw materials are both domestic and global in origin; increasingly the supply is secured from secondary raw materials recovered through recycling.[1] A portion of non-metallic resources, above all potash and rock salt, as well as most stones and soils, originate from domestic production. When it comes to primary metallic resources, however, Germany is almost entirely dependent on imports.[2]

In 2021, Germany produced 126.3 million metric tons of lignite (+17.6% compared to 2020), 1.81 million metric tons of petroleum (−4.7% compared to 2020), 6.0 billion cubic metres of natural gas, petroleum gas and firedamp (−0.1% compared to 2020), as well as approx. 620 million metric tons of mineral raw materials (−1.3% compared to 2020) plus approx. 5.4 million cubic metres of peat (+2.9% compared to 2020). In addition, there are another 200 mill tons of mineral raw materials or so from small, non-reporting companies. This production volume amounted to a total value of approx. € 13.5 billion (+17.1% compared to 2020). It therefore corresponded to 0.37% of the gross domestic product of the Federal Republic in 2021.[3]

In terms of both volume and value, sands and gravels were the most important mineral resources, with a raw output of approx. 309 million metric tons and a value of € 2.82 billion in the year under review, amounting to well over one third of domestic raw material production. Together with quarried natural stone (219 million metric tons), following in second place, they made up around 80% of the volume of raw materials extracted. Lignite took third place, and with the significant increase in production, it continues to be the most important domestic fossil energy source.[3,4]

Key mining areas and key mining companies

Germany is a country with a long tradition of mining and has a large amount of raw materials reserves, which, for geological reasons, are spread unevenly across the country.[5]

As early as Roman times, over 2.000 years ago, iron and other metals were being extracted in the foothills of the Alps. The Harz Mountains, a small mountain range in the middle of Germany, became a focal point for ore mining in the Middle Ages. Silver, copper, lead and iron, as well as other metals, were extracted. In the Ore Mountains, the border between Germany and the Czech Republic, mining has been taking place for over 800 years. While silver ore, tin, copper, iron and cobalt were once the most

[1] BMWK 2023: https://www.bmwk.de/Redaktion/EN/Dossier/raw-materials-and-resources.html
[2] BGR 2023: https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/min_rohstoffe_node.html
[3] BGR 2022: https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/min_rohstoffe_node.html
BGR 2022: Deutschland – Rohstoffsituation 2021. 162 p., Hannover
[4] DeStatis 2021: https://www.destatis.de/DE/Themen/Wirtschaft/Volkswirtschaftliche-Gesamtrechnungen-Inlandsprodukt/Methoden/bip.html
[5] BMWK 2023: https://www.bmwk.de/Redaktion/EN/Dossier/raw-materials-and-resources.html

sought-after minerals, uranium was then mined after the Second World War. The GDR (former East Germany) became the world's fourth-largest uranium producer. Uranium mining ceased after the reunification of Germany in 1990 and the state-owned company Wismut GmbH was established for remediation.[6] Moreover, the Ore Mountains contain one of the largest lithium deposits in Europe and its extraction is currently being explored.

Salt mining is also a centuries-old tradition in Germany and still plays an important role today. Around 18 million metric tons of potash salts are extracted annually from 14 active mines. Germany thereby ranks fourth in world production after China, the USA and India.[7]

The mining of hard coal in Germany ended in 2018. The RAG foundation was established for managing and financing the obligations related to the German hard coal mining.[8] The significance of the Ruhr region and the coal-mining district in Saarland, for the industrialization of Germany cannot be understated.

Mining of lignite took place in Germany since the late 17th century. Initially mined above ground, lignite was then also extracted underground in the 19th century. Since the beginning of the 20th century, lignite mining has taken place exclusively in opencast mines. Today, it is concentrated in three mining districts: the Rhenish district around the city of Cologne, the Central German district near Leipzig and the Lusatian district in the south of Berlin. In 2021, production stood at around 126.3 million metric tons. Land use amounts to around 1,800 km², of which 1,260 km² have been rehabilitated to the present date.[9] The most important active mining companies are RWE Power AG[10], LEAG[11] and MIBRAG[12]. In addition, the state-owned company LMBV ("Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH"),[13] was founded to remediate the consequences of GDR mining operations, with the exception of uranium mining.

According to German mining law and European environmental law, the operator of a mine is in general responsible for the remediation of hazards to both people and the environment, i.e. mine rehabilitation, (polluter pays principle). The federal states are responsible for safeguarding historical mining operations. Thus, LMBV is a special case with regard to German mining history being solely founded for remediation of abandoned mining areas of the former GDR.

After the reunification of Germany in 1990, all non-market competitive lignite-mining activities were terminated within a few years and separated from the market competitive units. The latter were sold to private mining companies. Only because of this division it was possible to continue the profitable units and thus secure an

[6] https://www.wismut.de/en/
[7] Verband der Kali- und Salzindustrie 2023: https://vks-kalisalz.de/bergbau/bergwerke/
[8] https://www.rag-stiftung.de/en/
[9] DEBRIV 2022: Jahresbericht 2021, Annex 1, 12
[10] https://www.rwe.com/en/the-group/rwe-power/
[11] https://www.leag.de/en/
[12] https://www.mibrag.de/
[13] https://www.lmbv.de/

industrial base in the industrially strongly mono-structured regions. The unprofitable units were combined in the rehabilitation-mining sector, the legal predecessors of the LMBV. In later years, these were merged in several steps into today's LMBV.

Today, the LMBV unites former GDR opencast lignite mines and mines of the former GDR potash spar ore mining industry in Brandenburg, Saxony, Saxony-Anhalt and Thuringia. The primary task of the LMBV is the remediation of consequence of non-privatized GDR mining (1949-1990), with the exception of uranium mining.

The corporation has the legal form of a limited liability company. The only shareholder of LMBV is the Federal Republic of Germany, represented by the Federal Ministry of Finance (BMF).

In doing so, the LMBV acts either based on its own duties as a mining company or as an administrative assistant to the respective competent mining authorities by carrying out the rehabilitation, safeguarding and other measures that fall under their jurisdiction.

As the state project management agency for mining rehabilitation, the LMBV has taken over the environmental consequences of former mining on an area of more than 1.000 km². This includes the task of restoring the land to a planned reuse, eliminating hazards for people and the environment, and reintegrating the land into natural cycles as well as the utilisation of areas taken up by GDR mining for the comprehensive restructuring and recovery of the former mining regions in the public interest.

Figure 1 illustrates the fields of work of the LMBV, among them the lignite mining sites of the Central German mining district and the Lusatian mining district.

