European Commission

Guidelines for Mine Closure Activities and Calculation and Periodic Adjustment of Financial Guarantees

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ABSTRACT

The Directive 2006/21/EC3 on the management of waste from the extractive industries ("the Directive" or "EWD") provides minimum requirements, procedures and guidance to prevent or reduce as far as possible any adverse effects on the environment and any resulting risks on human health from the management of extractive waste. The Directive requires the competent authority to demand a financial guarantee (FG), prior to commencement of any operations involving the accumulation of extractive waste.

In this context, the EWD requires the Member States (MS) to ensure that the operator draws up an Extractive Waste Management Plan (EWMP). The EWMP must include a closure plan, including site rehabilitation, after-closure procedures and monitoring. For waste facilities that require a permit, the EWMP is part of the permit application. The FG is to be established in accordance with procedures to be decided by the MS. The guarantee is lodged at the pre-operational phase and based on anticipated closure measures and their implementation cost, e.g. as specified in the EWMP. Since the operational phase of a mine might last for several decades, there is a degree of uncertainty associated with the FG. The EWD addresses this issue by requiring a review of the EWMP every 5 years and the FG periodic adjustment in accordance with any rehabilitation work needed to be carried out as described in the EWMP. For the closure and after-closure phase, the EWD requires MS to ensure that the operator requests an authorisation to start the closure procedure. This request is based on the latest periodic review of the EWMP taking into account the actual environmental impact of the waste facility and elaborates in detail the closure tasks and programmes including expected costs. Some MS require a separate closure plan.

The Commission has adopted a Decision on technical guidelines for the FG establishment in accordance with the EWD. Some MS suggested to provide additional technical guidance for the implementation of the FG provisions. The present guideline document (GD) aims to support the EWD implementation by elaborating technical guidance for

- Collection and description of the Closure Best Practices by Mining Typology
- FG calculation prior to the commencement of waste deposit, and FG periodic adjustment;
- Elaboration of updated closure plans taking into account the environmental impact of the operations; and
- Approaches for determining the cost of the respective activities to implement the closure plan.

As specified in the Terms of Reference for this project, the scope of the GD goes beyond the EWD requirements for the closure of extractive waste facilities and includes FG approaches for wider aspects of mine closure (e.g. brownfields, wastes not directly resulting from mineral extraction, decommissioning of infrastructures used for mining but not for waste management, and closure of cavities that might cause risk to human and environment). The GD focuses on FG for decommissioning, closure, rehabilitation and after-closure of mine sites, related infrastructure and associated waste facilities ("closure of a mine site"). This includes all mines associated with Category A waste facilities (e.g. TMFs and heaps) for which FG are required by the EWD as well as other

mining objects for which the competent authorities might require further FG to ensure public closure and post-closure safety.

The GD considers all mining typologies, e.g. aggregates, ores, energy, and industrial minerals, with all types of extraction approaches (underground, opencast, and borehole mining). The GD comprises two main topics:

- description of the technical solutions for mine closure (sections 1 – 4), and
- documentation of cost profiles and cost-relevant activities for the technical measures of those solutions (section 5).

The GD for the technical solutions is structured in the following sections:

- Part A - Provisions on the Establishment of Financial Guarantees: this section deals with the FG role and purpose, the financial options and instruments, as well as their applicability and routines for establishment.
- Part B - General Provisions on Best Practices for Closure, Rehabilitation and After-closure Design: this section deals with the general approach to closure design options, the permitting and implementation requirements and quality assurance of implementation.
- Part C - Overview on Closure Best Practices by Mining Typology: this section deals with the mining typologies, and the specifics and challenges of aggregates, industrial, and energy minerals as well as ore mining. The section is supported by mine closure show cases.
- Part D - Cost Profile, Cost-Relevant Activities and Unit Cost: Cost profiles and unit cost were obtained from about 30 closure plans and related Bills of Quantities (BoQs) from implemented mine closure activities of the last 20 years, mainly from Northern, Central and Eastern Europe. The data were complemented with information from comparable rehabilitation works, for instance landfill closure and aligned with information on unit cost provided by the MS.

The considered closure activities concern tailings management facilities (TMF) rehabilitation as well as other mining facilities closure, like cavities, mine seepage water outlets and mine waste disposal sites. Through these shaft and mine waste heap closure activities will be ensured to prevent a future release of waste materials into the environment. It is to be noted that the GD does not refer to unforeseen liabilities according to Art. 6 EWD.

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ABREVIATION LIST:

AMD	Acid Mine Drainage
BAT	Best Available Techniques
BATNEEC	Best Available Techniques not Entailing Excessive Costs
BREF	BAT Reference Documents
BoQ	Bill of Quantities
CP	Closure Plan
CP	Cleaner Production
CWATUP	Walloon Code of Land Planning, Urban Planning and Heritage
DIN EN ISO	German Institute for Standardisation (German: Deutsches Institut für Normung e.V), edition of European Standards
EC	European Commission
EIA	Environmental Impact Assessment
EU	European Union
EM	Environmental Monitoring
EMAS	EU Eco-Management and Audit Scheme
ERTD	Environment Restoration Technical Design
ESTA	Electrostatic Separation
EWD	Extractive Waste Directive
EWIW	Extractive Waste Influenced Water
FIDIC	Federation Internationale des Ingénieurs-Conseils
FS	Feasibility Study
GD	Guideline Document
GOP	Good Operating Practices
ICMM	International Council on Mining and Metals
IEC	International Electro technical Commission
IED	Industrial Emissions Directive
ISO	International Organization for Standardization
ITA-AITES	International Tunnelling and Underground Space Association
LHD	Load Haul Dump
MS	Member State
MWEI	Management of Waste from Extractive Industries

NAG	Non Acid Generating (extractive waste)
NACE	National Association of Corrosion Engineers
NAMR	National Agency for Mineral Resources
NORM	Naturally Occurring Radioactive Material
OSPAR	Oslo/Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
PAG	Potentially Acid Generating (extractive waste)
PPE	Personal Protective Equipment
QMP	Quality Management Plan
PRODCOM	PRODuction COMmunaitaire (French)
SMART	Specific, Measurable, Achievable, Timely (development approach)
SME	Small to mid-size Enterprise
TD	Technical Design
TDS	Total Dissolved Substances
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
TFEU	Treaty on the Functioning of the European Union
TMF	Tailings Management Facilities
TOP	Technical Operation Plan
UNCLOS	United Nations Convention for the Law of the
VLAREM	Flemish Environmental Permitting Regulations

1. Introduction

1.1 General Introduction: Objective of the GD

The GD objective is the provision of guidance for the assessment of the technical framework and measures for FG establishment according to Directive 2006/21/EC on the management of waste from the extractive industries (the Extractive Waste Directive - EWD). Waste from extractive operations involves materials that must be removed to gain access to the mineral resource, such as topsoil, overburden and waste rock, as well as tailings remaining after minerals have been extracted from the ore (European Commission, 2019). Further, mining waste water or treatment sludge might result as residue. Figure 1 shows an exemplified scheme of the mining process (Schneider & Wolkersdorfer, 2021). The EWD as such focuses on FG for mine waste, means material that is indicated in brown colour in figure 1.

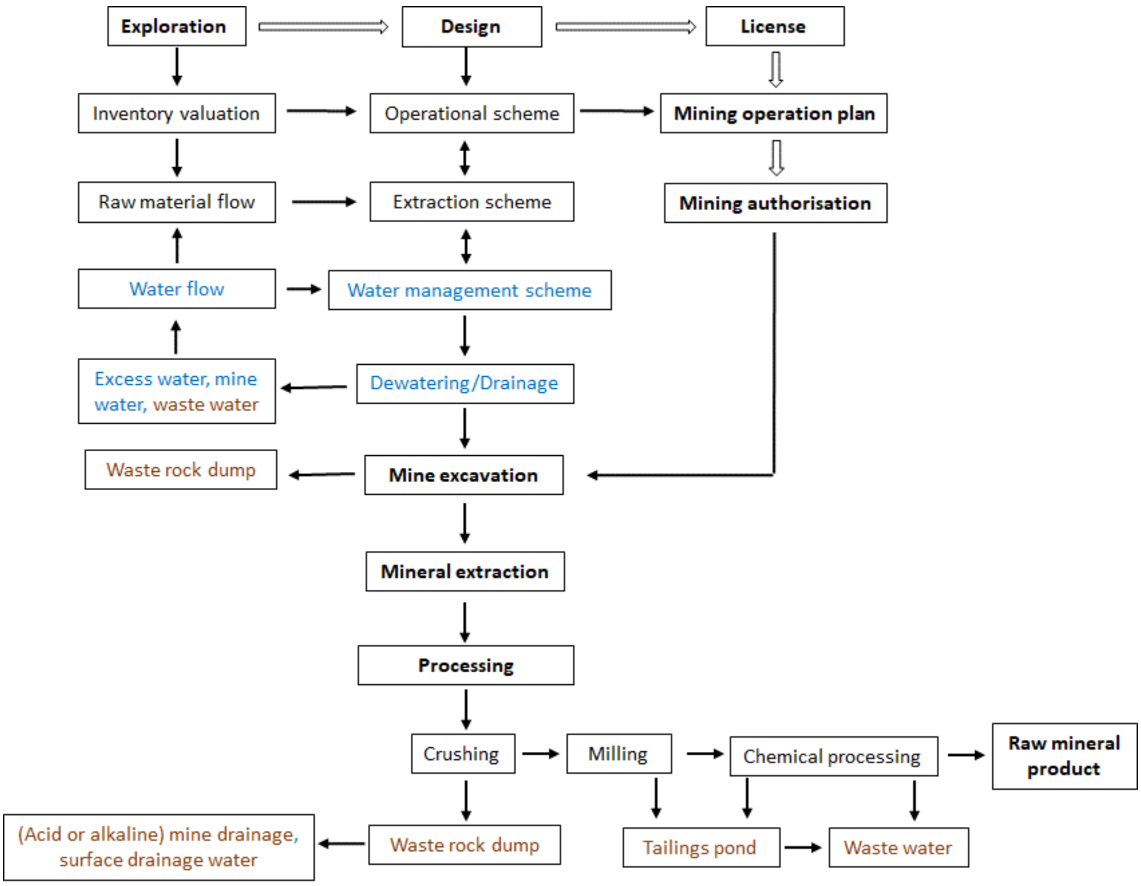

Figure 1: Exemplified scheme of mine design and mining process. Black words indicate activities related to mine preparation and operation, blue words indicate water-related flows and activities, words in brown colour refer to waste-related flows or activities (Schneider & Wolkersdorfer, 2021)

Mine waste might be inert and hence not likely represent a substantial pollution potential. However, other fractions, in particular those generated by the non-ferrous metal mining industry, may contain large quantities of dangerous substances, such as heavy metals or even radionuclides (European Commission, 2019). The extraction and subsequent mineral processing can foster metals and metal compounds to become chemically more available, resulting even in the generation of acid or alkaline drainage (figure 1). Tailings management facilities (TMF, also called tailings ponds) are intrinsically risky, as they are large ponds of mining residues retained by dams. The stored TMF material usually involves residual processing chemicals and elevated levels of metals. The collapse of dams or heaps may have serious impacts on environment and human health and safety (European Commission, 2019). Prominent examples are the accidents in Aberfan (Wales, 1966), Stava (Italy, 1985), Aznalcóllar (Spain, 1998), Baia Mare and Baia Borsa (Romania, 2000). Other likely significant impacts relate to the physical footprints of waste disposal facilities and resulting loss of land productivity, effects on ecosystems, dust and erosion (European Commission, 2019).

In practice, the separation of the closure activities for waste facilities from the closure and decommissioning of an entire mine site including its related infrastructure might be conceptually difficult. Therefore, the scope of the GD goes beyond the EWD requirements and includes FG approaches for the wider aspects of mine closure (e.g. mining brownfields, wastes not directly resulting from mineral extraction, decommissioning of infrastructures used for mining but not for waste management, closure of cavities that cause risk to human and environment). This GD focuses on FG for decommissioning, closure, rehabilitation and/or restoration and after-closure of mine sites, related infrastructure and associated waste facilities. This includes all mines associated with Category A waste facilities (e.g. TMFs and heaps) for which FG are required by the EWD as well as other residual mining objects for which the competent authorities might require further FG to ensure public closure and post-closure safety.

Fundamental criteria for closure processes, from initial planning through to actual implementation including the closure objectives are summarized in table 2 of the MWEI BREF (Garbarino et al. 2018). The purpose of this guideline is to support the financial aspects of the mine closure process, but not providing guidance to the closure process itself. It has to be underlined that site-specific information including the geographical location and local environment, type of the mineral resources extracted, type of deposit and extractive and processing methods, as well as characteristics of the extractive wastes and technical characteristics of the waste facilities and its confining structure, affect closure activities needed and therefore also closure cost. Also the planned after closure land-use, visual impacts of the site and measures needed to protect the biodiversity of the surrounding environment affect closure activities and costs (Garbarino et al. 2018). The closure scopes for extractive waste are highlighted in the MWEI BREF. That is to ensure long-term safe and environmentally responsible deposition of extractive waste, including chemical, physical and mechanical stability over time, in order to prevent any accident and to minimise emissions that could have a negative effect on the environment and/or human health. The requirements for log-term safety apply also to non-waste mining facilities to be closed.

1.2 Structure of the GD

The GD comprises two main topics:

- description of the technical solutions for mine closure (sections 1 – 4), and
- documentation of cost profiles and cost-relevant activities for the technical measures of those solutions (section 5).

The GD for the technical solutions is structured in the following sections:

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- Part D - Cost Profile, Cost-Relevant Activities and Unit Cost: Cost profiles and unit cost were obtained from about 30 closure plans and related Bills of Quantities (BoQs) from implemented mine closure activities of the last 20 years, mainly from Northern, Central and Eastern Europe. The data were complemented with information from comparable rehabilitation works, for instance landfill closure and aligned with information on unit cost provided by the MS.

The considered closure activities concern TMF rehabilitation as well as other mining facilities closure, like cavities, mine seepage water outlets and mine waste heaps. Through these shaft and mine waste heap closure activities will be ensured to prevent a future release of waste materials into the environment. It is to be noted that the GD does not refer to unforeseen liabilities according to Art. 6 EWD.

1.3 Glossary / Key Terminology

For the GD purposes, the meanings of the key terms used are as follows (terms that are used according to EWD definition are indicated).

Bank guarantee is a guarantee issued by an approved bank pursuant to an agreement between the bank and an operator whereby the bank agrees to provide funds to the relevant regulator named in the agreement from collateral provided by the operator if the operator does not fulfil the environmental obligations stipulated in the agreement.

Best Available Techniques (BAT) is the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole (Industrial Emissions Directive 2010/75/EU (IED), Art. 13):

- 'techniques' shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned,

- ‘available’ techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the MS in question, as long as they are reasonably accessible to the operator,
- ‘best’ shall mean most effective in achieving a high general level of protection of the environment as a whole.

Cash deposit is money deposited by an operator with a third party (e.g. in a bank account) and legally secured so that it can only be used for the intended purposes. For the purposes of this practical guide this includes ‘escrow accounts’.

Category A waste facility is classified after EWD (Annex III of Directive 2006/21/EC) if a) a failure or incorrect operation, e.g., the collapse of a heap or the bursting of a dam, could give rise to a major accident, on the basis of a risk assessment taking into account factors such as the present or future size, the location and the environmental impact of the waste facility; or b) it contains waste classified as hazardous under 91/689/EEC above a certain threshold; or c) it contains substances or preparations classified as dangerous under Directives 67/548/EEC or 1999/45/EC above a certain threshold.

Charge on asset is a mortgage/charge over a specific asset in favour of a regulator which enables the charge holder to exercise their power of sale over the asset if an operator defaults on its obligations.