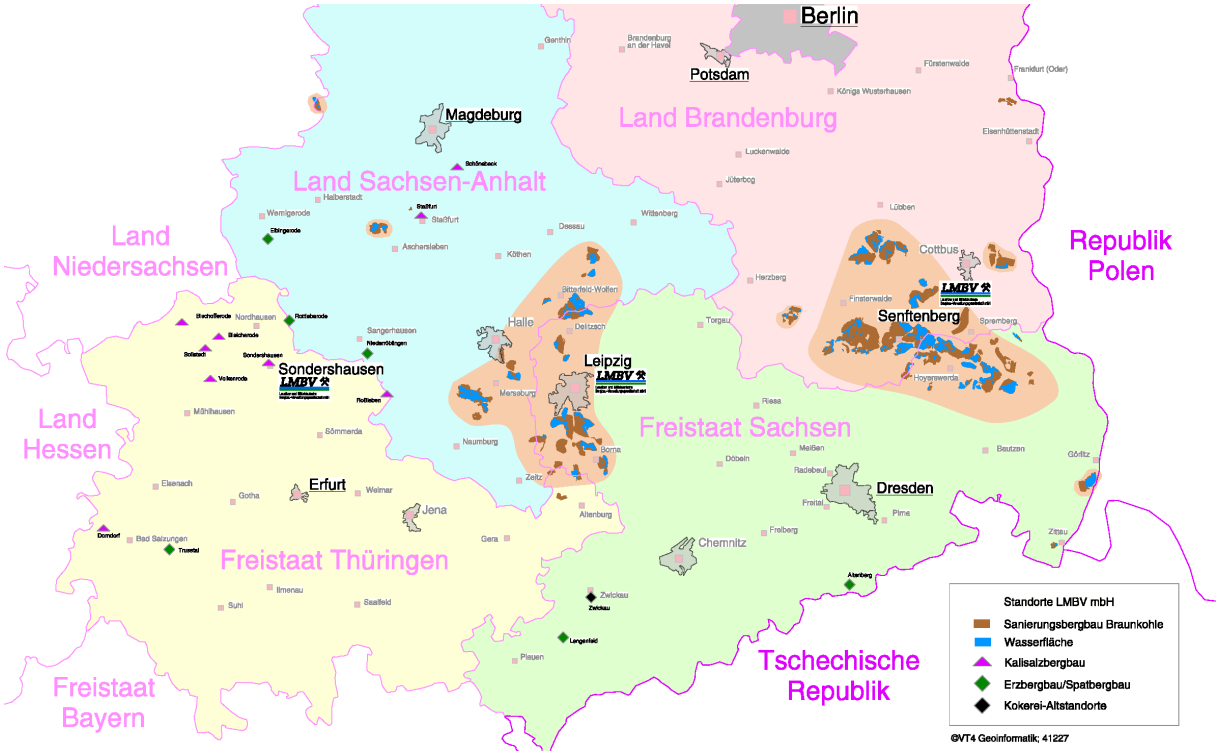

Figure 1: location of LMBV Work-Sites

2. Major Environmental Concerns Linked to Mining

Using the example of the tasks and successes of LMBV in the reclamation of the GDR's former lignite industry, the major environmental problems and the economic and social effects of unsustainable mining practices will be identified, and possible solutions will be presented.

Land degradation and degradation of the groundwater household

Due to the fact, that the economic policy of the GDR was very strongly focused toward autarky (self-sufficiency) in the extraction of raw materials, the result was in part extreme environmental pollution and the destruction of entire landscapes, far beyond the ecological and economic limits. The area devastated by lignite mining, for example, almost doubled to 1,520 km² between 1970 and 1990.[14] Nonetheless, the process of biological revegetation had already begun in the GDR, but under difficult economic and technological conditions.

At the end of the GDR, the environmental damage caused by the lignite mining industry consisted of 224 abandoned mining pits in 32 opencast mining areas, only a few of which could be backfilled with soil or made secure in some other way. The groundwater deficit resulting from mining activities in the areas assigned to the LMBV had grown to 12.7 billion cubic metres over 2.100 square-kilometres of land. It consists of 4.5 billion cubic metres of future lake volume and an additional 8.2 billion cubic metres of groundwater deficit.

Around 1.200-suspected contaminated sites presented a potential hazard for the rising groundwater and had to be remediated. Two briquette factories and six industrial power plants, 46 refining sites and 42 power plant facilities were obsolete and had to be demolished. This alone involved the dismantling of 11.7 million m³ of structural facilities and the generation of 6.6 million metric tons of scrap metal.

The termination of potash, spar and ore extraction in the federal states of Thuringia, Saxony-Anhalt and Saxony left behind 18 mines with open pits, shafts, light holes, galleries and 6 potash dumpsites. Additional responsibilities included two coking plants, hard coal dumpsites and an industrial tailing pond. In total, this involved an aboveground area of 757 hectares. [15,16,17,18]

Rehabilitation of the water balance

The regional water balance in Lusatia and the Central German mining district had been massively disturbed and over utilized. The shutting down of the drainage pumps

[14] Bismarck F. 2012: In: 20 Jahre Verwaltungsabkommen Braunkohlesanierung– Geschichten und Gesichter der Braunkohlesanierung, p.7

[15] Jantsch P. 2012: In: 20 Jahre Verwaltungsabkommen Braunkohlesanierung– Geschichten und Gesichter der Braunkohlesanierung, p.12

[16] Zschiedrich K. 2012: In: 20 Jahre Verwaltungsabkommen Braunkohlesanierung– Geschichten und Gesichter der Braunkohlesanierung, p.41

[17] LMBV 2022: Nachhaltigkeitsbericht 2021, 55 p.

[18] Drebenstedt C., Kuyumcu M. (Hrsg.) 2014: Braunkohlesanierung, Springer-Verlag, 688 p.

(dewatering) had to be monitored and coordinated so that the groundwater level could return to its natural level on its own.

The vast majority of 170 leftover pits of varying sizes have become post-mining lakes due to rising groundwater and the inflow of surface water in the meantime. LMBV mine-reclamation work creates, large, artificially water landscapes covering a total area of 270 square kilometres in the two mining districts. The goal is an equilibrated, largely self-regulating water balance of these former massively disturbed regional water areas. That means, that anthropogenic control interventions will be kept to a minimum. Some of these post-mining lakes are linked by navigable canals to form chains of lakes, thereby supporting the structural transformation of exploited, mono-structured regions into attractive, liveable landscapes. They are increasingly becoming tourist destinations.

Both mining districts are characterized by groundwater conditions that are in principle close to the floodplain, but the rivers that flow through the two districts are small and carry little water. The reduction of the groundwater deficit reached 11.1 billion cubic metres, to the present date. Increasingly long periods of drought in the summer have made the continuation of the process considerably more difficult in recent years.