Collateral refers, for the purposes of this guide, to funds or assets pledged as security by the operator (or a company associated with them, such as a parent company) in respect of a guarantee by a financial institution, to be forfeited in the event of the operator’s default under the guarantee.

Competent person is a natural person who has the technical knowledge and experience, as defined by the national law of the MS in which the person operates, to perform the duties arising from Directive 2006/21/EC (Art.3 (26) of Directive 2006/21/EC)

Competent authority is the authority or authorities which a MS designates as responsible for performing the duties arising from Directive 2006/21/EC (Art.3 (27) of Directive 2006/21/EC)

Concurrent rehabilitation is a rehabilitation that occurs during the process of mining as the ore body is mined out in parts of a mine.

Cost profile is the pattern of closure, restoration and after-closure costs over time for mines and landfills. A cost profile can also be known as a financial profile.

Dam is an engineered structure designed to retain or confine water and/or waste within a pond (Art.3 (11) of Directive 2006/21/EC)

Decommissioning is the process of taking infrastructure out of active service, from the end of its utility for site activities until the removal of all unwanted infrastructure and services.

Decontamination refers to the removal of contaminants from buildings or other infrastructure, for instance asbestos abatement, pipeline cleaning and general cleaning/washing.

Demolition/deconstruction refers to the process of physically taking apart infrastructure, may involve disassembly of some or all of the structures, or destruction of infrastructure with heavy equipment or explosives.

Environmental Management Plan is a plan to manage and rehabilitate the environmental impact as a result of prospecting, reconnaissance, exploration or mining operations

Environmental impairment liability insurance is insurance specially tailored to environmental liabilities including liabilities under the Environmental Liability Directive.

Environmental liabilities are costs relating to environmental obligations.

Environmental obligations are obligations on operators relating to environmental protection, such as closure, restoration and after-closure following cessation of an activity or clean-up and restoration in the event of an incident/accident.

Extractive waste is waste resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries but does not cover waste which does not directly result from such activities, waste which results from offshore activities, and injection/re-injection of groundwater as defined by the Directive 2000/60/EC.

Financial institution guarantee is a guarantee provided by a financial institution (e.g. a bank or surety) to pay if an operator defaults on its obligations. This includes 'bank guarantees', 'letters of credit', 'surety bonds' and 'performance bonds'.

Financial provision is the establishment of a source of funding for liabilities under environmental law or an environmental permit, licence or other authorisation. The terms 'financial guarantee' and 'financial security' can also be used. For the purposes of this document these three terms can be read interchangeably.

Foreseen liabilities are environmental liabilities that are known to arise. They include development, decommissioning, closure, rehabilitation, and after-closure of installations, activities or sites, or the costs of repatriation.

Hazardous waste are wastes featuring on a list of Annex Ia and Ib (generic types of hazardous wastes) of Annex II (constituents of wastes listed in Annex Ib which render them hazardous if they have properties listed in Annex III, any other waste which is considered by a MS to display any of the properties listed in Annex III, e.g., toxic, carcinogenic, inflammable (Article 1(4) of Council Directive 91/689/EEC on hazardous waste).

Heap is an engineered facility for the deposit of solid waste on the surface (Art.3 (10) of Directive 2006/21/EC)

Incident/accident is a change from normal operating conditions with actual or potential negative consequences.

Inert waste is waste, that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the eco-toxicity of the leachate must be insignificant, and in particular not endanger surface water and/or groundwater quality (Art. 3 (3) of the Directive 2006/21/EC (EWD))

Insolvency refers to a situation where the operator enters into legal proceedings because it does not have adequate financial viability to meet its liabilities.

Leachate means liquid percolating through the deposited waste and emitted from or contained within a waste facility, including polluted drainage, which may adversely affect the environment if not appropriately treated (Art. 3 (14) of the Directive 2006/21/EC (EWD)

Letter of credit is a guarantee issued by an approved bank pursuant to an agreement between the bank and an operator whereby the bank agrees to provide funds to the relevant regulator named in the agreement from collateral provided by the operator if the operator does not fulfil the environmental obligations stipulated in the agreement.

NEEI refers to the non-energy extractive industry

Mine Closure entails the process of rehabilitation at the end of a mine's life leading to the issue of a closure certificate by the competent authority.

Mine closure plan is describing and detailing the actions that are required from the decommissioning via further potentially necessary steps like demolition, depollution, and rehabilitation to achieve relinquishment.

Mineral resource or mineral is a naturally occurring deposit in the earth's crust of an organic or inorganic substance, such as energy fuels, metal ores, industrial minerals and construction minerals, but excluding water (Art. 3 (5) of the Directive 2006/21/EC (EWD)

Mutual fund/pool is a group financial provision arrangement under which the group pays the obligations of an operator who is a member of the mutual/fund or pool if the operator defaults on its obligations.

Operator is the natural or legal person responsible for the management of extractive waste, in accordance with the national law of the MS in which waste management takes place, including in respect of temporary storage of extractive waste as well as the operational and the after-closure phases (Art. 3 (14) of the Directive 2006/21/EC (EWD)

Parent company guarantee is a guarantee by the parent of the operator to pay or fulfil the operator's obligations if the operator defaults.

Performance bond is an indemnity agreement for a specified amount issued by an approved bank, other financial institution or surety. The provider of the bond agrees to pay the relevant regulator up to the amount of the bond, as specified in the bond, if the operator defaults on its environmental obligations.

Planned mine closure is a form of mine closure that occurs when closure is undertaken in a planned way as outlined in a long-term mine plan.

Polluter Pays Principle describes the principle according to which the person responsible for harming the environment (i.e. the polluter) should bear the costs of remedying pollution or environmental degradation and consequent adverse health effects to the extent of either the damage done to society or exceeding an acceptable level (standard) of pollution.

Pond is a natural or engineered facility for disposing of fine-grained waste, normal tailings, along with varying amounts of free water, resulting from the treatment of mineral resources and from the clearing and recycling of process water (Art.3 (12) of Directive 2006/21/EC)

Post-closure management is the on-going management of residual environmental impacts for a specified period as determined after closure.

Premature mine closure is a form of mine closure that occurs when closure is unexpectedly necessitated before the anticipated time of closure as outlined in a long-term mine plan. Reasons for this form of closure can include unforeseen technical difficulties in mining, sharp decreases in ore prices, etc.

Rehabilitation is the treatment of the land affected by a waste facility in such a way as to restore the land to a satisfactory state, with particular regard to soil quality, wild life, natural habitats, freshwater systems, land scape and appropriate beneficial uses 'rehabilitation' means the treatment of the land affected by a waste facility in such a way as to restore the land to a satisfactory state, with particular regard to soil quality, wild life, natural habitats, freshwater systems, landscape and appropriate beneficial uses (Art.3 (20) of Directive 2006/21/EC)

Rehabilitation plan is describing and detailing the concrete actions that are required to adequately mitigate environmental impacts and achieve rehabilitation outcomes.

Relinquishment refers to the end of site ownership by the mining company and of their responsibility for the site, with transition of ownership and residual liability to the jurisdictional authority or a third party. Completed closure was approved by the competent authorities.

Self-provision is financial provision by the operator itself. This includes 'provisioning in accounts' and 'self-insurance'.

Site is all land at a distinct geographic location under the management control of an operator Art.3 (28) of Directive 2006/21/EC)

Surety bond is a bond issued by a surety (usually an insurance company) pursuant to an agreement between the surety, an operator or its parent company, and the relevant regulator in which the surety agrees to carry out the obligations specified in the agreement up to the specified amount if the operator defaults on those obligations. Surety bonds may be payment bonds, in which case the surety agrees to pay the regulator up to the amount specified by the bond, or performance bonds, in which case the surety agrees to perform the activities on which the operator has defaulted up to the monetary limit of the bond.

Tailings are waste solids or slurries that remain after the treatment of minerals by separation processes (e.g., crushing, grinding, size-sorting, flotation and other physical-chemical techniques) to remove the valuable minerals from the less valuable rock (Art.3 (9) of Directive 2006/21/EC).

Treatment of mineral resources refers to mechanical, physical, biological, thermal or chemical process or combination of processes carried out on mineral resources, including from the working of quarries, with a view to extracting the mineral, including size change, classification, separation and leaching, and the re-processing of previously discarded waste, but excluding smelting, thermal manufacturing processes (other than the burning of limestone) and metallurgical processes (Art.3 (8) of Directive 2006/21/EC)

Unforeseen liabilities are potential environmental liabilities arising from incidents/accidents.

Unpolluted soil is soil that is removed from the upper layer of the ground during extractive activities and that is not deemed to be polluted under the MS national law where the site is located or under Community law (Art. 3 (4) of the Directive 2006/21/EC).

Waste means any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force (Article 1(a) of Directive 75/442/EEC)

Waste facility any area designated for the accumulation or deposit of extractive waste, whether in a solid or liquid state or in solution or suspension, for the following time-periods: a) no time-period for Category A waste facilities and facilities for waste characterised as hazardous in the waste management plan, b) a period of more than six months for facilities for hazardous waste generated unexpectedly, c) a period of more than one year for facilities for non-hazardous non-inert waste, d) a period of more than three years for facilities for unpolluted soil, non- hazardous prospecting waste, waste resulting from the extraction, treatment and storage of peat and inert waste (Art.3 (15) of Directive 2006/21/EC).

1.4 Legal Framework

1.4.1 European Union Legislation

As a complement to applicable horizontal EU environmental legislation, a specific framework for the safe management of waste from extractive industries at EU level is in place comprising:

- Directive 2006/21/EC on the management of waste from the extractive industries (the Extractive Waste Directive EWD). Commission report on the implementation of Directive 2006/21/EC,
- Best Available Techniques reference document Management of Waste from Extractive Industries in accordance with Directive 2006/21/EC (MWEI BREF),
- the Seveso III Directive which includes in its scope operational tailings disposal facilities, including tailing ponds or dams, containing dangerous substances,
- 2009/335/EC: Commission Decision of 20 April 2009 on technical guidelines for the establishment of the financial guarantee in accordance with Directive 2006/21/EC of the European Parliament and of the Council concerning the management of waste from extractive industries (notified under document number C(2009) 2798); and
- Guidance document on non-energy mineral extraction activities in Natura 2000 protected areas.

The overall scope of the guideline on financial aspects is to provide support in terms of financial data on the closure process. Further, there is a relation to the Environmental Liability Directive 2004/35/CE. Further apply the provisions of the Public Procurement Directive (2014/24/EU) (public works contracts).

According to Directive 2006/21/EC, the FG provision has to be foreseen for category A facilities. According to Annex III of 2006/21/EC, waste disposal facilities are assigned to category A if:

- the risk assessment, taking into account factors such as current or future size, location and environmental impact of the waste disposal facility, shows that a failure or improper operation, such as the slipping of a heap or a dam break could lead to a serious accident, or
- the plant contains waste that is classified as dangerous according to Directive 91/689/EEC above a certain threshold, or
- the system contains substances or preparations which are classified as dangerous according to the guidelines 67/548/EEC or 1999/45/EC from a certain threshold value.

Further, following parts of the environmental acquis and the respective primary and secondary legislation apply (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Directorate Industrial Transformation and Advanced Value Chains, 2017):

- Treaty on the Functioning of the European Union (TFEU)
- EU´s Raw Materials Strategy framework, in connection with the classification according to the NACE Rev. 2 and the PRODCOM
- eight conventions (Aarhus, Espoo, Lugano, on the Protection and use of Transboundary Watercourses and International Lakes, on the Transboundary Effects of Industrial Accidents, the OSPAR, UNCLOS and London Conventions)
- internal market Directives (Services, Concessions, Public Procurement, Utilities Procurement, Accounting, Transparency, and Professional Qualifications Directives)
- the European Framework Directive on Safety and Health at Work (particularly the Occupational Health and Safety Framework Directive 89/391/EEC) and the Carcinogens Directive
- environmental Directives (EIA, Birds, Habitats, Extractive Waste, Environmental Liability, Seveso III, and the Water Framework Directive).

1.4.2 National Legislation

The national legislation is briefly presented per EU MS in alphabetical order (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Directorate Industrial Transformation and Advanced Value Chains, 2017, amended by the authors).

Austria: Mining is governed by the Mining Law (MinroG Act No. 38/1999, last time amended 2019) which regulates the exploration and extraction of all mineral raw materials. The Austrian Mining Law includes a dynamic reference (§ 221a. MinroG) to other Federal Laws. Following laws may be concerned: Commercial Code 1994 (BGBl. Nr. 194), Federal Acts on Environmental Impact Assessment (UVP-G 2000), Water Management (215/1959) and Construction Coordination (BauKG 37/20099), Acts on Nature Protection and Acts on Land Use Planning, Work Inspection Act 1993 (ArbIG), among others. Austria has a mixed permitting regime with decentralised and centralised procedures depending on the type of mineral.

Belgium: In the Flemish region, the main laws relevant to mine permitting are the Flemish Environmental Permitting Regulations (VLAREM) and the Flemish Codex of Spatial Planning. In Wallonia, the main law is the Decree "Carrières" of July 4th 2002 as amended by Decree of May 31 2007; for environmental regulations, the Decree of 11th March 1999 governing environmental permits and the Walloon Code of Land planning, Urban planning and Heritage (CWATUP). In Flanders, only extraction permitting procedures are subject to spatial planning; there are no specific exploration permitting procedures for surface mineral resources. With regards to extraction permits, for quarries, it depends whether the parcel of land is already included in a Sector Plan as "extraction zone" or not.

Bulgaria: Mining is regulated by the Concessions Act (SG No. /36/2.05.2006, last time amended 2016) and the Subsurface Resources Act (No. 23/12.03.1999, last time amended 2005). Other laws of relevance for permitting procedures include the Waste Management Act (53/13.07.2012, last time amended and supplemented 2019), the Environmental Protection Act (that requires EIA), the Nature Protection Act, the Protected Areas Act (133/11.11.1998, last time amended 2012), the Act for the protection of the environment (SG 91/25.09.2002, last time amended and supplemented 2020), the Water Act (67/27.07.1999, last time amended and supplemented 2017), Law for Biological Diversity (SG/77/09.08.2002, last time amended and supplemented 2018) and the Health and Safety Working Conditions Act, among others. Bulgaria has a centralised regime where all licenses for all kind of commodities are processed after a written application to the Ministry of Energy.

Croatia: Mining in Croatia is governed by the Mining Act (Official Gazette 56/13 and 14/14.), the Geological Explorations Act (Official Gazette 34/86), the Concessions Act (Official Gazette 143/12) and the Regulation on compensation for concession for exploitation of mineral resources (Official Gazette 31/14). The regulatory framework has been recently complemented with the Act on the Exploration and Production of Hydrocarbons (Official Gazette 55/18), the Decree on Petroleum Mining Projects and Procedure for Verification of Petroleum Mining Projects NN 95/2018, Decree on reserves NN 95/2018, and the Decree on construction of oil and mining facilities and installations NN 95/2018. Croatia has a centralised permitting regime. Concerning exploration permits, the decision to grant an exploration permit for the purpose of granting a concession for exploitation can only be provided in areas planned for of mining activities in the planning documents. Concerning extraction permits, a concession shall be performed on the basis of one public tender in a single procedure consisting of four phases.

Cyprus: the Chapter 270 is the main encompassing law that sets up a general framework for exploration/exploitation permits and the running of the industry overall. The substantive part of the licensing procedure is delivered by the Council of Ministers' regulations, pursuant to the provisions of the general law (Mines and Quarries Regulations 1958-2014). The key permitting authorities in the exploration and exploitation are the Council of Ministers, the Mines Service, the Town Planning and Housing Department, the Ministry of Agriculture, Rural Development and Environment, the Department of the Environment, and the District Administrator. For exploration, reconnaissance or prospecting permits must be applied to the Mines Service, including an environmental management study, and, if applicable, a permit for waste management through a centralised permitting regime.