In Lusatia, a flood control centre has been set up at the LMBV for the management and aftercare of the flooding of post-mining lakes. In coordination with a cross-state river basin management-working group, “Spree, Schwarze Elster and Lusatian Neisse”, this centre controls the water regime of post-mining lakes and supports the two states of Saxony and Brandenburg in safeguarding the ecological requirements of the rivers themselves, as well as the Spree Forest biosphere reserve located downstream.

In addition to replenishing the groundwater’s cone of depression, its character and its impact on streams must also be considered. As the lignite originated, the formation of iron disulphides, especially pyrite and marcasite, also took place. These are finely distributed throughout the coal seams. The excavation of the soil masses above the coal aerated these minerals, which triggered their oxidation. The released iron, sulphate and protons reached the surface water via groundwater pathways. When adding atmospheric oxygen, acid develops and is leached into the groundwater, into emerging lakes and into streams. The process of pyrite weathering also occurs in the groundwater’s cone of depression. The dissolved iron is oxidized under the influence of water and atmospheric oxygen to form iron hydroxide, which is left by the streams on riverbanks and riverbeds, causing negative impacts on the habitat of the streams.

Without intervention, these acidic waters, with pH values below 3, would have a very negative impact on the ecology of streams and would prevent the natural development of the emerging post-mining lakes, as they adapt to the natural environment. Therefore, LMBV set up a complex system of water treatment plants and monitoring wells. Many thousands of groundwater measuring points monitor the groundwater quality. The post-mining lakes and streams are regularly examined with regard to quality as well as hydrochemistry and limnology.

An area of 270 square kilometres of lakes will have been created, when the reclamation process is completed. Currently up until today, there are around 210 square kilometres

already completed. However, many of the emerging post-mining lakes are highly acidic and the overburden dumpsites have a high acid potential. Therefore, a long-term concept for neutralizing the lakes was required. The targeted introduction of neutralizing agents by specialized ships has proven to be an effective and economically sensible method, in order to solve the evolving problems. LMBV constructed a ship, that is able to reach that special task and it started the service in 2016. Another method for neutralization of the lakes is the introduction of the agents via stationary facilities.

These new, artificially created water landscapes consist of more than 50 larger lakes, some of them connected by canals. Boats and excursion ships can use these canals. At the same time, the lakes have become important resting places for migratory bird species in particular, such as geese, cranes and swans, and provide valuable breeding habitats for native bird species.

Rehabilitation of dumpsites

Open dumping areas covering more than 300 square kilometres in the Central German and Lusatian mining districts were inaccessible to the public and in some cases caused considerable dust pollution.

One prerequisite for restoring the landscape for later use was the shaping of the nearly 1.200 kilometres of steep open pit embankments into secure grounds. Only about 44% of them were so-called naturally grown open pit slopes. The majority of the embankments, with a length of 670 kilometres, resulted from the dumping of overburden, which causes special geotechnical and soil-mechanical requirements.

In the Lusatian lignite mining district in particular, the shape and grain size of the Pleistocene sands make this un-compacted overburden prone to settlement flows and extensive ground fracturing. Elaborate methods for the compaction of embankments and inner-dump sites have been developed and are now in use. Up until today, around 1.2 billion cubic metres of dumped soil mass has been compacted for the long-term, thereby securing hundreds of kilometres of embankments. The securing of inadequately stable inner-dumpsites is a current focus of the LMBV.

These inner dumpsites can serve a variety of subsequent uses. From more than 1.000 square kilometres of mining area, 385 square kilometres have been restored as forest and 115 square kilometres as agricultural land so far. The process of biological revegetation had already begun in the GDR, but under difficult economic and technological conditions. Therefore, in addition to the ongoing rehabilitation, older areas are also being improved by LMBV.

The careful cultivation of the soil and the restoration of soil functionality is a central task of biological revegetation.

For this purpose, the top metre of dumped substrates is soil-geologically analysed and treated with lime and the macronutrients of nitrogen, phosphorus and potassium (NPK), based on expert opinion and reports. The remediation includes the loosening of heavy compacted topsoil. By seeding a protective plant cover, erosion by wind and water is prevented, the introduced fertilizers are fixed, and initial soil development is induced. The goal is to initiate and establish nutrient cycles and soil life.

The aim is not to restore the original landscapes, as they existed before the beginning of intensive and extensive mining operations in the 19th century, but to create landscapes that are integrated into the natural balance, while meeting modern-day requirements for use. In this way, undesirable developments of the past, such as heavy deforestation in the Central German mining district, can be corrected. For example, the forest area around the Leipzig-Halle urban region had shrunk to 10% when the mining process took place. It will increase to more than 30% upon completion of the mining reclamation work. In Lusatia, the share of forest area will eventually reach about 50%, compared to the size as it was in the mid-19th century in the areas affected by mining.

Since 1991, lignite reclamation has thereby enabled the long-term sequestration of over 4 million metric tons of CO2 into the soil and forest. Every year, an additional 86.000 metric tons of CO2 are fixed into biomass and the soil. The restoration of usable terrestrial ecosystems can therefore contribute significantly to carbon sequestration.

These terrestrial systems, nevertheless, also play an important economic role in the production of food and fodder, as well as in the production of renewable raw materials.

Pollution (chemical contamination)

Fly ash and sulphurous flue gases were everyday occurrences in the vicinity of the lignite refining plants. A result was the severely altering of forest and agricultural soils. The ecology of the forest was disturbed and specially adapted biological communities formed in response to the high levels of ash.[19] However, the acidic, sulphurous flue gases also led to large-scale forest dieback. Biological revegetation was made more difficult by these emissions. Only a few tree species could be planted successfully under these environmental conditions.

Much more long-term and serious, however, are the effects of mining-related impacts on the groundwater and on surface waters in the lignite mining regions, due to pyrite weathering, as well as the severe salt contamination of some rivers due to the leaching of potash-salt tailings.

A long-term consequence of lignite mining is the weathering of the iron-sulphur minerals of pyrite and marcasite into the ground, and the leaching of decay products into surface waters. Acid, sulphate and iron are released into surface waters via the groundwater. This leads to changes in the ecological properties of the affected streams. The extraction of drinking water via bank filtration is consequently impaired.

The open dumping areas of the opencast lignite mines were geotechnical unstable, highly acidic primarily due to iron-sulphur mineral weathering and were frequently too deep. The rehabilitation work therefore involved extensive amounts of earthmoving and the generation of fertile soils.