Czech Republic: The primary legal basis of mineral extraction activity is the Mining Law (Mining Act) No. 44 of 1988, as amended by Law No. 186 of 2006. For prospecting and exploration for reserved mineral deposits the most relevant law is the one No. 62/1988 Coll., on Geological Work (the Geological Act), and MoE Decree No. 368/2004 on geological documentation. Other important national Acts are the Act on EIA, Forest Act, Act on Land and Soil, Act on Nature and Landscape, etc. For permitting of exploration of mineral deposits the Ministry of Environment is the relevant authority. Regarding exploitation, the District Mining Authorities are the relevant state bodies. These are part of the State Mining Administration (SMA), which is composed also by the Czech Mining Office in Prague (central mining authority), establishing a centralised permitting regime. For prospecting and exploration, an application for "reserved" minerals is to be considered by the Ministry of the Industry and Trade with the approval of the Ministry of the Environment.

Denmark: The exploration and extraction of Danish minerals is mainly governed by the Raw Material Act of 2016 and by the Act on the Use of the Danish Subsoil of 2011, amended by the Consolidated Act no.1190 of 2018. Another important regulation is the

Government Regulation No. 949 of 2016 on Marine Raw Materials. Further relevant laws are the Drilling Act, the Water Supply Act, the Environmental Protection Act, the Nature Protection Act, among others. Denmark has a decentralised permitting regime for land-based minerals and a centralised regime for offshore ones. It is the responsibility of the Regional Council to assess whether or not an Environmental Impact Assessment should be made for the intended extraction activity.

Estonia: The primary legal basis of mineral extraction activities is the Mining Act (Riigi Teataja No. 20, 118 of 2003) amended by legal instruments (mainly focused on safety, mandatory documentation, rights to operate) and the Earth's Crust law (Riigi Teataja No. 84, 572 of 2003) amended by legal instruments (regulates research and issuance of permits for exploration and extraction). The relevant authority for mining permitting is Ministry of Environment (if mining is planned in a mineral deposit of national importance), otherwise it is the Environmental Board the organism with competence on permitting procedures.

Finland: The primary legal basic of mineral extraction activity is the Mining Act 621/2011 which covers metallic ores and industrial minerals. Non-claimable minerals are regulated by the Land Extraction Act No. 555/1981. The Government Decree on mining activities (391/2012) provides important provisions to the Mining Act. The Finnish Mining Act establishes that mineral exploitation rights belong to the discoverer. Other relevant laws are, i.e., the Nature Conservation Act (1096/1996), the Environmental Protection Act (527/2014), the Act on the Protection of Wilderness Reserves (62/1991), the Land Use and Building Act (132/1999), the Water Act (587/2011), the Reindeer Husbandry Act (848/1990), the Off-Road Traffic Act (1710/1995), and the Government Degree on Mine Waste (190/2013). The Mining Authority responsible for onshore and offshore mining permits is the Finnish Safety and Chemicals Agency (Tukes). The Regional State Administrative Agencies (AVI) grant the environmental permits. In Finland are applied two financial guarantees for mining projects, a financial guarantee for waste management according to the Environmental Protection Act and a guarantee for safety aspects of mine closure according to the Mining Act.

France: Under French Law, the exploitation of materials defined as "eligible for concession" ("mining substances" according to Art. L. 111-1 of the Mining Code) is ruled by the regulations on mines, and the exploitation of materials defined as "non-eligible for concession" ("quarried minerals") is ruled by the regulations on quarries. Exploration and extraction operations are governed mainly by two centralised items: the French Mining Code, which defines the mine nature and the exploitation conditions along with post-mine dispositions, and the French Environmental Code. The mining administrative procedures defined by Decree n°2006-648 and Decree n°2006-649 constitute the main mining legal corpus applicable in France. The application of the Metropolitan mining code was extended to overseas departments. For onshore minerals, the main permitting authority for non-energy minerals is the Ministry of Economy and Finance. Quarry materials depend on the Ministry of Environment, Energy and Sea.

Germany: The primary legal basis of mineral extraction activity is the Federal Mining Act (Bundesberggesetz – BBergG, BGBl. 1310/1980, as amended 1962/2016 and Allgemeine Bundesbergverordnung, ABBergV). Other relevant federal laws include the Federal Water Resources Act (Wasserhaushaltsgesetz WHG), Federal Imission Control Act (Bundesimmissionsschutzgesetz BImschG), Environmental Impact Assessment Act for Mining (Verordnung über die Umweltverträglichkeitsprüfung bergbaulicher

Vorhaben – UVP-V Bergbau), Federal Nature Conservation Act (Bundesnaturschutzgesetz BNatSchG), among others. The German federal system is characterised by the fact that the legislative competencies are held by the federal states. The execution of the laws is pursuant to Art. 83 of the Basic Law regularly conducted by the federal states (Länder) as their own affair. According to BBergG, regional authorities have administrative instruments for efficient supervision, including the issue of mining ordinances, the grant, refusal and revocation of mining licences, the approval of operating plans as well as the power to give individual instructions for prevention of dangerous situations and to enforce the law and the right to be informed by the mining companies. As established in the Section 52 (2a) BBergG, a general operating plan is required and a planning approval procedure (Planfeststellungsverfahren) pursuant to the provisions of Sections 57a and 57b BBergG shall be executed for its approval if a project requires an environmental impact assessment (EIA) as stipulated by Section 57c BBergG. For the closure of operations, closure plans (Abschlußbetriebsplan) shall be prepared.

Greece: The Greek Legislation (the Mining Code, namely L.210/1973, amended by 274/1976 and 4512/2018) distinguishes mineral raw materials into two broad categories: a) “Metallic Minerals” which, either on the surface or underground, do not belong to the landowner of the area they occur in nor to the state, and b) ”Quarry Minerals”, which belong to the landowner of the area they occur in. Additional important legislation includes L.669/1977 on the exploitation of ornamental rocks and industrial minerals, L.1428/84 as amended by L.2115/93 on the exploitation of aggregates, and Mining and Quarrying Activities’ Regulation (KMLE) (Ministerial Decision 2223-FEK1227/14-6-2011). In Greece, the basic legislation for the environmental permitting of all types of projects and activities is L.4014/2011. This Law applies to the permitting of mining projects and activities in combination with Ministerial Decision 37674/2016213 (on the classification of projects / activities into groups and categories, depending on the significance of their environmental impacts) and Ministerial Decision 167563/2013, which specifies the procedures and criteria for this permitting.

Hungary: The legal basic of mineral extraction activity is Act No. XLVIII of 1993 on Mining (Mining Act) as last amended by Act No. LXXXVI of 2014 and 311/2014 (XII. 11) Government Regulation. Important pieces of law for permitting procedures are Governmental Decree No. 203/1998. (XII.19.) (detailed permitting rules), Government Regulation No. 267/2006 on the Hungarian Office of Geology and Mining (MBFH) (on involvement of co-authorities), Government Regulation No. 53/2012 on mining construction permitting, Government Regulation No. 314/2005 on EIA and IPPC, Act No. LIII of 1996 on nature conservation, Government Regulation No. 275/2004 on Natura 2000 sites, Government Regulation No. 312/2012 on construction permitting, Ministerial Decree No. 14/2008 (IV. 3.) on mining waste management, and Ministerial Decree No. 8/2014 on the mining concession tender procedure. For permitting procedures, Act No. CXL of 2004 on the General Rules of Administrative Proceedings and Services is also highly important.

Ireland: The Minerals Development Act 2017(Act 23 of 2017) governs onshore and offshore mineral exploration and development in Ireland. Other laws of importance are the Environmental Protection Agency (EPA) Act of 1992 which constituted the Irish EPA, the IPPC Regulations 2012 (S.I. No 282 of 2012) ensuring an EIA procedure is carried out where required under Directive No. 2011/92/EU (and amendments) in relation to relevant decisions of the EPA to grant an IPC licence, the European Communities (Birds and Natural Habitats) Regulations 2011 (and amendments), the Air Quality Standards Regulations 2011 and the Planning and Development Act 2000, the main Act covering developments of any type. Exploration and extraction permitting is governed by the Minister for Communications, Energy and Natural Resources, which acts through the Exploration and Mining Division (EMD) of the Department of Communications, Energy and Natural Resources (DCENR).

Italy: The primary legal basic of mineral extraction activity in Italy is the Mining Law (Royal Decree) No. 1443 of 1927 (consolidated in 1999) which divides minerals into two categories (Art. 2): “first” and “second” category. With the Legislative Decree no. 616/77 (related to second category minerals), the Legislative Decree 112/98 and the Constitutional Law 3/2001 (related to first category minerals) competences related to planning and management, including permitting, passed from the national State to the Regions. Other important national laws in Italy are Presidential Decree 128/59 (Police rules for mining and quarrying), Legislative Decree 152/06 (legislative framework applicable to all matters concerning environmental protection including EIA, SEA and IPPC), the Law of 23 December 2000 no. 388, Art. 114, which provides a special plan for rehabilitation and environmental recovery of mines, Legislative Decree no. 624/1996 (health and safety of workers) and Legislative Decree no. 117/08 (transposing Directive 2006/21/EC and important for the management of extractive waste). Italy has a decentralised regime and each region has its own relevant regional laws (RL) regulating extraction and environmental permitting procedures.

Latvia: The law regulating mining is the Law on Subterranean Depths as of 1996. Licencing procedures are prescribed in the Regulation No. 696/2011 of the Cabinet of Ministers “Procedure for the Issue of Licences for the Use of Subterranean Depths and Authorisations for the Extraction of Widespread Mineral Resources”. Important is also the Cabinet Regulation No 570 of 2012 “Procedures for the Extraction of Mineral Resource” which sets requirements for all mining related work stages and Cabinet Regulation No 1055 of 2006 Regulations regarding the State Fee for a Licence for Use of Subsoil, an Authorisation for the Extraction of Widespread Mineral Resources and a Passport of the Deposit. For prospecting, exploration and extraction of minerals a company or a natural person needs a Licence for use of subterranean depths.

Lithuania: The main law is the Underground Law No. I-1034/1995 and its implementing Government Resolutions (No. 1433/2001, No. 198/2002, No. 584/2002), which regulate the exploration and extraction permits. Other important laws regulating permits and licences for the authorisation of exploration and extraction include the Environment protection Law I-2223/1992, Proposed economic activity environmental impact assessment Law No. I-1495/1996 (which regulates the EIA process), Environment minister order No. 166/1996 on exploited mining areas rehabilitation, Protected Areas Law No. I-301/1993, Water Law No. VIII-474/1997, Spatial Planning Law No. I-1120/1995 and Environment minister order No. D1-145/2014, both of which regulate spatial planning (and set provisions for the extraction and reclamation plan). The competent authority granting exploration and extraction permits is the Lithuanian Geological Survey under the sphere of the Ministry of Environment.

Luxembourg: The main legislation governing permitting procedures involves the law of 21/04/1810 (last amended in 1994), the law of 10/06/1999 relative to the classification of potentially dangerous establishments (amended by Grand Ducal regulation of 10/05/2012) which classifies the extractive industry as “class 1” and makes it subject to an “authorisation to operate” procedure following an investigation procedure called “commodo-incommodo”. Other relevant laws are the amended law of 19/12/2008 on water and Law of 19/01/2004 on the conservation of nature and natural resources. Relevant authorities are the Ministry of Labour, Employment and Social and Solidarity Economy and the Ministry of Sustainable Development and Infrastructure which are the competent authorities for issuing the “authorisation to operate” supported by its Inspectorate of Labour and Mines (ITM) and the Department of Environment (organized in three Administrations: Environment, Nature & Forests and Water Management), the Administration of the Environment, the College of burgomasters and aldermen and the Communes. Concerning exploration for industrial or construction minerals, it only requires the permission by the landowner, except when it involves drillings that require a permit according to commodo-incommodo law.

Malta: The authorities do not provide a license for exploration but only for exploitation. Malta has a centralised permitting regime and licensing is handled exclusively at the national level. Companies need to express their interest by applying for a land use permit with the Planning Authority (PA). The PA consults the Environment and Resources Authority (ERA), the Malta Resources Authority (MRA) and the Agency for Energy and Water as the main Consultees including the other statutory Consultees in Schedule 3 of L.N. 162 of 2016 Development Planning Act (Cap. 552). ERA and MRA may only issue their respective permits and licences, once the development consent is issued through the development planning permit. Other entities consulted during the process are the Superintendence for Cultural Heritage and the Regulator for Energy and Water Services.

The Netherlands: The main mining law is the Mining Act of 2002 (last amended in 2018). Other relevant laws are the Mining Decree of 2003 (last amended in 2017), the Mining Regulation of 2013, the Excavations Act of 2008, the Environmental Licencing Act of 2010, the Nature Protection Act, the Flora and Fauna Act, the Spatial Planning Act and the Water Act. In 2021, the Dutch Senate passed the bill to amend the Mining Act to further stimulate investments in the Dutch Mining industry and to prevent that natural gas reserves are left behind when existing infrastructure is being decommissioned. The State Supervision of Mines (SSM) is the agency within the Ministry of Economic Affairs that oversees the production of minerals and the Netherlands’ continental shelf. The agency is responsible for drafting and enforcing mining laws, mine safety, and mineral production regulations on and offshore. Netherlands has a mixed (centralised-decentralised) permitting regime in which the SSM grants the exploration and extraction permits, and the Ministry of Infrastructure and Environment grants the environmental and water extraction permits.

Poland: The principal legislation concerning permitting procedures is the Geological and Mining Law (unif. text J.L. of 2015, item 196), Act on the Liberty of Economic Activity (unif. text J.L. 2014, item 1446), Nature Conservation Law (unif. text J.L. 2015, item 1651), Environmental Protection Law (unif. text J.L. 2013, item 1232), Water Law (unif. text J.L. 2015, item 469) and Act on Land Use Planning and Space Management (unif. text J.L. 2015, item 199). The competent authorities and the procedures for obtaining the license are different for state-owned and land-owned mineral deposits, and for exploration and extraction phases, their location, as well as extraction method and size. For exploration, in order to receive a prospecting or exploration licence, it is necessary to obtain the environmental permit. The competent authority that grants the environmental permit is the Regional Director for Environmental Protection.

Portugal: The legal basis for the extraction of state-owned minerals is Law No. 54/2015, which is the legal framework regime for exploration and use of existing geological resources in the country, including those located in the national maritime area. For land-owned (or privately owned) minerals extracted in quarries (mineral masses also called construction minerals) the guiding principles relating to their exploration and extraction are regulated by Decree-Law No. 270/2001 which was amended by Decree-Law No. 340/2007 of 12th October. The Decree Law No 88/90 (Minerals Law) establishes the mineral deposits regulation. Another relevant law for the permitting chain is Decree-Law No. 151-B/2013, which establishes the regulatory framework for Environmental Impact Assessments. The Portuguese national mining authority for state-owned minerals is the DGEG (under the Ministry of Economy) which acts as a “one-stop shop” for mining permits in the exploration, extraction and post-extraction phases.

Romania: Mineral resource extraction activities and the management of solid mineral resources are regulated by the Mining Law no. 85/2003, whose provisions are detailed by the Norms of application of the Mining Law and technical instructions on specific problems (Joint Order of NAMR and MoEn no. 58/19 of 25/02/004 resp. 09/04/2004, amended through Order nr. 2.026 of 26/07/2010, and NAMR order no. 22/2006, etc.). The Romanian authorisation system for permits/licences for the project development around solid mineral resources is of a multi-authorisation nature, i.e. up to 6 permits, licences or approvals are necessary so that exploration or exploitation works can be conducted. Prospecting permits and exploration licences are issued by the National Agency for Mineral Resources (NAMR) and up to 5 co-authorities might be involved in the process. Extraction licences are also granted by the NAMR and between 6 and 9 co-authorities may be involved in the process. An environmental rehabilitation plan and technical project are required due to NAMR Order no.17/2005.

Slovakia: The Ministry of the Environment acting under law No. 569/2007 and registration N.51/2008 provides oversight and management of the country’s mineral deposits and energy sources. Mining activities are administered by the Main Mining Bureau at the Ministry of the Economy. The tasks of the Main Mining Bureau are set out in law No. 44/1988, revised in Law 214/2002. The legal framework relevant for permitting procedures comprises mainly the Mining Law (Law No. 44/1988 Coll. 216 with amendments) and the Geological Law (Law No. 569/2007 Coll. with amendments). The Ministry of the Environment issues the licences to undertake geological exploration programs in compliance with Law No. 569/2007 and by Registration No. 51/2008. Other important laws are Law No. 543/2002 Coll. on nature and landscape protection, Law. No. 24/2006 Coll. on the environmental impact assessment, Law No. 39/2013 Coll. on integrated prevention and environmental pollution control, and the Water Law (Law No. 364/2004 Coll.). Competent authorities are the Ministry of Environment of the Slovak Republic, Ministry of Economy of the Slovak Republic, Main Mining Office and the Regional (or District) Mining Offices.

Slovenia: The primary legal basis of mineral extraction activity is the Slovenian Mining Act No. 56/1999, consolidated in 2004 and amended subsequently, which defines the conditions for the exploration activities and extraction of minerals. Other important laws are the Environmental Protection Act and the Spatial Planning Act. The competent authority for granting exploration and extraction rights for mineral resources is the Energy

Directorate (within the Ministry of Infrastructure). The local municipalities are an important co-authority as they are responsible for the municipal spatial plans. All areas with a mining concession (or with mining rights) need to be included in the municipal spatial plans and designated as "mineral extraction areas". For such plans strategic environmental assessment or at least screening is needed.

Spain: Mining operations are governed by the Spanish Mining Law 22/1973, of 21 July, and its regulations were approved by Royal Decree 2857/1978 and Law 21/2013 on Environmental Assessment. The Royal Decree 975/2009 on the management of extractive industries waste and the protection and rehabilitation of the sites affected by mining activities, refers to the main environmental issues arising from the exploitation of a mine. These laws are applicable to the whole country. Each of the 17 Spanish Autonomous Regions may enact additional mining rules provided the basic mining system governed by national provisions is respected. According to the Mining Law, all mineral deposits and geological resources within Spain are public domain goods, thus mining activity must be preceded by the corresponding permit/concession. The permit/concession allowing mining activity depends on the type of mineral commodity ("mineral section"). The competent authorities governing mineral exploration and extraction are: the General Directorate of Energy and Mines Policy (Ministry of Energy, Tourism and Digital Agenda), Ministry of Agriculture and Fisheries, Food and Environment, Ministry of Education, Culture and Sports and the Ministry of Public Works, Departments of Industry, Environment, Culture and Public Works of each of the 17 Autonomous Regions.

Sweden: Mineral exploration and the extraction of "concession minerals" in Sweden are governed by Minerals Act (1991:45) and Minerals Ordinance (1992:285), as amended subsequently, which is applicable in parallel with other legislation to all exploration and extraction works, e.g. the Planning and Building Act (2010:900), Environmental Code (1998:808), Cultural Heritage Act (1988:950) and Off-Road Driving Act (1975:1313). The Swedish Environmental Code is particularly relevant, as permits for extraction must be granted under both the Minerals Act and the Environmental Code. The primary law concerning the extraction of "non-concession minerals" is the Environmental Code (1998:808), which is applicable in parallel with other legislation (as above). The Minerals Act does not apply to these sub-groups. The competent authority for mining is the Mining Inspectorate. For extraction to commence, besides the extraction concession, an environmental permit is required. The application for an environmental permit required under the Environmental Code is handled by the Land and Environmental Court or by any of 12 (out of 21) responsible County Administrative Boards. The extraction of national resources from the seabed and Swedish economic zone is regulated in the Act on Continental Shelf (1966:314) and Continental Shelf Ordinance (1966:315).

1.4.3 Licensing / Permitting Conditions

The EWD is of importance for permitting procedures in all three phases of mining, i.e. exploration, extraction, post-extraction (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Directorate Industrial Transformation and Advanced Value Chains, 2017). The EWD has three major instruments relevant in terms of permitting:

- completion of a waste management plan prior to the commencement of extraction;
- elaboration of an external emergency plan for “Category A” facilities, and
- FG provision to secure proper rehabilitation of the affected land.

All these instruments are highly relevant to permitting of mineral resource projects.

According to Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs and Directorate Industrial Transformation and Advanced Value Chains (2017), the number of co-authorities is smaller for exploration than for extraction permits. Permitting procedures differ not only by the type of mineral and its ownership, but also due to the mineral development phase.

Concerning the terms related to the withdrawal of material from the earth´s crust, apply the definitions given in Art. 41(1) of the EU Accounting Directive (2013/34/EC). According to Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs and Directorate Industrial Transformation and Advanced Value Chains (2017), there are three major permitting stages:

- ***exploration permitting:*** from the green field phase until the competent authority issues a resolution on the first exploration technical operation plan (TOP) (or equivalent national legal term), with which the holder may start exploration activities promptly;
- ***extraction permitting:*** starting from the approval of the exploration report and/or mineral reserves reporting to the valid authority resolution on the first extraction TOP or equivalent permit with which the holder may start extraction activities promptly;
- ***post-extraction permitting:*** closure and rehabilitation TOP, after-care measures, including monitoring of reclamation measures.

The present guideline refers mainly to the phase of post-extraction permitting, however when it comes to FG also the extraction permitting is relevant, as the financial obligations must be deposited during the operational lifetime of the mine. There is a diversity or terms regarding the permitting system, referring mainly to the two terms “permit” and “licence” that are used to refer to the authorisations, permissions or approvals granted by public authorities to companies before they can proceed with any phase of the mineral development cycle.

There are two distinct procedures to obtain exploitation permits in the EU (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Directorate Industrial Transformation and Advanced Value Chains, 2017). Most MSs have a procedure which depends on the application for the permit by the interested party (DK, EE, FI, FR, DE, EL, HU, IE, IT, LT, PL, PT and ES) whilst others have an inherited public tender system (HR, RO). In some MSs, a previous spatial planning (or development plan) has to be issued in the area of potential exploitation (BE, DK, IT, PL, SI, RO) before a concession can be granted, whereas, in general, exploitation can be carried out anywhere, provided the necessary authorisations have been obtained.

All EU MSs require Environmental Impact Assessment (EIA) and subsequent environmental evaluation and authorisation previous to the exploitation concession grant (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Directorate Industrial Transformation and Advanced Value Chains, 2017). The duration of the mining exploitation permit is regulated by law in most MSs between 20 years (BE, but unlimited for quarry) and 75 years (in the case of ES or FR after extensions) or EL (50 y + 2 extensions of 25 for metallic ores); most include extensions to the original permit, for instance, DK (10y +10 y), FR (50 y + renewal), HU (35y+17.5), PL (3-50 y). In the case of AT is open ended and RO is 20 y plus 5 years' period renewal with no limit. In the case of IE it is related to the predicted length of the operations.

1.4.4 Institutional Framework

According to Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs and Directorate Industrial Transformation and Advanced Value Chains (2017), there are first-instance and second-instance permitting levels in the European Union. The definitions are:

- ***First-instance permitting*** (local, regional, national): first-instance permitting authorities are those government agencies primarily in charge of granting a relevant permit or licence for any mineral development to take place at local, regional and national level. They also include co-authorities. This level involves all relevant authorities with professional competence to issue legally binding permissions.
- ***Second-instance permitting*** (regional, national): second-instance permitting refers to the level at which there is a legal option for the applicant (a mining company, an investor) or for any other interested party to appeal against the resolution of the first-instance authority within the public administration system, i.e. not yet involving any court actions. Only regional and national levels (courts) are considered (unless a local court is of high importance for any MS).

2. Part A: Principles and Purpose of Financial Guarantees

2.1 Overview of the Financial Provision Determination Process

The main FG scope is to ensure the mining companies responsibility for the responsible closure of their mining sites, means to generate financial deposits during the mining operation period in order to have the necessary budget for an environmentally sufficient mine closure.

The range of liability scenarios include (Bradley et al. 2017):

- ***Foreseen liabilities:*** liabilities that are known to arise. They include development, decommissioning, closure, rehabilitation, and after-closure of installations, etc.
- ***Unforeseen liabilities:*** environmental liabilities arising from incidents /accidents.

A closure plan serves as basis for the determination of the FG amount by the competent authority. A guarantee should reflect the cost of a mine closure and be adjustable, up or down, to reflect changes in the proposed closure plan (Mota de Lima, 2003). An exemplified scheme of a mine balance sheet for environmental rehabilitation is given in figure 2. Following types of cost have to be considered: direct closure costs, indirect closure costs, mobilization and site preparation, contingencies, engineering and Design, profit and overhead, closure management, administrative costs, maintenance costs, and monitoring costs.

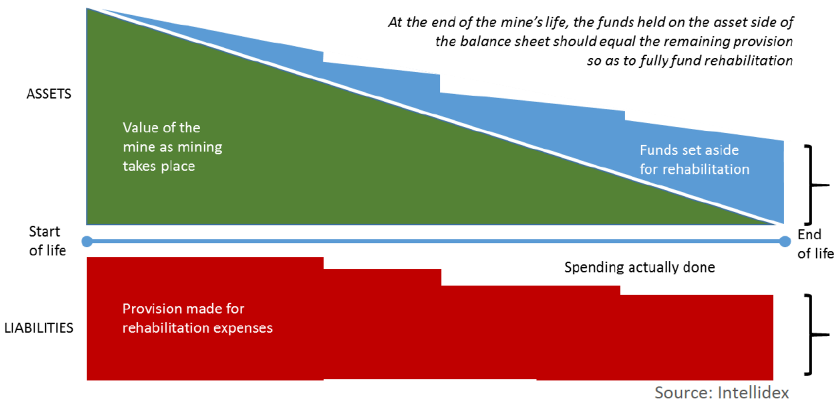


Figure 2: Exemplified scheme of a mine balance sheet for environmental rehabilitation (Tambo& Theobald, 2018)

The approach to defining the need and scope as well as amount of financial provisions is illustrated in Figure 3 (after Bradley et al. 2017).

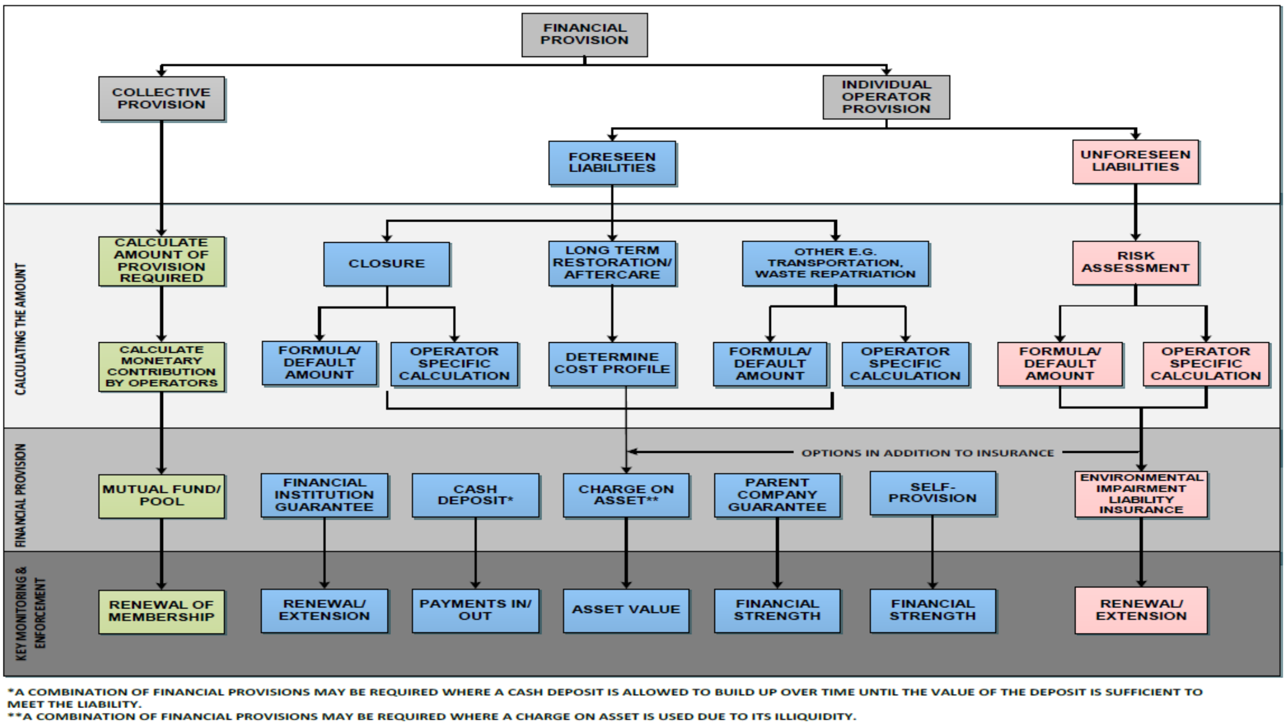


Figure 3: Approach to defining the need for and scope of financial provisions (Bradley et al. 2017)

Financial instruments can be divided in three main categories depending on the degree to which the FG is decoupled from the mine operator's assets (MonTec, 2008):

- FG remains within the operator company
- FG is guaranteed by a third (commercial) party
- FG is transferred to the government or a trust fund

The calculation of the volume of the financial provisions is based on the prognosis of closure and restoration costs after termination of the mining activities. For some types of mining, the closure takes place only after termination of all mining activities (typically for instance in ore mining) while for other types of mining closure takes place in parallel to the extraction activities. This is typically the case for open cast lignite mining where the area of the foreland of the open pit is consumed for mining while extraction waste is deposited backwards and restored in parallel. This approach leads to the need of combined closure and restoration plans. Thus, the combined strategy must be developed already from the beginning of mining. This is also necessary to generate the financial provisions that are taken from the current mining activities and are established as financial deposit. According to the Environmental Protection Agency of Ireland (2014), sites with no soil or groundwater contamination or other long-term liabilities require a closure plan only, while sites with soil or groundwater contamination and certain sectors such as landfills and mines require a closure strategy and plan. Figure 4 illustrates the general approach to assessing and costing environmental liabilities (Environmental Protection Agency of Ireland, 2014).