Biodiversity

Mining, especially opencast mining, destroys the existing landscape, its functional networks, the habitats of plants and animals, and has negative effects on the water

[19] Hartmann P., Fleige H., Horn R. 2009: Veränderung bodenphysikalischer Eigenschaften von Humusauflagen auf ehemals flugaschebeeinflussten Waldstandorten der Oberlausitz. In: Waldökologie, Landschaftsforschung und Naturschutz, Edition 8, pages 41– 52

balance. Biodiversity, the abundance in terms of quantity and variety of species, decreases in the exploited area. Therefore, according to European law, it is mandatory to implement so-called CEF (Continuous Ecological Function) measures for NATURA 2000 protected species before any intrusion takes place, i.e., to create or to find fully-functional replacement habitats, and to relocate the corresponding species. Suitable new habitats must then be re-established during the rehabilitation process.

Post-mining landscapes, such as those of the former lignite mining industry, are particularly suitable for reclamation by strengthening the green infrastructure of a region. The protected areas of the European NATURA 2000 network are central to these efforts. In the post-lignite-mining landscapes, more than 88 square kilometres of Fauna Flora Habitat (FFH, now known as Special Areas of Conservation, or SAC) and over 220 square kilometres of Special Protection Areas (SPA) have been designated for the protection of endangered species of flora and fauna and wild bird species.[20]

Successful rehabilitation, in turn, provides new habitats and long-term refuge for protected and increasingly rare species of flora and fauna. Their success is remarkable and can be attributed to the ecological niches of the former opencast mines and dump-sites.

Firstly, rehabilitation creates habitats that are comparable to the surrounding cultural landscapes, i.e., agricultural areas or managed forests. Secondly, it creates habitats that have become rare, e.g., poor, open sandy soils, undeveloped riverbanks, wet meadows, and many other areas that are considered unproductive. Thirdly, creating landscapes that did not previously exist in the natural areas. These include ash-containing soils, saline soils, highly acidic dumping areas that were deliberately not ameliorated, and the large, deep post-mining lakes.

This mix of heterogeneous habitats provides a home for 31% of Germany's vascular plants, 68% of amphibians and over half of indigenous wild bees, wasps, grasshoppers and spiders, as well as 60% of the bird species that breed in Germany. The large post-mining lakes have become important resting places for migrating bird species such as cranes, swans and geese.[20] More than 15% of LMBV's post-mining landscapes are specifically used for nature conservation purposes and have been transferred to foundations and associations.

Social effects

Workplace closures on this scale, such as those that took place in the lignite and potash industries in the early 1990s are always associated with massive job losses. In 1989, the lignite industry alone employed around 150.000 people. Ten years later, this figure had shrunk to around 10.000 employees. In the potash, spar and ore mining operations, the number of employees shrunk from around 29.000 to just a few hundred. In addition to their personal fates, this also had dramatic consequences for the entire respective region. By the end of the 1990s, regional unemployment rates had reached 22% in the potash district and 23% in the Lusatian mining district. Without mine

[20] Landeck I., Kirmer A., Hildmann Ch., Schlenstedt J. 2017: Arten und Lebensräume in den Bergbaufolgelandschaften – Chancen der Bergbausanierung für den Naturschutz im Osten Deutschlands. Shaker-Verlag, 560 p.

reclamation and the associated deliberate employment of many former miners, these numbers would have been much higher. [21,22,23]

For this reason, the planning and realization of mine reclamation measures were aimed at achieving a high impact on employment levels and were actively supported by subsidies from the Federal Employment Agency. In the competitive awarding of contracts for lignite reclamation activities, contractors were required to employ eligible workers. In the first phase of reclamation, up to 1995, the number of employees in subsidized jobs rose to more than 17.000. An additional 7.000 jobs were secured with subcontractors, by maintaining the purchasing power held in the mining districts and by the management organization for mine reclamation, LMBV.[24]

In other words, the remediation of ecological damage was also utilized to stabilize labour markets in those regions. Nevertheless, some level of migration out of the regions was unavoidable. Between 1991 and 2009, the labour force fell by more than 180.000 in the relevant municipal districts ("Landkreise") of the Lusatian mining district, and by around 165.000 in those of the Central German mining district. At the end of 2010, there were almost 294.000 and 328.000 fewer people living in the two regions, compared to 1990. Lusatia lost 17% of its population over these two decades. Parts of the Central German mining district lost a similar amount. [25,26,27]

The example of the small town of Hoyerswerda, located in the middle of the Lusatian lignite-mining district illustrates this impressively. In the 1950s, this small town, with its population of just a few thousand, was developed into the GDR's second model socialist city and grew to a population of 71.000 by the early 1980's. Its population was one of the youngest in the GDR, with and average age of approx. 30 years. It suffered a population loss of almost 60% by 2019, and the average age has risen to 52 today, well above Germany's average age of 44.7 (2021). [28,29,30]

3. Statutory Framework and Provisions for Mine Reclamation and Rehabilitation

In principle, mining operations in Germany are either subject to the Federal Mining Act (BBergG) or, in addition, to the special excavation rights and building regulations of the individual federal states regulated under building law. In addition, the mining company

[21] Drebenstedt C., Kuyumcu M. (Hrsg.) 2014: Braunkohlesanierung, Springer-Verlag, p. 12
[22] Rudolph H. 1990: Mitteilungen aus der Arbeitsmarkt- und Berufsforschung, 23.Jg./1990 Offprint, p. 474-503
[23] Motzkus A. 2001: Regionale und strukturelle Aspekte der Arbeitslosigkeit in Ost und West. In: Informationen zur Raumentwicklung. Edition 1/2001, 10 p.
[24] Drebenstedt C., Kuyumcu M. (Hrsg.) 2014: Braunkohlesanierung, Springer-Verlag, p. 28
[25] Vetter M. 2012: In: 20 Jahre Verwaltungsabkommen Braunkohlesanierung– Geschichten und Gesichter der Braunkohlesanierung, p.56
[26] Fritz, W. 2001: Historie der amtlichen Statistiken der Erwerbstätigkeit in Deutschland. Historical Social Research, HSR - Supplement No.13. Cologne: ZA – ZHSF. Amtliche Statistik der Erwerbstätigkeit in der DDR. GESIS Data archive, Cologne. ZA8078 Data file version 1.0.0, https://doi.org/10.4232/1.8078
[27] Zundel et al 2016: Strukturwandel in der Lausitz Wissenschaftliche Auswertung der Potentialanalysen der Wirtschaft der Lausitz, from 2010, 107 p.
[28] Wikipedia 2023: https://de.wikipedia.org/wiki/Einwohnerentwicklung_von_Hoyerswerda
[29] Stadtverwaltung Hoyerswerda 2020: Strukturdaten der Stadt Hoyerswerda nach Stadt- und Ortsteilen, 2019
[30] Handelsblatt 2023: https://www.handelsblatt.com/politik/deutschland/hoyerswerda-die-stadt-der-alten/4321432.html

must also generally implement and observe federal and state regulations from water, immission protection, environmental and nature conservation law, as well as the associated, in some cases, special approval procedures.