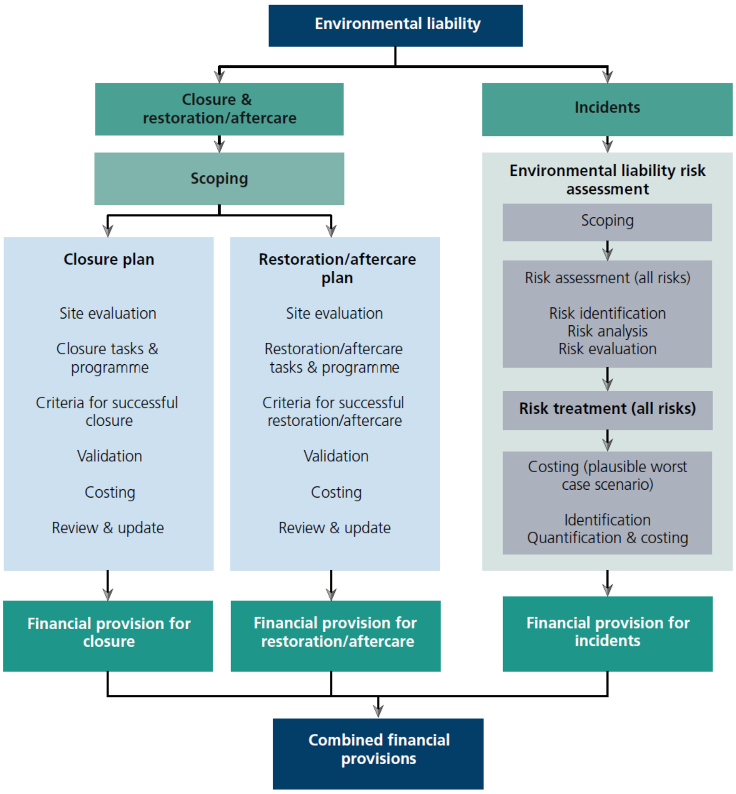


Figure 4: General approach to assessing and costing environmental liabilities (Environmental Protection Agency of Ireland, 2014)

A particular case is incidents or accidents that might occur during mining operation, and often lead to a premature closure. Even incidents or accidents create unforeseen liabilities; their occurrence shall already be assessed through an environmental liability risk assessment as basis for the creation of financial provisions for unforeseen liabilities. In practice, usually there are different types of financial deposits for unforeseen and foreseen liabilities (figure 5):

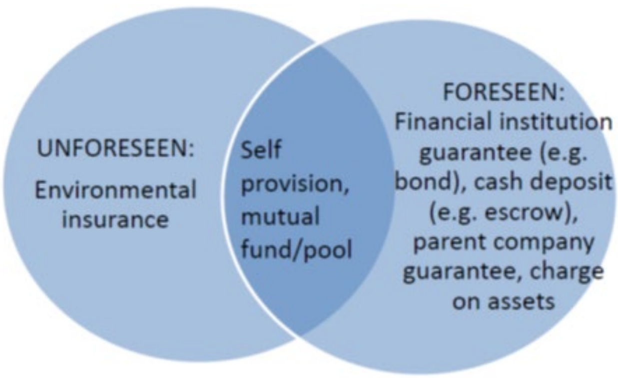


Figure 5: Approach to financial deposits for unforeseen / foreseen liabilities (Bradley et al. 2017)

The calculation of unforeseen liabilities comprises the following cost types (in analogy to Bradley et al. 2017):

- Immediate emergency measures
- Environmental damage assessment
- Primary rehabilitation (according to baseline)
- Complementary rehabilitation (of a different resource)
- Compensatory rehabilitation (for interim losses)

Some published resources are available for the calculation of unforeseen liabilities (Bradley et al. 2017):

- An evaluation of the potential for wider application of the Dutch, Irish and Spanish methods (IMPEL report 2018/XX) is available at https://www.impel.eu/projects/financial-provision-what-works-when/
- The Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente (Spain) has developed a computer application (Modelo de Oferta de Responsabilidad Ambiental (MORA), 2017) for calculating potential environmental damage costs. The English version of the MORA and IDM models is available at https://servicio.mapama.gob.es/mora/login.action?request_locale=en
- Ireland has also developed guidance ('Guidance on assessing and costing environmental liabilities') for costing potential liabilities arising from incidents (i.e. unforeseen liabilities).
- A Dutch model has been developed as a tool for the competent authorities responsible for issuing permits for Seveso companies and IED Annex I-category 4 companies (chemical industry) in the Netherlands to help determine the amount of financial security needed to cover the costs of rehabilitation of environmental damage. The Dutch model is available at https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2016/11/22/financiele-zekerheidstelling-voor-milieuschade-bij-majeure-risicobedrijven/Financi%C3%ABle+zekerheidstelling+voor+milieuschade+bij+majeure+risicobedrijven.pdf.

Subject of the present GD are foreseen liabilities. Important is to estimate a realistic volume even the closure will be far in the future. For that reason, it is necessary the estimation to be as comprehensive and transparent as possible as well as designed according to BAT. Furthermore, all cost of conceptual and technical design including supporting studies, permits, proofs, endorsements and contingencies must be covered. The Extractive Waste Directive requires that the calculation of the FG shall be made, inter alia, on the assumption that independent and suitable qualified third parties will assess and perform any rehabilitation work needed. This requirement ensures the availability of an adequate FG in case of a bankruptcy of the operator of a mine.

2.1.1 General Approach

Figure 5 shows the principal steps to calculate a FG (MonTec, 2008). Section 5.3 provides a practical example (show case) for a calculation methodology applied to energy mineral resource extraction.

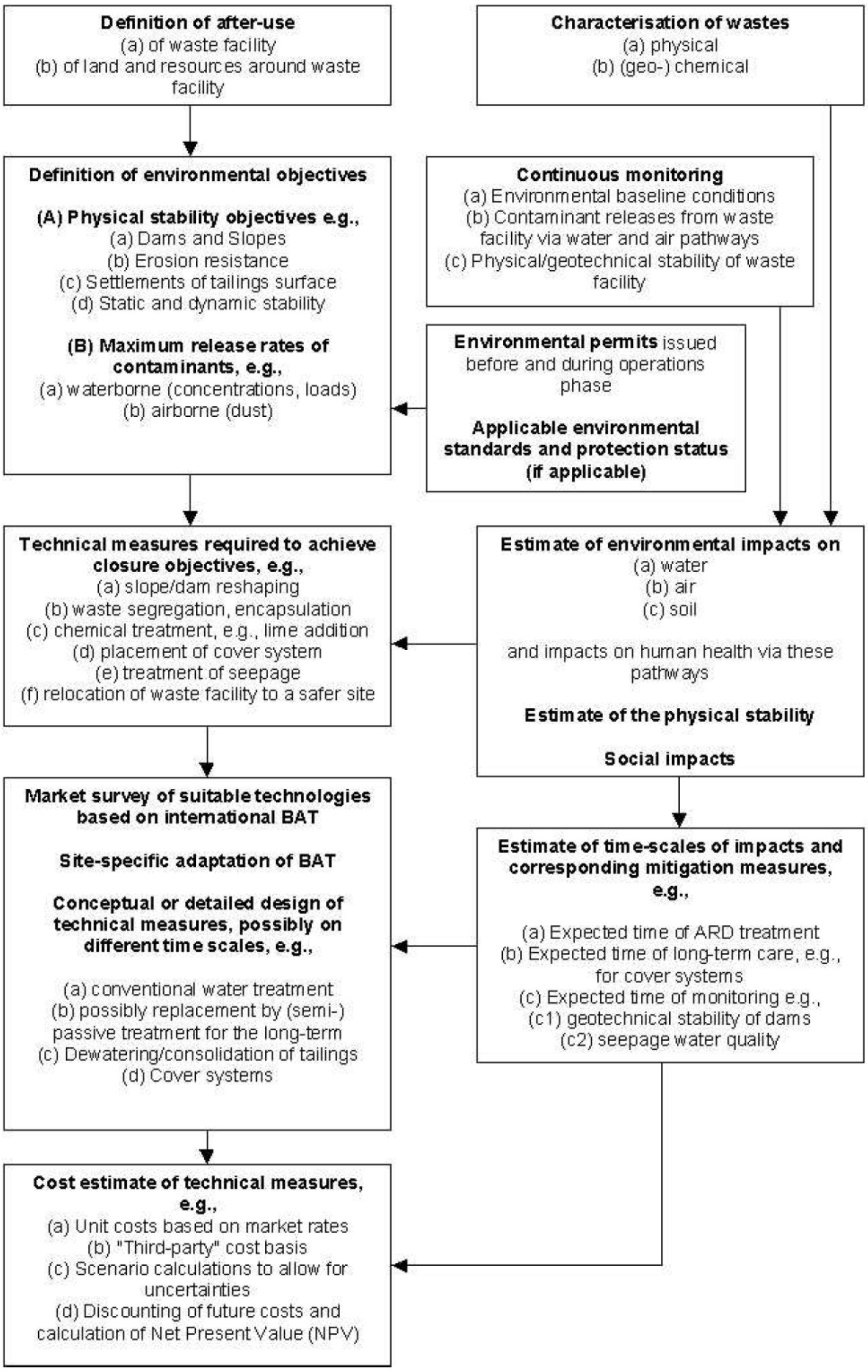


Figure 6: Flow sheet of the principal steps to calculate a FG (MonTec, 2008)

Defining the appropriate amount of financial provision and timing of the availability of the provision is important (Bradley et al. 2017). For facilities that are subject to progressive closure, the financial provision needs to reflect the partial closure works as well as the final stage of closure, and the period of after-closure. The duration of the after-closure period needs to be determined, for instance at landfill sites typically being considered to require after-closure financial provisions for at least 30 years (Bradley et al. 2017). For ore mining sites, the time might be substantially longer. In the particular case of uranium mining, more than 100 years typically are relevant. Further it is to be ensured that the financial provision is protected in case of operator insolvency or dissolution.

For foreseen liabilities following issues apply (Bradley et al. 2017):

- The calculation should typically be based on the potential liability as determined by a risk assessment, and should apply any legally required formulas or default amounts.
- The calculation should allow for the scenario where a third party needs to complete the works, to provide for cases where the liability is abandoned.
- Where the liability is going to change throughout the life of the operation, calculations should take account of the cost profile of the operation.
- For operations where the liability is unlikely to change significantly (e.g. a maximum amount of waste that is permitted to be held at a waste transfer facility), calculations should be based on that maximum amount.
- Contingency is necessary to provide for the uncertainty in costing complex and remote events, e.g. mobilisation issues or design changes, and for inflation. An example from Sweden determined the uncertainty with 28%.
- The calculation should not include the assets of the operation to offset the amount of the financial provision, to ensure that a sufficient amount will be available to the regulator in the case of insolvency or dissolution.

2.1.2 Overview on Financial Provision Instruments

Figure 7 shows categories of FG instruments and typical examples (MonTec, 2008). A preferred mechanism of a reclamation bonding system is that the bond amount be sufficient for a third-party to do the reclamation work and supervised by the administrative authority (Cheng & Skousen, 2017; van Zyl et al. 2012). Bonds are provided by a financial institution to pay if an operator defaults on its obligations. This includes performance bonds, payment bonds, and letters of credit. Bank guarantees and surety bonds possess similar characteristics to these. Bonds tend to be used by operators that are subject to financial provision requirements for foreseen costs such as closure or reclamation costs.

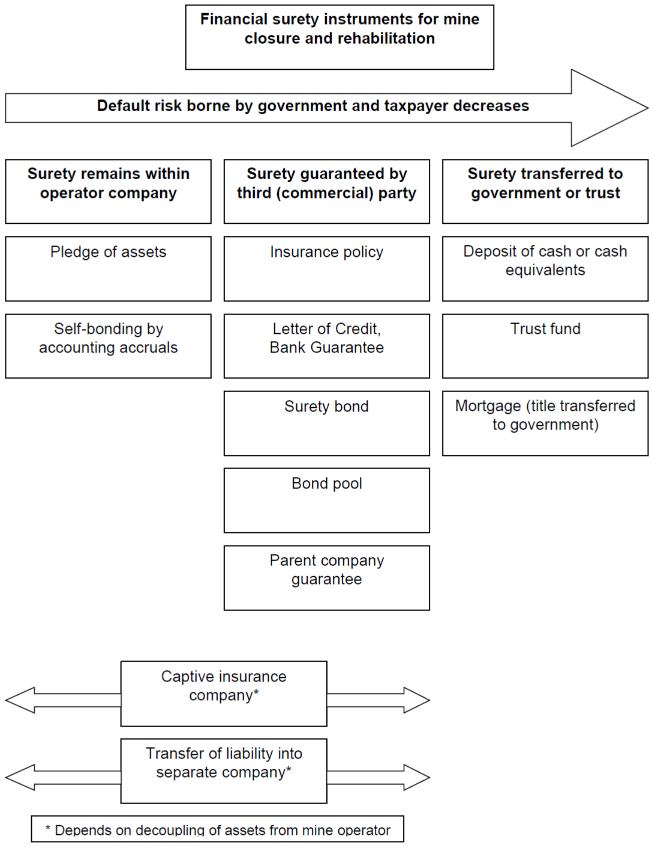


Figure 7: Categories of FG instruments and typical examples (MonTec, 2008)

Following general FG types are used (Mackie et al. 2016):

Performance Bond: issued by a bank or other financial institution or a bonding company (called a surety). The bank or surety agrees to pay the regulator up to the amount of the bond if the operator defaults on its obligations under environmental law or its environmental permit, as specified in the bond. Bonds are issued by a surety by charging a premium for them; bonds issued by a bank reduce the amount an operator may borrow.

Payment Bond: bank or surety agrees to pay monies demanded by the regulator up to the amount of the bond instead of paying the costs incurred by the regulator in carrying out measures that the operator failed to carry out.

Letter of Credit: agreement by an approved financial institution, to pay the amount specified in the agreement to a regulator on demand. The institution requires the operator to provide collateral (such as cash, securities, bonds or other monetary instruments) in the amount of the letter of credit and also charges the operator for providing it. Regulators generally require letters of credit to be irrevocable.

Self-provision: financial provision by the operator itself. This includes 'provisioning in accounts' and 'self-insurance'. It is, in essence, a promise by an operator to cover their environmental liabilities when required. It does not require an operator to set aside money. Generally, self-provision is based on the operator's demonstration of sufficient financial strength. The operator must generally update the above information on an annual or other regular basis.

Parent Company Guarantee: legally-binding agreement by the operator's parent company or another affiliate to satisfy the operator's obligations under environmental law or an environmental permit if the operator fails to do so. As with self-provision, the information must generally be updated regularly. Also as with self-provision, a parent company guarantee does not require the corporation to set aside funds.

Secured Fund: money deposited by an operator with a third party (e.g. in a bank account) and legally secured so that it can only be used for the intended purposes. Examples include 'escrow accounts' and 'trust funds'. A trust fund is a particular type of secured fund established by an operator and managed by a trustee for the benefit of specified beneficiaries, generally including the regulator. A variant of the secured fund is a cash deposit with the regulator. Secured funds tend to be used for foreseen responsibilities and not for costs arising from a pollution incident.

Mutual or Pool: a group financial provision arrangement that an operator can join and pay into and which will pay if the operator defaults on its obligations. Legislation sometimes allows a group of operators to satisfy financial provision requirements by membership in an approved mutual (sometimes called a pool). Acceptance into the mutual requires each member to provide evidence of a specified amount of financial provision, or to pay a specified amount into the mutual each year. Members must agree to pay up to a specified (or unspecified) amount if another member of the mutual fails to do so. If the amount of such payment exceeds the monies held by the mutual, an additional drawing is made on its members.

Charge on asset: mortgage/charge over a specific asset in favour of a regulator which can be triggered if an operator defaults on its obligations. It is commonly taken over premises.

Common FG instruments with their advantages and disadvantages are illustrated in Table 1.

Table 1: Mine Reclamation Financial Provision Instruments (MonTec, 2008; amended by the authors)

Types	Characteristics	Advantages	Disadvantages
Surety bonds	• Most heavily used instrument. • A premium is paid by the mining company to the underwriting institution that is the guarantee.	• The cost of getting it is relatively low. • Cost associated with putting it are expensed as a tax deductible item. • Once in place only a minimal amount of administration is required. • Many ways of initiating and releasing bonds through phased implementation and phased release.	• Often a Letter of Credit is required to back up the bond, which makes it more expensive. • Its availability may be restricted by a company's credit and its environmental risk. • The full face value of the surety may be required.
Cash Trust Funds	• The funds must be structured in such a way as to give reasonable assurance that sufficient funds will be available to meet expected closure costs. • It is highly desirable that the income earned by the fund be	• The company has control over its fund since any surpluses created, or earned should be returned to the company • The company have the incentive to ensure sound	• Uncertainty about the size of the fund in view of the long time frame involved; • If large amount is required a transition period is necessary to allow time to the company to build up the required FG.

Types	Characteristics	Advantages	Disadvantages
	tax protected until it is withdrawn company;	management of the fund; • Are more visible and often better understood by government and the public than other alternatives.	
Letters of Credit	• Similar to a surety bond. • The content of a LC should reflect the terms and conditions agreed between a company and the government with respect to a specific closure plan.	• Low initial cost (about 1% per annum of the face value). • Cost associated with opening a LC are expensed as a tax deductible item. • Once in place only a minimal amount of administration is required.	• Issued by a bank and usually for a larger sum of money than originally estimated for closure. • The availability of a LC may be restricted by a company's credit and its environmental risk. • Issued for a period of one year - short-term solution for a long-term problem. • Reduction of the company borrowing power.
Insurances	• Special form of surety bond. • The premium paid will be a function of the estimated closure cost with actuarial calculations to annual pay-out levels and the total amount of the insurance.	• May require smaller up-front cash commitments than a cash trust fund. • Premiums would be tax deductible. • Less administration is required than with a cash trust fund	• Initial premiums may be very high to ensure substance of the insurance. • In addition to premium amounts there could be taxes and insurance brokerage fees. • A new, not well tested guarantee instrument.
Self-guarantees	• Also known as corporate guarantee or self- insuring. • Based on an evaluation of the assets and liabilities of the company and its ability to pay the cost of closure requirements.	• Financial instrument of choice for a mining company.	• Require long history of financial stability and an annual financial statement prepared by accredited accounting firm. • Gaining access to assets may be problematic in the case of firms facing bankruptcy.
Mortgage	A mortgage is a property title (e.g., real estate) which the operator of a mine transfers to the competent authority in order to secure the performance of a predetermined closure and rehabilitation duty. As soon as the duty is fulfilled, the property title is transferred back to the operator.	• Easy to administrate • No cash outflow from company	• Value of mortgaged property may change (lose) with general market conditions • Administrative cost to government to liquefy mortgaged property • Discount on property value in case rapid liquidation is necessary • Mortgage reduces ability of mining company to obtain loans
Cash deposit	A mortgage is a property title (e.g., The amount required to cover all closure and rehabilitation costs is paid into a bank account accessible only by the government. In case the mine operator defaults on its obligations, the government has immediate access to the funds in the account	• Cash is readily available for closure and rehabilitation • Investment-grade securities (treasuries) can be traded with minimal risk of liquidity • High public acceptance ("visibility" of guarantee) • for small and junior mining companies, if they fail to meet the criteria of a bank • Can be dissolved only partly in case of need • Can be transferred into a pooled fund	• Significant capital is tied up for the duration of the mine life, especially for large mining projects • Some governments may be tempted to use the deposited cash for purposes other than securing the mining project • Cash is more vulnerable to being lost to fraud or theft

Countries that already implemented a mine reclamation bonding system are the United States, Canada, Australia (Cheng & Skousen, 2017), Ireland (Environmental Protection

Agency of Ireland, Office of Environmental Enforcement, 2014), and South Africa (2015, 2018). Proven bond types are cash deposits, bank guarantees, insurances, and trust funds (Cheng & Skousen, 2017; van Zyl et al. 2012). Cheng (2009) arguments that a desirable bonding system should form economic incentives rather than economic burdens for mining companies. For that reason, cash bonds are rare because high cost of bonding reduces investment in and by the mining industry (Cheng & Skousen, 2017). Cash bonds may impose liquidity constraint and economic burdens on some companies and are usually expected when the financial strength of the company is questionable, or the permit time is short (Cheng & Skousen, 2017).

A combination of financial provisions may be used by operators to cover the full liability (Bradley et al. 2017). Examples of such scenarios are:

- covering foreseen liabilities with one financial provision (e.g. cash deposit) and unforeseen liabilities with another (e.g. environmental impairment liability insurance)
- covering the gap with, for example, a financial institution guaranty, while a cash deposit is accumulating; and
- using a variety of insurance products to achieve full cover for unforeseen liabilities

2.1.3 Time Schedule for Establishing the Financial Guarantee

The FG is requested in case of exploration and exploitation. Exploration is performed based on an exclusive license granted for any of the mineral resources. The evaluation of environmental rehabilitation project takes into consideration: the works required for the protection and restoration / rehabilitation of the environment, funds allocated to the works required for the environmental protection and rehabilitation, correlation of the environment rehabilitation project with the proposed exploration program.

The exploration license is granted for a certain period (depending on country specific rules), provided a fee is paid in advance for the exploration activity and an appropriate FG for the environment rehabilitation is submitted, determined under the environmental rehabilitation project. The FG for environmental rehabilitation in case of an exploration license should to be deposited annually in the first month of the period covered, and is established within the license so that to cover for the environmental restoration works specified in the environmental rehabilitation project.

2.1.4 Coverage of the Financial Guarantee

A closure plan serves as base for regulatory body's determination of the FG amount. A FG reflects the cost of a mine closure and has to be adjustable, up or down, to reflect changes in the proposed closure plan. This cost will frequently be higher than the cost to the operator, because, in the event of a bankruptcy of the operator, the state will not be able to use site's mine production equipment and personnel, with resulting marginal cost (Hollands, 1999). Long-term commitments (e.g., monitoring, after care, etc.) have to be taken into account on a best-estimate basis, even though no clear official calculation methods exist. The other method to calculate the FG often applied by the surveyed companies is based on unit amount calculations (e.g., per t of mine wastes produced, etc.). FG must cover closure and post-closure activities.

2.1.5 Approach to Financial and Economic Analysis

An investment requires financial and economic analysis, two approaches that serve two different purposes. The financial analysis is used to document a reasonable expected return on investment to prospective investors. The economic analysis is used to document that the project is a net benefit to society as a whole – this is especially interesting in relation to public investments. The main traits of the financial and economic analysis respectively are:

Financial Analysis:

- Investor's perspective
- Based on market prices
- Including taxes, tariffs, subsidies etc.
- Does not include externalities

Economic Analysis:

- Society's economic perspective
- Applies economic prices excluding taxes, tariffs, subsidies etc. to reflect the value of the project to society.
- Externalities (positive and negative) are included and quantified in monetary terms (such as reduction in GHG emissions).

The central economic concepts are briefly introduced which are essential to understanding financial and economic feasibility studies (FS).

Interest Rates

Interest rates are a central element in financial and economic analyses. The interest rate is the opportunity cost of capital, i.e. what is the expected return on investment.

The return of a project shall be compared to the alternative return, given the money is invested elsewhere. Therefore, the appropriate discount rate for a financial assessment is the *weighted average cost of capital* often referred to as the WACC, that is calculated using following formula:

$$WACC = Share\ of\ Equity \times Cost\ of\ Equity + Share\ of\ Debt \times After\ tax\ Costs\ of\ Debt$$

where the corporate tax shield is deducted from the cost of debt.

Economic/Social Discount Rate: the appropriate discount rate, when performing an economic analysis is the rate of return of the entire economy, i.e., the national opportunity cost of capital. In comparison, the WACC applied in the financial analysis is only relevant to a specific investor, as the WACC calculation is based on a single investor´s cost of equity and debt. The economic discount rate is typically lower than the WACC.

Interest rates are very important to economic and financial FS, as they enable the comparison of costs and revenues at different points in time.

Discounting and annuities

Interest rates are used to compare payment streams today with payment streams tomorrow. Such a comparison can employ one of two main methods:

- Net Present Value
- Total Annual Net Cost

These methods each have their strengths and weaknesses. The Net Present Value method is good for keeping track of cash flow and variations in costs and revenues over time. The Total Annual Net Cost method is good for managing complex projects with many technical components with different technical life spans.

Net Present Value

On some projects, revenues and costs vary over time, e.g. up front investments and revenues that fluctuate (in real terms) over time. In that case will be needed to use the Net Present Value method to calculate the difference between the present value of all future costs and the present value of all future revenues. This method allows to keep track of cash flow, as the method requires to plot all costs and revenues over time.

NPV: The *Net Present Value* is a measure of profitability used in corporate budgeting to assess a given project´s potential return on investment, the NPV is the difference between the present value of cash inflows and the present value of cash outflows. Due to the value of the time, the NPV takes into account the discount rate (here the WACC) over the lifetime of the project, thus presenting the annual cash flows in present values.

The interest rate applied for calculating the NPV is either the WACC or the economic discount rate. The NPV is calculated using the formula:

$$NPV\ (i,N) = \sum_{t=0}^{N} \frac{C_t}{(1+i)^t}$$

where **i** is the financial discount rate (WACC), Ct the net cash flow at time t and N the total number of time periods.

A NPV of zero (0) implies that the return on the investment equals the WACC. Therefore, a negative NPV can be found for a project with a positive return, but where this return is lower than the investor’s required return.

Total Annual Net Cost

On project where revenues and operating costs are constant over time it may be an advantage to use a simpler approach than NPV. The Total Annual Net Cost method annualizes all capital costs into annual payments on a loan with either WACC or the Economic Discount Rate as the interest rate. Since operating costs and revenues are identical from one year to the next it will be sufficient to calculate the sum of the annual payment on the capital investment, the annual operating cost and the annual revenue for a single year. This Total Annual Net Cost is directly comparable to other alternatives calculated in the same manner.

This method is especially effective when there is a project that includes many technical components with different technical life spans. The annual payment is calculated on each component separately, and based the payment calculation on a loan with the same duration as the technical life span.

Key Indicators

When one or more alternatives are compared, it is usually sufficient to directly match the Net Present Value or the Total Annual Net Cost in order to assess which project is the better alternative. However, in many cases you will also want to directly assess whether the preferred alternative is economically and financially feasible. The primary indicator of this is simply the value of the Net Present Value or the Total Annual Net Cost. A positive value means the project yields a net surplus – and a negative value means a net loss. In addition to this direct assessment of the value exists several ways to extract more detailed information on the profitability of a project.

IRR: The *internal rate of return* is a measure used for assessing the profitability of potential investment. The internal rate of return is the discount rate that makes the net present value if all cash flows equal to zero.

DSCR: The *debt service coverage ratio* is the ration of cash available for debt servicing to interest, principal and lease payments. The DSCR is a measurement of an entity´s ability to earn enough cash to cover its debt payments.

$$DSCR = \frac{Net\ operating\ income}{Total\ debt\ service}$$

The higher this ratio is, the lower the risk of the lender. To be confident that the investor or project owner can repay his debt, financial institutions (lenders) will demand that the DSCR is larger than one (1) by a certain margin.

Financial Analysis

A financial analysis estimates the profitability of a project, from an investor's perspective. In a financial analysis are compared the costs of the project to the expected revenue over the project lifespan. This includes costs of financing and taxes/subsidies. Figure 8 shows the approach to Financial Analysis.

Figure 8: Approach to Financial Analysis (Legend: CAPEX: Capital Expenditure, OPEX: Operational Expenditure)

The goal of the financial analysis is to demonstrate the ability of the project to generate a sufficient return on investment to be interesting for investors. The results of the financial analysis are typically presented as the Net Present Value and the Internal Rate of Return. Investors will also be interested in the Debt Service Coverage Ratio to assess the financial risk of the project.

Economic Analysis

An economic analysis takes a broader view of the profitability of the project. In an economic analysis, you include external effects such as environmental impacts and health impacts. The value of external effects is typically assigned using economic opportunity costs or shadow prices. An economic analysis does not include taxes, tariffs, subsidies, etc. These costs do not add to economic productivity and are merely transactions between entities within the economy.

Figure 9: Approach to Economic Analysis

An economic analysis is always a comparison between a base case – the expected present and future situation without the project – and the project alternative. Without this comparison, it would be impossible to assess whether the external effects are an improvement or not. Whenever the term "benefit" is used in an economic analysis it refers to the change in external effects that can be attributed to the project.

The goal of the economic analysis is to demonstrate that the project is a net gain for society. This is typically mandatory whenever there is an element of public financing or regulation, e.g. tariffs. Economic analysis is also more and more frequently being used to brand private investments as being socially responsible. Typically, there is a greater variation in how the results of the economic analysis are reported as opposed to the financial analysis. The financial analysis serves a very specific purpose, whereas the economic analysis is used to communicate the benefits of the project to many different stakeholders.

2.1.6 Cost – Benefit - Analysis

The assessment of the several remedial options for the mine objects is based on a cost benefit analysis. This means that the evaluation of whether rehabilitation actions should be undertaken or not and to select a preferred rehabilitation option with the maximum effect in relation to the money spent and other potentially negative impacts. A scoring system is needed to assess the effects of each option. Each factor has the same weighing except the costs. Following factors of relevance in the cost benefit analysis are usually chosen:

- Improvement of geotechnical stability, water-related aspects, air-related aspects, and soil-related aspects
- Facilitation of beneficial after-uses
- Worker safety
- Sustainability, and
- Costs

The options for all objects are compared through rating points. The total points will indicate the preferred option (the higher the more preferred).

2.1.7 Structure of Costing

The structure of costing of closure activities comprises following basic cost types:

Closure cost:

- Investment and maintenance cost

- Design, engineering and supervision cost
- Administrative cost (permits, fees and taxes)

After-closure cost:

- After-closure and monitoring cost
- Inspection cost

It should be noted that costings associated with conformance checks, reviews, audits and safety evaluations as set out in the BREF for the Management of Waste from Extractive Industries must be included at all stages.

Table 2 provides an overview on closure guarantee factors, illustrating which types of cost must be covered through the FGs.

Table 2: Closure Guarantee Factors (after Legislative Audit Division, 1997; Mota de Lima, 2003; Cheng & Skousen, 2017; amended by the authors)

Costs	**Description**
Direct closure costs	Calculated using conditions which represent the maximum closure cost.
Indirect closure costs	Contract preparation and administration costs. Calculated by project staff and site specific.
Mobilization and site preparation	1 to 5 % of direct closure cost
Contingencies	Project uncertainties and unexpected natural events, up to 30 % of direct closure costs is possible.
Engineering and Design	Redesign to reflect current conditions. 2 to 10 % of direct costs.
Overhead	Overhead not included in direct cost calculations, 3 to 14 % of direct closure costs.
Closure management	Project inspection and supervision, 2 to 7 % of direct closure costs. Administrative maintenance
Administrative costs	Permitting cost. Country and site specific.
Maintenance costs	Operation of the environmental operation system, water treatment etc. Duration and cost site specific. 2 to 10 % of direct costs.
Monitoring costs	Environmental observation, duration and cost site specific.

There is inherent uncertainty in costing closure and after-closure due to the complexities involved and lack of knowledge of the circumstances that will pertain at the time of closure. Therefore, the final costing should include a level of contingency. The contingency is a specific provision for unplanned or unforeseeable items and provides an additional level of confidence in relation to the costing. The rate of contingency should reflect the level of uncertainty inherent in the costing.

As mentioned in table 2, the cost to be considered concern engineering and design, direct closure costs, indirect closure costs, mobilization and site preparation, contingencies, closure management, administrative costs, maintenance costs, and monitoring costs including and overhead. Cost profiles in this GD consider engineering works and technical works. Cost-relevant activities are given in section 5. Initial costs of closure, rehabilitation and after-closure should be adjusted to account for future inflation. The inflation rate used and justification for it should be provided by the permit holder.

2.1.8 Costing: Investment and Maintenance Cost

Construction costs represent investment costs as a price expression of the investment costs for a building. They are estimated as part of the construction planning. There are four primary methods used to estimate construction costs that are not specified in terms of application to a certain design level or in terms of determination of the relevant cost information (Xu et al. 2014):

- project comparison estimating
- area and volume estimating
- assembly and system estimating, and
- unit price and schedule estimating

A unified model of these four methods consists of quantity and pricing (Xu et al. 2014), and this is the approach that is typically applied in closure design projects. Scope of the cost estimation is the net present investment value that must be supplemented with the (future) proofing costs, contingencies, and the consideration of inflation and discounting. The resulting value is the direct investment cost. Hence, in-order to define the scope of Work (and thereafter to prepare a cost estimate) following details are required.