The remediation of public hazards after the end of mining operations as well as the creation of an area suitable for subsequent use, and which is in line with public interest, are the fundamental obligations of a mining company.

Environmental law in the countries of the European Union is based predominantly on European directives, such as the directive on the conservation of wild bird species (Special Protection Areas, or SPA), the fauna flora habitat directive (Special Areas of Conservation, or SAC), and the Water Framework Directive (WFD), which are integrated in the NATURA 2000 objectives. An additional directive on soil protection is being developed. This comprehensive environmental legislation on soil, water and nature protection, immission control, as well as strict occupational health and safety laws and laws on regional planning, must be followed both when a new mining project is initiated and during its rehabilitation.

According to the federal Regional Planning Act and the planning laws of the federal states, regional spatial development plans define the boundaries of a mining operation, its required infrastructural facilities and the future landscape once mining operations have ceased. These decisions are made in regional committees and are confirmed by the respective federal state. The regional committees consist of public authorities, interest groups, social, cultural and religious representatives, and representatives of the municipalities connected to the plan. The plans are made available to the public. Citizens and stakeholders (public agencies) get the opportunity to ask questions, raise concerns, comment on certain parts, raise objections and to file lawsuits.

Permits for intrusions into the natural foundations of soil and surface and groundwater, as well as for the destruction of nature, subsequently require separate approval procedures. Planning approval procedures involving extensive environmental studies are required. An extensive approval process that includes the obligation to provide adequate compensation also precedes the removal of existing infrastructure or even human settlements.

Regional plans in Germany usually cover a time horizon of 10 to 15 years, and then undergo further development. However, the reclamation of the opencast mines goes well beyond this time lab, so that high forecasting requirements have to be set during the planning. An example will illustrate this: The regional plans for the reclamation of LMBV opencast mines were developed and adopted by the mid-1990s. Classic uses such as agriculture (15%), forestry (40%), and the emerging post-mining lakes (25%) and, as a new concern, large open areas for nature conservation (7%), were the dominant target usage categories. The percentages show the rounded summary area shares for the Lusatian and Central German mining districts of LMBV. The remaining areas are commercial areas, areas for tourism and areas for the management and operation of the lakes. Areas for renewable energies were not yet in focus. Since then, the post-mining landscapes have become a hotspot for wind power and solar installations. Within a few years, the proportion of land used for renewable energy grew to more than 4% of rehabilitated dumping areas, and further expansion now competes

with the land use targets that were confirmed in the regional plans of the 1990s. In the future, floating PV systems may also be installed on selected post-mining lakes.[31]

Meanwhile, the energy transition is also underway in the post-mining landscapes. So far, LMBV has sold about 1.770 hectares of land for the usage of photovoltaic systems and another 1.550 hectares for the usage for wind turbines. Moreover, the potential has not yet been exceeded. Further amounts of additional land will be developed over the next few years.

The example of the LMBV is also unique in legal aspects. The obligations resulting from the former GDR mining operations, opencast mines, tailing piles, groundwater lowering and environmental damage had to be assessed after the reunification on the now new, federal legal framework. The same applied to the problem of groundwater recharge after the cessation of mining dewatering.

This encountered various legal and factual difficulties, as in the course of time the mining regulations in the GDR had developed differently from those in the Federal Republic of Germany.

For example, in 1947 various legal regulations of the provincial governments in the GDR expropriated mines and mineral resources and transferred their property and rights (assets) to the people's ownership. Moreover, according to GDR mining law the responsibility for the process of rehabilitation was divided: reclamation work became an obligation of the mining company; the subsequent user was responsible for the re-cultivation. In contrast, according to the Federal Mining Act (BBergG) obligations of mining companies also include use-oriented re-cultivation measures.[32]

Within the framework of the reunification of Germany on October 3rd 1990, regulations were created in the Unification Treaty, which took into account and harmonised the differences between the regulations of the GDR mining law and the Federal Mining Act (BBergG).

In general, it is decisive for the mining law responsibility of the LMBV whether the legal predecessors of the LMBV carried out all the work required under the GDR mining law provisions at the time of the cessation of operations. If all legally required work was properly carried out at that time and mining operations were discontinued, any present-day hazards are in general the responsibility of the federal states (“Länder”) under police law. If the reclamation was not yet completed or if the extraction phase continued beyond October 3rd 1990, the LMBV is in principle obliged to rehabilitate the site in accordance with the Federal Mining Act. Sometimes individual cases differ from that general perspective.

4. Institutional Framework for Monitoring and Evaluating Mine Rehabilitation

The monitoring and evaluation of mine rehabilitation is carried out at various levels in Germany.

[31] www.lmbv.de

[32] Piens/Schulte/Graf Vitzthum, Bundesberggesetz, 3. Auflage 2020, Kohlhammer Verlag

a) Mining activities, from exploration, extraction and processing to mining and reclamation, are subject to legal regulations, in particular the Mining Act (BBergG). Typically, for each step, a corresponding plan must be submitted to the relevant authorities for approval, or for subsequent authorization within an approved framework. Along with their approval or authorization, authorities impose conditions for the monitoring of reports and documentation that must be submitted. This so-called “mining supervision” does not end until the plans are fulfilled and there is no more danger to third parties, to other mining operations and storage sites, or of any harmful impacts to the public expected for the future. If that is the case, the mining supervision ends by law, without any administrative act by the mining authorities. Nevertheless, it has become a habit, that the mining authorities declare the end of the mining supervision.

b) Economic viability must be demonstrated, particularly with regard to the remediation of hazards to people and environmental assets resulting from the approved mining activities. The relevant authority may require reserves and collateral.

c) Authorizations for the further continuation of mining activities within the approved framework are only granted for a limited period of time. Further continuation, evidence of compliance with the conditions imposed in a permit, e.g., progress reports on rehabilitation efforts that are carried out in the interim, surveying documents and environmental reports, must be submitted.

d) Companies are also required to report to regional planning associations, if appropriate.

e) Approvals and permits from the environmental authorities (water, immission control, soil protection, nature conservation, etc.) have to be additionally obtained from the respective authority and settled. In addition, the respective competent authorities may in principle issue further administrative acts.

As a special case of a mining company, the LMBV must, also comply with the above-mentioned regulatory obligations within the framework of the obligations described in section 3. In addition, however, there are further levels of control and monitoring.

LMBV is a federally owned company and is therefore obliged to report to its shareholder, the Federal Ministry of Finance, and in certain cases is subject to directives. Furthermore, any activities not related to mine reclamation, e.g., the sale of land, must be reported to a supervisory board, the “Steuerungs- und Budgetausschuss der Braunkohlesanierung” (StuBA)

It is a unique committee consisting of federal representatives and representatives of the state ministries of the four federal states of Brandenburg, Saxony, Saxony-Anhalt and Thuringia.

The committee has to make decisions about financing the projects of the LMBV. The LMBV itself, as the project management organisation for mine reclamation, plans the relevant projects and submits the connected financial applications to the StuBA. The Office of the StuBA has to check the applications and has to monitor the expenditure of the tax money, provided by public funds from the federal government and the four federal states involved. The base for this fund is a treaty between the federal

government and the four federal stats mentioned above, with a maximum amount of tax-money for a five-year period.

LMBV owns an extensive digital map series. Surveying from the ground or from the air by helicopter or airplane (airborne) keeps the data constantly up to date. Annual aerial photographs document the changes in individual reclamation projects over the entire landscape. Map series and their regular updating are to be handed over to the mining authorities by the mining companies. The maps must be complete and correct. The company's special mining surveyor, in German the Markscheider, is liable for this. This system of public control, developed over centuries, ensures reliable map series over the years from the beginning of the mine until the last step of re-cultivation.

The companies contracted for reclamation activities must submit extensive evidence of their work, the materials used, the proper disposal of waste, etc. LMBV documents the origin and recycling of waste separately and prepares an annual report for the authorities. Every year, the LMBV commissions contracts worth several hundred million euros, following a competitive public procurement process.

LMBV has an extensive measurement network for monitoring the groundwater in terms of both quantity and quality. Several thousand measuring points provide the data either directly or through on-site monitoring. The created lakes and the rivers connected to them are sampled regularly. Geotechnical sensitive areas have a separate measurement network, detecting immediately any changes within the dangerous areas.

LMBV prepares the results for its final documentation, in order to request the termination of its mine supervision for a specific area from the responsible mining authority.

5. Key Institutions Involved in Mine Reclamation and Rehabilitation

In the Federal Republic of Germany, the responsibility for the approval, monitoring and termination of mining activities lies with the individual federal states. The mining authorities are state-level authorities and perform their duties in accordance with the Federal Mining Act.

Since mining is always a spatial undertaking, state planning must decide on the basic permissibility of a mining project. Each federal state has a state planning structure, which may be further subdivided into planning regions.

Mining cannot take place without impacting environmental systems, air, soil, water, as well as flora and fauna. Accordingly, these specialized authorities play an important role at every step of mining activities.

LMBV also goes a step further here. The specific design of a reclamation measure is presented to and agreed upon in regional working groups in the respective federal states. These regional working groups submit a vote on the implementation of a specific reclamation measure to the StuBA.

Finally, the mining companies are involved in mine reclamation and re-cultivation.

6. Financing Arrangements for Mine Reclamation and Rehabilitation

In accordance with the *polluter pays* principle, each mining company is solely responsible for rehabilitation of the affected areas in line with the public interest. This also applies to any resulting financial obligations. Companies are required by commercial law to set aside financial reserves during the operational period of mining, which are used for rehabilitation after the end of the operation. Auditors certify the amount of the financial reserves annually. Moreover, the mining authorities check the reserves in terms of reason and amount and so these reserves are constantly adjusted according to rehabilitation needs. In addition to the reserves, there may be also precautionary agreements between mine operators and federal states that financially secure the fulfilment of the re-cultivation obligations after the end of active mining.

The situation is different in the cases of mines with cessation of mining operations before the time, when the Federal Mining Act (BBergG) was implemented on January 1st 1982.

If the mines were cessated before the implementation of the BBergG, the respective federal state is obliged to implement the necessary safety and danger prevention measures in accordance with the relevant police law provisions by itself, in order to eliminate dangers to public safety and order. These historical mining operations pollute surface waters, for example, by releasing highly acidic runoff containing heavy metals. Remediation is therefore the responsibility of the respective federal state. Mining rehabilitation is carried out to the extent necessary. In principle, there is no financial restriction.

As outlined, LMBV and its financing are an exceptional case. Since revenues of mining activities flowed into the GDR's state budget and there were no reserves, the LMBV is financed by funds from public budgets.

The federal government and the four participating federal states enter into consecutive public administrative agreements with a maximum amount over a five-year period. For this purpose, the respective remediation projects are defined in advance and then financed on a project-related basis proportionally with funds from the federal government and the respective states concerned (Brandenburg, Saxony, Saxony-Anhalt or Thuringia). The first administrative agreement was signed in 1992.

The Federal Government and the four federal states share the costs for mine reclamation either 75 % Federal Government and 25 % Federal States for the obligations based on the regulations of the BBergG, or 50% each for the implementation of police law based hazard prevention. The difference arises from the respective legal basis of a specific reclamation project. LMBV is currently working under the seventh administrative agreement. Activities that go beyond mine reclamation and serve the purpose of infrastructural development and subsequent use, such as harbour facilities, recreational beaches, bicycle paths, and the conversion of old industrial sites into tourist destinations, are financed in full by the respective federal state.

A total of 13 billion euros has already been spent on lignite reclamation between 1992 and the end of 2022.[33]

7. Role of Private Sector / Other Stakeholders and Local People in Rehabilitation

The mining industry in Germany is owned predominantly privately, but it is subject to state supervision. Accordingly, rehabilitation is also the sole responsibility of the respective private mining companies.

Germany has very active citizens' movements that are critical of mining activities in particular. This affects not only large opencast lignite mines, but also gravel quarries or the excavation of gypsum, or other minerals. The announcement of a project may lead to conflict with the local population or nationwide interest groups.

Minimising negative impacts of necessary interventions needs great effort on the part of the mining companies, but also the acceptance of the people affected.

Acceptance can be reached by a high level of transparency in the initial planning phase as well as a successful restoration of mining affected areas and it derives from the resulting satisfaction of all those involved.[34] Therefore, the LMBV established an internal process of including stakeholders, especially the people living close to a specific rehabilitation site. Informing and hearing them in the different stages of rehabilitation allows including concerns in the planning process and the technical realization. Beside the public relation department, the departments for planning, realization control and the legal department are involved.