1. Detail drawing

2. Material Specification

3. Standard of work man ship

4. Method specification/ statement of the intended construction

5. Time period

6. Reasonable up to date rates applicable for various trade items. Involved with construction.

A cash flow showing expenses and incomes must also be a part of the FS for the implementation of the mine. The cash flow should be linked to the staggering of investments, the exploitation production rate, the closure and rehabilitation works including post closure monitoring and maintenance. Closure and rehabilitation works are designed, if technically possible, as much in parallel with the exploitation works. Dimensional characteristics of the mining elements, as they are at the time when the entire reserve has been extracted according to the mining plan, including as build drawings for all constructions and utility networks, will be the starting point in dimensioning the closure and rehabilitation works.

The various positions constituting the investment will correspond to all expenses and margins of the engineering company to carry out the project. The main items constituting the cost of the investment are generally the following:

Project evaluation and cost estimation

- the main equipment

- secondary materials
- packaging and transportation
- construction work, including temporary site installations
- supply studies and start-up services
- specialized studies (topography, soil, hydrometry, noise, pollution ...)
- financial expenses: deposits and known financial charges
- basic insurance: professional liability, transport of equipment and personnel start-up of construction site
- insurance
- the general expenses and the profit of the company

All items must be supplemented by technical and unexpected provisions and the provisions needed to cover inflation and foreign exchange risks over the life of the project. As the detailed and semi-detailed methods are based on contractual prices, there is no need to correct the final assessment by a location factor. To have a correct cost estimate in the above presented context, detailed and semi-detailed cost estimation methods should be used. These methods are based on the definition of the various items constituting the investment. This definition is based on:

- the cost breakdown structure, itself based on the tasks to be performed to carry out the project and the required resources (work breakdown structure)
- the "cost code" or project account plan which is a categorical cost classification system

The structure of this "cost code" is based on a logical cut of the construction project in controllable elements to meet the following two objectives:

- estimate of the investment
- control of the investment during the realization of the project.

Firstly, the breakdown of costs is based on the physical decomposition of the project (technical chart). The principle of cost splitting makes it possible to better identify the essential elements and to ensure the completeness of the costing. The approach is starting from the main installation to get to all its components. Maintenance expenses are the costs incurred to keep an item in good condition or good working order. When purchasing an item that requires upkeep, consumers should consider the initial price tag as well as the item's ongoing maintenance expenses.

2.1.9 Costing: Engineering and Supervision Cost

Engineering and supervision cost comprise design and management activities that are necessary to develop the project implementation documentation. Based on technical dimensions, mandatory technologies and materials specification in the above-mentioned conditions the cost of closure and rehabilitation works can be evaluated.

The objective of the cost estimate is to produce, depending on the project's progress phase, information to establish the project budget. The project estimation methods used depend on the project's progress phase. As a result, the choice of an estimation method depends on the level of information available. Table 3 shows the cost estimation levels during the design process.

Table 3: Cost estimation levels during the design process

	Initial / conceptual studies	Feasibility studies (FS)	Basic studies: project design	Project development / detailed design
Budget Categories	Budget "order of magnitude"	"Preliminary" budget	"Goal" budget	Initial or contractual budget
Estimation method	Global method or similarity	Modular method or factor method	Semi-detailed method	Detailed method
Level of precision	40 to 50 %	25 to 30 %	15 to 20 %	5 to 10%

Engineering cost include further design, engineering and supervision cost. The starting point in calculating the FG would be the TD for restoring the environment affected by mining activities and the Bills of Quantities (BoQ) for the environmental rehabilitation works. The TD for mine closure should be based on the elements presented and estimated in the preparation of FS and TD based on which the capital works are performed. Still compared to the FS mine closure cost estimate, the FG value should consider that decommissioning and rehabilitation works will be performed by independent and properly qualified third parties so additional cost chapters (compared to the situation where is considered that the mining operator will do the mine closure and rehabilitation works by itself or under own management) should be included:

- Obtaining endorsements, approvals, permits
- Design and engineering (compared to the technical design prepared at the beginning of the mining objective, the re-designing of the closure and environment rehabilitation works will be usually required in order to correlate them with the status of the objective at the moment of ceasing the activity and given the requirement of implementing technical solutions adjusted to possible new technical standards and regulations approved meanwhile.
- Organizing the procurement procedures
- Consultancy
- Technical assistance

In order to be able to physically build the mining project’s elements there is a need for a detailed design. Project design will serve as input to the development consent applications and will be assessed in an Environmental impact assessment (EIA) process if required.

In order to establish a correct FG value that should cover the mine decommissioning and rehabilitation cost including post closure monitoring and maintenance, there is a need for a calculation methodology which is a) high enough to be sure that in the case of bankruptcy the tax payer does not need to step in, but also b) low enough in order to attract investment. The outcome of the designed decommissioning and rehabilitation works must match the post-mining land use(s) that has been proposed/agreed with key stakeholders including regulators. The design for closure and rehabilitation works must follow all applicable standards and norms that will impose technical dimensions, mandatory technologies and materials specification.

2.1.10 Plausible Worst Case Scenario

It is to be underlined that the FG function is not to cover the consequences of accidents and incidents, as these are unforeseen liabilities. The plausible worst case scenario refers to the plausible event that poses the maximum environmental liability in the case of foreseen liabilities, i.e. consequence, during the period to be covered by the financial provision (Environmental Protection Agency, 2014). A worst-case scenario is a concept in risk management wherein the planner, particularly in planning for potential disasters, considers the most severe possible outcome that can reasonably be projected to occur in a given situation. In case of FG establishment for mine closure this topic is particularly relevant in terms of provision for premature closure. The plausible worst case scenario may be represented by the risk with the highest consequence rating.

Although practical planning for premature closure (permanent or suspended operations under care and maintenance) may not be done in detail in the early stages of the project, consideration must be given in the Mine Closure Plans for how a proponent plans to deal with these closure scenarios which may arise from economic, environmental, safety or other external pressures (Department of Mines and Petroleum, 2015). In such an event, an accelerated closure process will need to be implemented. In particular, this should include confirmation that appropriate materials are available on site and contingencies are provided to make landforms such as tailings storage facilities and mine waste heaps secure and non-polluting/ non-contaminating in the event of premature closure (Department of Mines and Petroleum Australia, 2015). The dimensions of premature closure must be considered during the closure design already, based on a risk assessment.

To assess the risk, the source – pathway - receptor model might be used. The model starts with the risk source and the pathway how the hazard can reach through the environment. Finally, it is considered how the receptor of the hazard is affected. A receptor can be human and/or environment. Usually for each source, there are multiple pathways and receptors. After identification of the sources, the pathways and the receptors, the next step is the assessment of the impact of the risk or hazard to the receptor with respect to the following parameters:

- Spatial extent of the impact
- Temporal extent of the impact
- Severity of the impact.

The significance of the impact is calculated by multiplying the assigned values for magnitude of the potential impact and the sensitivity of the receptor to generate an evaluation matrix. The risk matrix according to Nohl & Thiemecke (1988) is a common methodology for technical risk assessment. These two elements of a risk can be presented in a matrix that allows risks to be categorised by different qualitative risk classes. The aim of the matrix is to estimate the risk significance (figure 10). The severity of impacts is ranked according to the following qualitative scheme that is based on the sensitivity of receptors and magnitude of impacts. When determining impact magnitude, conservative assumptions are often used.

			Sensitivity of Receptors		
			1	2	3
			Low	Medium	High
Magnitude of the impact	1	Minor	Negligible	Minor	Moderate
	2	Moderate	Minor	Moderate	Major
	3	Major	Moderate	Major	Critical

Figure 10: Risk Evaluation Matrix according to Nohl & Thiemecke (1988)

The most sensitive facility in terms of the plausible worst case scenario is a dam failure of the TMF that can lead to the spreading of tailings material. Santamarina et al. (2019) argue that given the number of tailings facilities worldwide (over 9000), there is an urgent need to gain a better understanding of the mechanisms of tailings dam failures, and to use this understanding to improve management practices. Figure 8 illustrates potential TMF failure mechanisms that must be considered during the Technical Design. There must be taken precaution indicator during the design to avoid TMF dam failure, that are:

- the impoundment must be stable under all static and transient loads; for that must be identified failure modes
- the impoundment must be stable for seismic loading and must pass design flood
- the transient load design magnitudes must be sufficient
- the surface and groundwater quality must meet regional and global water quality standards

To analyse the physical stability in the short and long term according to Eurocode 7–1 (EN 1997-1:2004 - Part 1) or equivalent national standards and to the provisions of the ICOLD guidelines (including Bulletin 139 and 148) or equivalent national standards in the case of large dams.

It is essential for the stability and or integrity of a TMF to manage decant pond water, the combination of supernatant and runoff. The starting point for good management is an integrated water balance model that will allow the prediction of the water volume needed to be managed (figure 11).

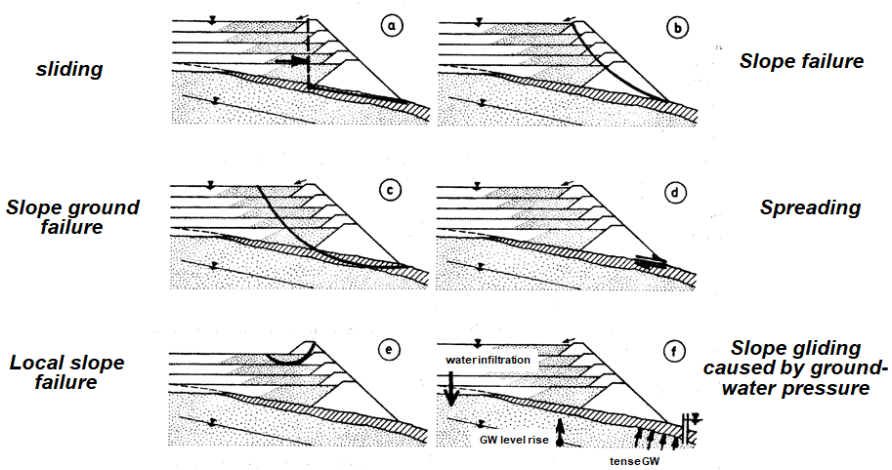


Figure 11: Potential TMF failure mechanisms (ATV-DVWK-M 503)

The main hazards in terms of potential TMF failure mechanisms are:

Foundation instability:

- collapse due to mine subsidence allows tailings to escape into mine or void;
- sliding on weak soil or liner interface
- compression of weak soils leads to cracking of dam
- construction pore pressures rise and foundations move
- seepage through a poor membrane or pervious soils into groundwater system, bypassing seepage recovery systems
- seismic liquefaction of foundations
- seismic deformation of foundations
- non-seismic liquefaction of foundations

Structural failures:

- piping around a culvert or decant pipe
- reclaim tower fails
- pumps fail due to loss of power
- pipeline or conduit fails
- landslide blocks spillway

Without prejudice to other Community legislation, and in particular Directives 92/91/EEC and 92/104/EEC, MS have to ensure that major-accident hazards are identified and that the necessary features are incorporated into the design, construction, operation and maintenance, closure and after-closure of the waste facility in order to prevent such accidents and to limit their adverse consequences for human health and/or the environment, including any transboundary impacts. Article 6 “Major accident prevention and information” of the Directive 2006/21/EC shall apply to waste facilities, save for those waste facilities falling within the scope of Directive 96/82/EC (The Seveso II Directive).

According to article 6 of EWD each operator must, before the start of operations, draw up a major-accident prevention policy for the management of extractive waste and put into effect a Safety Management System, implementing it in accordance with the elements set out in the Directive (Section 1 of Annex I). The document is intended to give an overview of how the operator ensures a high level of protection for people and environment. As part of that policy, the operator must appoint a safety manager responsible for the implementation and periodic supervision of the major-accident prevention policy. During the design, extraordinary meteorological situations, particularly forecasts of 100 and 1000 years rain events must be taken into account.

However, the Safety Management System does include the procedures necessary to ensure that an adequate Internal Emergency Plan is developed, adopted, implemented, reviewed, tested, and where necessary revised and updated, specifying the measures to be taken on site in the event of an accident. The procedures should also cover the necessary arrangements for communication of the plans to all those likely to be affected by an emergency. Best Practice is an integrated risk management and the implementation of a Risk Management System According to ISO 31000:2018.

2.1.11 Content of Technical Design

The TD for environmental rehabilitation shall be drawn up in compliance with the respective legislation. It must be based on a comprehensive risk assessment. The FG cannot be lower than the total value of the environment rehabilitation works provided in the TD for environment rehabilitation, namely: (i) the value of the works for restoring the environment affected by mining works planned for the next guaranteed period, and (ii) the value of outstanding works or of the works not properly carried out for the rehabilitation of the environment affected as a result of mining works performed to date. Any changes made to the development-mining TD or to the exploration works design shall be accompanied by the appropriate updating of the Technical Design for environment rehabilitation, and the updated version will be considered only after all the required endorsements, approvals and permits are obtained according to the applicable legislation. Following specific issues shall be considered in the TD:

General information on the mining facility:

- administrative – territorial location
- access in the area
- surface morphology
- geology of region and ore body
- status of resources / reserves

General presentation of the mining facility:

- description of the mining works program
- current status of the mining works
- mining works planned for the next period
- planned decommissioning works
- status of land as at the date of drafting the study and at the end of the period

Environment deterioration generated by the mining activity;

- stability of the land surface, of the open pit slopes and embankments
- land degradation caused by excavation, waste disposal, soil stripping, etc.
- pollution of buildings, plant and equipment
- pollution of surface and underground aquifer layers

Degradation of water quality due to emissions of dust, exhaust gases, etc.:

- deterioration of vegetation (deforestation, soil stripping, etc.)

Environmental rehabilitation works:

- works for stabilizing the natural slopes and open pit/mine waste heap embankments
- placing back of extractive waste into excavation voids and filling back other wastes for recovery works
- works for environmental rehabilitation of tailings ponds and/or decant dams
- water management (collection, drainage, wastewater treatment, discharge)
- land decontamination works
- land consolidation works
- works for restoring the vegetation (planting, grassing)
- other works required

Physical volume and value of environment rehabilitation works:

- lists of works to be carried out and quantities required
- unit costs by categories of works
- total costs of the environment rehabilitation works
- funding sources for the environment rehabilitation works

Schedule of the environment rehabilitation works;

- carry out the environment rehabilitation works in correlation with the mining works schedule
- phases for carrying out the environment rehabilitation works

Monitoring:

- objectives of the monitoring program
- estimated period of the monitoring works
- maintenance and/or rehabilitation works
- costs of the monitoring works

2.1.12 Bills of Quantities

Base of the cost estimates are the Bills of Quantities (BoQ). BoQ is a document prepared by the cost consultant (often a quantity surveyor) that provides project specific measured quantities of the items of work identified by the drawings and specifications in the tender documentation. Figure 12 provides a simplified sample of a BoQ. The quantities may be measured in number, length, area, volume, weight or time. Preparing a BoQ requires that the design is complete and a specification has been prepared. The BoQ is issued to tenderers for them to prepare a price for carrying out the works.