8. Community Involvement and Engagement

An extensive planning process precedes the approval of a mining project. Various public interest groups are involved during the process. These include nature conservation groups, farmers and foresters, representatives of business and tourism, religious groups and minority groups like the Sorbs and Wenden in Lusatia. The planning and approval process goes through several stages in which the planning status is available to the public and local hearings take place in the areas affected. The development of LMBV's reclamation plans applies to the same process. They were developed as special plans within the regional development planning process.

The municipalities have planning sovereignty in their municipal area. They have to set up urban land-use plans as soon as and to the extent necessary for urban development and order. When setting up these urban land-use plans, a large number of public concerns, including those of regional and federal state planning, must be taken into consideration.

[33] LMBV 2023: Finanzierungsgrundlagen https://www.lmbv.de/unternehmen/finanzierung/

[34] Müllensiefen K et al. Tagebau im Spannungsfeld zwischen Eingriff und Ausgleich. In: Der Braunkohlentagebau. Berlin: Springer. 2009.

Municipalities on the other side have the right to participate in the development of super-ordinated planning on a regional and a federal level. This means that the rehabilitation objectives defined in the regional plan for an area affected by mining can be influenced by municipal demands. Alterations require the approval of the municipality.

The post-mining landscapes developed into desirable residential and tourist destinations. LMBV's mining reclamation laid the foundation, and additional public and private investments have created exclusive residential areas, harbours, floating houses and recreational beaches. Former mining towns have changed their very character.

9. Academic and Research Institutions Involved, and their Contributions

In the specific case of lignite reclamation, a major deficit of knowledge existed at the beginning. It existed in two directions. On the one hand, the level of knowledge about the scope of the task, as well as the affordable technologies required for it, had to be developed. On the other hand, more ambitious solutions integrating ecological, economic and social aspects needed to be pursued in order to achieve the goal of sustainability set at the UN Conference on Environment and Development in Rio de Janeiro in 1992.

From the year 1994 to the year 2000, nearly one hundred joint and individual research projects accompanied lignite reclamation. The Federal Ministry of Research and Education had launched a research program for this purpose. Topics included geo-technology, groundwater quality and water treatment for lakes, soil and biological revegetation, nature conservation, limnology and fisheries, remote sensing and socioeconomics, as well as the treatment of contaminated sites. The results of this research raised mine reclamation to a new level. During the following years and up to today, research projects have accompanied mine reclamation and have led to innovations. Above all, LMBV directly facilitates applied research projects that have a high probability for implementation. Advisory boards of representatives from universities and scientific institutions support LMBV in this endeavour. At national and international conferences and symposia, LMBV reports on its reclamation results and the technologies utilized. Additionally, dissertations and post-doctoral theses at universities also accompany mine reclamation.

10. Capacity Building on the Rehabilitation of Mining Areas

Mine reclamation and the remediation of environmental damage in the area affected by mining require a great deal of staying power. This therefore requires, for one thing, well-qualified personnel at the institutions concerned. At German universities, colleges and scientific establishments, institutes have emerged that deal specifically with the management of legacy mining sites. Questions concerning the long-term stability of dumpsites and embankments, the effects on ground and surface waters, the impact on nature, and even social and economic consequences are being addressed scientifically.

There is a need of companies that can perform reclamation tasks. For this reason, a ground-breaking decision was made at the beginning of lignite reclamation. LMBV is both the project management organization for mine reclamation and the legally responsible company under mining law, but it is not the entity that carries out work projects. Tendering and awarding the work in compliance with procurement and competition law is the standard process. This applies to both surface and underground work. The same also applies to scientific and expert appraisals. This has created a market for the rehabilitation of mining areas and the prevention of hazards. As a result, innovative technologies have emerged, technical and scientific expertise has broadened, and costs have fallen. Examples include the verifiable and targeted compaction of loosely deposited substrates to depths of greater than 50 m over hundreds of square kilometres, the low-energy and cost-effective treatment of geogenic (naturally occurring) acidic lakes, the underground treatment of acidic, sulphuric groundwater, and the restoration of fertile soils derived from extreme substrates that are hostile to vegetation. Companies have already successfully utilized those technologies developed all over the world. In addition, technologies developed for mine reclamation are also applicable, with some adjustments, to other fields of work.

Through consultation and project support, LMBV has also contributed to capacity building in other countries, e.g., China, Vietnam, South Korea, Mongolia, Peru and Brazil, as well as European countries.

11 Challenges and risks

The challenges and risks of lignite-mine reclamation lie in its sheer size and scope, the long timeframe required, the funding required the changing demands of society over time, and the impacts of climate change.

The latter, in particular, makes it difficult to achieve the goals of 1990. The frequency of very dry years has increased significantly, and there has been a rise in average temperatures, with new peaks being reached during the summer months. As a result, evaporation is increasing and the available water in rivers and streams is decreasing. Due to the planned phase-out of coal in a few years, this deficit will increase even more, because those pits left-over by still-producing lignite mining companies will then also have to be flooded, and the water that is currently being pumped out for the extraction process will no longer be available.

The high peak temperatures, heavy precipitation, storms and associated secondary damage to forest trees are all damaging native forest vegetation. Agricultural land is losing productivity. This endangers the rehabilitation work of the LMBV.

On behalf of LMBV, a study is being prepared that will predict the effects of climate change and the phase-out of coal on both previous and future mine reclamation activities, as well as on the post-mining landscapes. The climate scenarios to be used in the forecast calculations were coordinated on a cross-border basis. The internationally renowned Potsdam Institute for Climate Impact Research (PIK) has laid important technical foundations for this. A recent study by the German Environment

Agency (UBA) on the consequences of the phase-out of lignite mining in Lusatia and Central Germany highlights additional needs for action.

Concepts have been developed for biological revegetation that allow for an even greater degree of proper, preparatory treatment of the soil. The intention is to improve the important soil functions of water storage and nutrient exchange sustainable. Furthermore, the expansion of the plant spectrum in biological revegetation is tested.

The reclamation work of LMBV is not yet finished. LMBV will continue to operate in these regions for several more decades, until the tasks it was given have been completed.

12 Replication considerations

The experience gained from the reclamation of the lignite and potash industries in eastern Germany shows that starting rehabilitation work at the end of mining processes is the most complex and expensive option. It is therefore crucial to take rehabilitation into consideration as early as the planning stages of a future mine, to incorporate rehabilitation measures while excavation and the dumping of overburden are still ongoing, to accompany this with the creation of vegetation-friendly soils as well as their greening, and to intensively examine the effects of any interventions on the water balance.

The involvement of the local population and professional authorities is also important. Local knowledge and expertise as well as the consideration of legitimate concerns generate trust and prevent mistakes.

Mining and rehabilitation activities reach far into the future. Good forecasts are therefore important. Consequently, studies of alternative scenarios under different climatic conditions are necessary.

Spinning off economically viable units from the oversized burdens of past mining activities can be a way for a region to retain economic power, jobs and industrial expertise. However, these new economic units must be monitored and given an appropriate share of the reclamation work.

Mining reclamation projects are complex, costly and time-consuming. Financing that is aligned with the progress of reclamation and the strict control of cash flows are crucial in this context. For this purpose, LMBV has a close-knit, multi-level monitoring system consisting of internal and external controls.

The generation of knowledge and innovation was crucial for the success of LMBV. Therefore, large reclamation projects should be scientifically supported and economic incentives for innovation should be created.

13 Rehabilitation of open-cast lignite mine Espenhain – Transforming an industrial mining region into a near-natural post-mining area

Part 2: Best Practice Details	
1. Title	**Rehabilitation of open-cast lignite mine Espenhain – Transforming an industrial mining region into a near-natural post-mining area**
2. Responsible Agencies/ Institutions	Funding provider: **Federal Ministry of Finance** (BMF) and **Federal Ministry of Environment** (BMUV) in cooperation with the four affected **Federal States** (Länder), based on a joint Administration Agreement. Responsible project agency: **Lusatian and Central German Mining Administration Company** (LMBV)
3. Description	After the reunification of Germany in 1990, non-market competitive mining activities of the former GDR were terminated within a few years. In order to manage the **rehabilitation of state-owned opencast lignite mines of the former GDR**, the German Government established the **state-owned mining rehabilitation company** LMBV for this unique case. The LMBV is responsible for 100 former industrial sites, 224 pit-holes spanning 1000 square kilometres, 1,200 legacy-sites and a dewatered groundwater-cone of 2,600 square kilometres. Additionally, LMBV is responsible for the closed down potash-, salt- and ore- mines of the former GDR. One example of their work is the **rehabilitation of the former opencast mining area "Espenhain"** close to the city of Leipzig, which had active mining activity from 1937 to 1996. At a size of around 40 square kilometres, 570 million tons lignite were extracted, 1.7 billion cubic metres overburden were removed and 14 villages were destroyed. The Espenhain mining and large power plant complex was one of the most important lignite-based industrial complexes in Germany combining a power plant, briquette factory, smelter and facilities for processing smelter products. At the end of the GDR the complex was regarded as "nation's industrial polluter". Mining and production activities caused severe **impact on the water regime** south of the city of Leipzig as well as massive **air and water pollution**. The rehabilitation work was carried out with the **aim** of **normalizing the area's water balance**, integrating the resulting lakes **into the post-mining landscape**, and offering the surrounding communities conditions for **attractive recreational areas**. The **overall results** are the creation of **two lakes** with a size of 12 square kilometres in total, new **forests** on 10 square kilometres and designated nature protected areas. The creation of two lakes was for reasons of public acceptance and a result of involvement of locals in the planning process. Additionally, there are now high-quality **touristic resorts** and public **leisure areas**, which benefit the local population. Furthermore, the former mining area is now being used for **photovoltaic power plants** as well as **industrial parks** and the University of Leipzig has built a **science-campus** on the former mining grounds. Looking on some **specifics of rehabilitation work**: One of the central tasks in mine rehabilitation was the **construction of geotechnical safe slopes**. For this purpose, more than 80 million cubic meters of soil were moved along the more than 30 km long embankments. The existing mining technology was used for this purpose. Carrying out the **flooding**, 220 million cubic metres of water – by rising groundwater, water from the adjacent rivers and by drained water from an adjacent privatized opencast lignite mine – create two lakes. Active flooding shortened the time of filling

	of the two lakes by 50 to 60 years. The flooding was accompanied by extensive **monitoring of the groundwater in terms of quantity and quality**. A large-scale hydrological model was used to forecast the effects in the area surrounding the opencast mine. Today, it is used for further water management control. Acidification of one lake due to acid mine drainage (AMD) caused by pyrite, is a challenge. Regular liming by a special rehabilitation vessel counteracts this process. 140,000 cubic metres of **soil was compacted** to establish geotechnical safety in the former opencast mine area. Different technologies of vibro-compaction were used. **Dismantling of buildings, demolition and scrapping of equipment** resulted in 141,000 tons of waste. In total, 427,700 tons of waste had to be disposed of in the former industrial complex. The total costs of the rehabilitation project Espenhain covered by LMBV, are about 290 million Euro.
4. Lessons Learned	The experience gained from the reclamation of the lignite industries of the former GDR shows that **undertaking rehabilitation work at the end of mining processes** is the **most complex and expensive option**. It is therefore crucial to consider rehabilitation as early as the planning stages of a future mine, to **incorporate rehabilitation measures while excavation and the dumping of overburden are still ongoing**, to accompany this with the creation of vegetation-friendly soils as well as their greening, and to intensively examine the effects of any interventions on the water balance. The **involvement of the local population and professional authorities** is also important. Local knowledge and expertise as well as the consideration of legitimate concerns generate trust for sound planning processes. Mining and rehabilitation activities reach far into the future. **Good forecasts** are therefore important. Consequently, studies of alternative scenarios under different climatic conditions are necessary. Moreover, the **generation of knowledge and innovation** was crucial for the success of LMBV. Mining reclamation projects are complex, costly and of long duration. Financing that is aligned with the progress of reclamation and the strict control of cash flows are crucial in this context. For this purpose, LMBV has a close-knit, **multi-level monitoring system** consisting of internal and external control.
5. References	"Views - Redevelopment and re-cultivation of mining landscapes / Einblicke - Sanierung, Sicherung und Rekultivierung von Bergwerken und Tagebauen" (https://www.lmbv.de/wp-content/uploads/2021/04/LMBV_Einblicke_2017_deutsch_englisch.pdf) "Preparing the Ground for the Future - Mine Re-cultivation" (https://www.lmbv.de/wp-content/uploads/2021/10/LMBV-Broschuere-Rekultivierung-englisch-WEB-1.pdf) – this publication is also available in German, Spanish, Chinese and Russian "Espenhain" Wandlungen und Perspektiven, Mitteldeutsches Braunkohlen-revier Band 2, (https://www.lmbv.de/wp-content/uploads/2021/04/doku-02_Espenhain.pdf "Sanierungsplanung Tagebau Espenhain" Wandlungen und Perspektiven, Mitteldeutsches Braunkohlenrevier, Band 24 (https://www.lmbv.de/wp-content/uploads/2021/04/doku-24_Sonderheft-Espenhain.pdf)

	The area of the open-cast mine “Espenhain” in the 1990s and results of rehabilitation activities:  

LMBV 2023

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