Bills of Quantities
Environment Rehabilitation Works provided in the Technical Design

No.	Item	M.U.	Quantity	Unit Price	Total Value
0	1	2	3	4	5
1.	Works in the area affected by mining				
1.1	Depositing soil on berms and compacting				
1.2	Planting shrubs				
1.3	Maintenance Works				
.....	....				
2.	Works in the area of tailings stockpiles				
2.1	Organizing the area				
2.2	Covering the land with mesh				
2.3	Transportation of topsoil				
2.4	Fertilisation				
2.5	Grass sowing				
2.6	Maintenance				
.....	....				
3.	Other works for environment rehabilitation				
.....	....				
TOTAL					

Figure 12: Simplified sample of a BoQ

2.1.13 Cost Profile and cost-relevant activities

The GD summarizes the technical steps for a closure that is safe in the long term. It contains the cost-relevant activities for the respective closure activities.

2.1.14 Periodic Adjustment of the Financial Guarantee

According to Article 14(3), the FG size has to be adjusted periodically in accordance with any rehabilitation work needed as described in the waste management plan. Pursuant to Article 5(4) of the Directive, the EWMP must be reviewed every 5 years, or more frequently in case of substantial changes of the operations. According to Article 7(4), competent authorities have to reconsider and, where necessary update permit conditions in case of substantial change of the operations, or on the basis of monitoring results, or in case of important modification of the Best Available Techniques.

Any changes in TD or Exploration Works Design shall be accompanied by the appropriate updating of the Environment Restoration Technical Design (ERTD). The update will be considered only after all endorsements, approvals and permits are obtained. A modification of the general cost estimate related to the TD for environmental rehabilitation shall implicitly lead to the FG modification. The ERTD shall highlight the values for the environmental rehabilitation at the end of each exploitation/exploration year, underlining the balance between the additional rehabilitation works associated with any new exploration/exploitation impact generating works and the environment rehabilitation works forecasted for each of the next years during the lifetime of the mining facility. Therefore, after the reception of the environmental rehabilitation works for the previous year, the value of the FG shall be adjusted. The annual FG amount update is also necessary because of potential price changes. The FG shall be constituted and updated respectively, prior to the commencement of works, namely in the 12^{th} month of each exploration/exploitation year, based on the values determined in the ERTD and on the documents confirming the carrying out of environmental rehabilitation works.

a) Initial FG Assessment

The FG amount will result from the cost estimate of the ERTD. For the calculation of the amount software might be used which includes a data base with all the Cost Estimate Norms and is easily updated with materials and norms required by the new construction technologies.

b) Verification Methods

In order to verify the value correctness, it is necessary to check the compliance between sizes and specifications from drawings and bills of quantities, and subsequently with works cost estimates. Price verification can be conducted using a software with updated prices.

c) FG Periodic Adjustment

The time period for FG periodic adjustment might be adapted in case of lower risk and likelihood of environmental consequences (In analogy to The World Bank Group Oil, Gas and Mining Policy Division, 2008). In case of a medium risk and likelihood of environmental consequences the periodic adjustment might be conducted every 3 years, in case of a low risk and likelihood of environmental consequences every 6 years.

2.1.15 Quality Management due to ISO 9001:2015

Quality management of the closure design and implementation process plays a substantial role and comprises two parts:

Quality assurance during the design process

- design verification, and
- establishment of a Quality Assurance Plan (QAP) as part of the design documents. The QAP contains the requirements for the material testing (at least soil mechanics and chemistry), that is parameter sets and the analysis procedures requirements. Analytics has to be performed by a lab accredited according to DIN EN ISO/IEC 17025.

Quality assurance during the implementation process

- Comprises implementation verification and field testing
- implementation verification is performed by an independent certified assessor. Following levels of independent implementation verification is performed in practice:
    - Prefabrication of materials / components / systems

  - Self-monitoring of the manufacture by the manufacturer
  - External monitoring of the construction by a commissioned third party
  - Construction on the construction site
    - Self-examination of the executing construction company
    - External inspection by a commissioned third party (commissioned by the client), which must be confirmed by the competent authority
  - Inspection by competent authority

2.2 Financial Guarantee Implementation

FG must be complemented by permitting, inspection, enforcement and education process to be effectively implemented. The permitting process is necessary for clarifying the criteria for mine closure, impelling planning for closure from the outset of mine planning and successfully ensuring enforcement of closure criteria. The enforcement capacity of the regulator should be clearly and explicit defined since it allows all parties involved to be aware of the FG implications in case of permit violations or bankruptcy. Inspections require good communication between mining companies and regulators with the goal of identifying faults in the previous closure plan and problems during their formative stages (Anderson, 1999).

2.3 Review and Release of the Financial Guarantee

The FG amount and the appropriateness need to be reviewed periodically. FG review is mostly done annually or bi-annually. In some countries the review is undertaken at any time on request of the State Mining Authority, as it is the case in Poland. In Finland the review is carried out only in the case the permit is updated (after 9 years) and in Greece every 5 years. The FG release shall depend on the waste facility liability period described in the Mine Closure Plan, which also regulates how and when the FG has to be released. Only after approval of the plan by the competent authority the FG will be released. The process might be supported by the review and approval of an external auditor stating that all closure and rehabilitation measures have been finalised according to best practice and to the closure plan, and that no further hazard exists.

FG shall be released only to the holder regardless the changes occurred during the lifetime of the facility. In order to have the FG released, the operator, after full completion of the environmental rehabilitation works provided in the TD, shall submit an application to the competent authority. This shall be accompanied by documents confirming the carrying out of environmental rehabilitation works in accordance with the ERTD provisions. After the completed closure was approved by the competent authorities, the end of site ownership by the mining company and of their responsibility for the site, with transition of ownership and residual liability to the jurisdictional authority or a third party can be established (relinquishment).

a) Formalities regarding FG release

Within 30 days from submitting the application on releasing the guarantee and related proving documents, the competent authority shall send a written response to the operator, either positive or negative. During the evaluation period the competent authority shall conduct, through its territorial representatives, the verification on site of the environmental rehabilitation works carried out and draw up a verification report.

b) The case when the exploration/exploitation title is transferred to another mining operator.

In case of changing the mining operator within one perimeter, FG obligations shall be taken over by the new operator.

c) The way rehabilitation works are to be carried out in case the mining operator goes bankrupt.

In case the mining operator fails to meet its obligations on environmental rehabilitation, the competent authority shall commence the tender procedure for the environmental rehabilitation works based on the Technical Specifications within the ERTD. The procedure will be followed in accordance with the legislation in force on public procurement. The amounts required for the tender procedure and funding all the expenses for the environmental rehabilitation works provided in the General Cost Estimate shall be funded by the competent authority out of the environmental rehabilitation guarantee submitted.

3. Part B: Best Practices for Closure, Rehabilitation and After-closure Design

Closure cost must also cover engineering cost, particularly closure design cost, and in this way must be included into the FG. For this reason, also best practices for closure, rehabilitation and after-closure design are included into the GD.

3.1 Combined Closure, Rehabilitation and After-closure Plans

The closure of mining sites requires a combined approach of decommissioning and rehabilitation, laid down in a closure plan. However, the technical closure strategy including the closure options to be taken into consideration does substantially depend on the after use scenario. Depending on the mining typology, following closure approaches can be distinguished.

- Closure after termination of mining
- Closure in parallel to mining (progressive closure).

After-closure plans refer to the closed mine that undergoes monitoring and inspections for a certain period that is determined by the competent authority. In analogy to the Environmental Protection Agency of Ireland (2014), the closure plan shall include, as a minimum, the following:

- a scope statement for the plan;
- the criteria that define the successful decommissioning of the activity or part thereof, which ensures minimum impact on the environment;
- a programme to achieve the stated criteria;
- where relevant, a test programme to demonstrate the successful implementation of the decommissioning plan; and
- details of the costings for the plan and the FG to underwrite those costs.

The closure plan must be validated through a final validation report in order to achieve a certificate of completion for the closure plan that shall be emitted by the competent authority (CA) within a certain period. For closure in parallel to mining, that typically takes place for lignite open cast mining, milestones must be defined over the whole operation period of several decades in order to already dismiss parts of the recultivated land to the public. If closure after termination of mining takes place, the closure plan must be submitted to the CA together with the application for exploration to provide the complete necessary data to allow the CA the assessment of all cash flows for operation and closure for a comprehensive assessment of a sustainable financing plan.

3.2 Definition of the Rehabilitation Scope and Resulting Closure Steps

The main goal of rehabilitation is to return affected areas as near as possible to their economic and ecological value. It does not aim to return them to original state (UNEP, 1983). The EWD defines as overall rehabilitation scope the "*treatment of the land affected by a waste facility in such a way as to restore the land to a satisfactory state,* *with particular regard to soil quality, wild life, natural habitats, freshwater systems, landscape and appropriate beneficial uses*".

The rehabilitation scope depends on the level of potential pollution resulting from the mining activities and the requirements for the geotechnical long terms stability. Already during the mining operation, an estimate or preliminary soil and water quality assessment is needed to determine whether soil or water are contaminated and, where applicable, to define the scope of the rehabilitation work. The characterization must:

a) determine the contamination level; depending on the future use of the mining site
b) find the precise location of the contamination and determine whether and where it is spreading;
c) determine the volume of each type of contaminant.

If a need for rehabilitation has been identified, the development of a suitable technology for the rehabilitation of the mining legacy sites needs to be based on state of the art technologies. The aims of these technologies are:

- to exclude existing acute dangers or comparable unacceptable risks from the objects to human health and safety;
- to create long term stable site conditions for existing piles, former operational areas and underground facilities;
- to interrupt the pathway for the transfer of pollutants to human beings;
- to minimize the impact of the objects to the environment.

The rehabilitation techniques shall be economically and technically feasible. The closure plan involves the consideration of (Düzgün & Demirel, 2017):

1. Land use prior to mining and natural and cultural factors affecting the land use,
2. Land capability prior to mining, to support a variety of uses,
3. The alternatives for land use after completion of mining and rehabilitation
4. A detailed description of how the proposed post-mining land use is to be achieved
5. Methods for ensuring that mining and rehabilitation operations are in line with declared land use plans and programs
6. Mining methods used to ensure that closure plan is compatible with local physical, environmental and climatic conditions,
7. The economic and technical feasibility of the closure plan, and
8. The current mining and regulatory conditions.

The assessment of closure alternatives is not only a requirement for the assessment of economically efficient solutions, but also a regulatory requirement of the European environmental legislation, particularly the requirement for Environmental Impact Assessment (EIA). If EIA is required, it can be seen from the Annex I of the newly amended EIA Directive 2014/52/EU. GD Annex 1 provides a correlation between the annex of the EIA Directive with the formalities of the codes of the Statistical Classification of Economic Activities in the European Community (commonly referred to as NACE).

3.3 Definition of After-closure Options

Extractive activities create changes to topography with ongoing potential to impact the environment long after a extraction activity has ceased. The restored landscape can be designed as:

- agricultural land, field or meadow, including fisheries and gardening
- forest
- biotope and greenfield including left to natural succession
- wetland
- waste disposal site (for instance preparation and operation as landfill)
- waste disposal site
- culture and recreation
- military facilities
- industry and infrastructure.

Even ore mining sites require often large rehabilitation efforts, Kivinen (2017) reported a variety of documented after-closure uses for closed mining in Finland that illustrate the general options:

Mining sites in general: cultural heritage site of national significance, outdoor recreation, nature trail, holiday village, museum, dive site, swimming, disc golf course, sand/gravel pit, bus scrapyard, concrete element factory, military facilities, and fire rescue exercises.

Rehabilitated TMFs: Birdwatching, concentration of ore, military facilities, motorsport venue, airport (light aircraft), raw materials research, rally/dirt biking track, sand/gravel pit, shooting range, unofficial landfill, golf course, waste water treatment plant, greyhound racing, waste facility of a potato processing factory, temporary parking lot.

Waste rock facility: Off-road driving, construction material.

Water-filled open pit: dive and swimming site, concerts.

Underground mine: museum, research site on mine water treatment.

Buildings: Restaurant; concentration plant, school, museum, engineering works, military battle training, observation tower, sawmill, protected building, cultural events, railway vehicle manufacturing, lighthouse, warehouse, offices, mushroom cultivation.

Figure 13 illustrates some after-closure options in practice. The figures show: above - after-closure as mining museum and underground teaching and research site in Freiberg (Germany), Centre – after-closure use as swimming and diving site Blue Lagoon in Gotland (Sweden). Below – after-closure use as hotel and recreation area in post-industrial atmosphere at a former limestone quarry in Gotland (Sweden).

Figure 13: After-closure options in practice

3.4 Design of a Closure Plan

3.4.1 General Approach

Closure plans leave mine and TMF site in an acceptable condition ensuring public health and safety, minimising the risk of contamination and, where possible, allow productive use of the land or creates a stable environment. Best Practice in staged approach as risk-based closure process (Department of Mines and Petroleum at the Environmental Protection Agency Australia, 2015) that includes:

- Identifying a range of closure scenarios commensurate with risk
- Early identification of potential risks to successful closure
- Development of acceptable and realistic criteria to measure performance
- Orderly, timely and cost-effective closure outcomes
- Reduced uncertainty in closure costs; and
- Continual improvement in industry rehabilitation standards (e.g. cover design, and management of contaminated drainage, erosion and seepage)

Figure 14 illustrates the integrating stages of mining and mine closure plan.

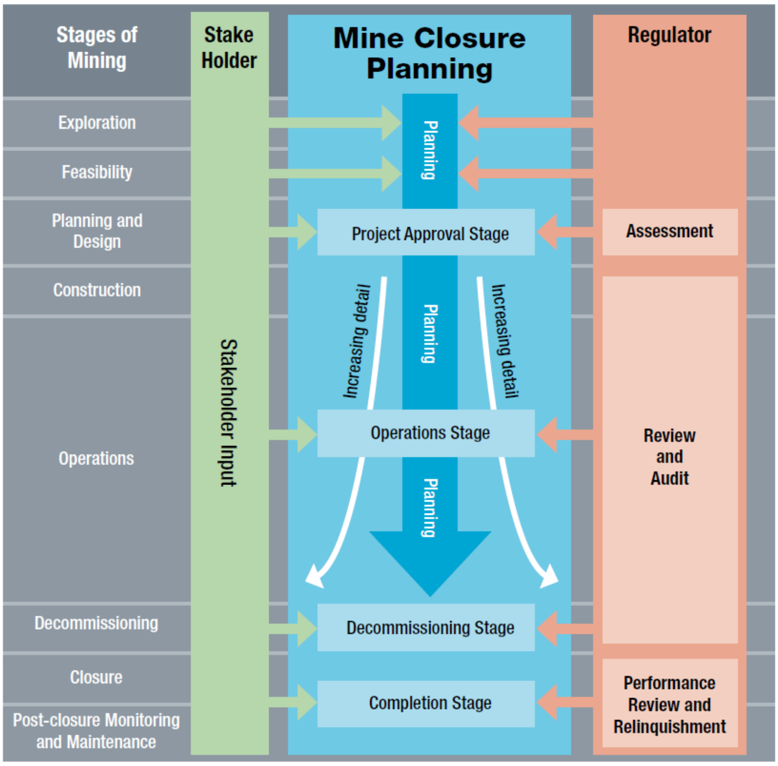


Figure 14: Integrating stages of mining and mine closure plan (Department of Mines and Petroleum at the Environmental Protection Agency Australia, 2015)

For the integration of mining and mine closure plan, following planning steps are necessary (Düzgün & Demirel, 2017):

- Inventory of the pre-mining conditions
- Evaluation and decision on the post-mining requirements of the area consistent with the needs and requirements of the local communities
- Analysis of alternative mining and rehabilitation schemes to determine best alternatives that meet the overall objectives
- Review of the rehabilitation experience at neighbouring mines or at mines operating in similar conditions to determine successful rehabilitation practices and parameters, and
- Develop an acceptable mining, rehabilitation and land use scheme to be integrated with existing technical, social, environmental, political and economic conditions

In the European Union exist since a few years, special requirements for the installation of certain industrial activities, among them the energy industries, production and processing of metals, and the mineral industry regarding the inventory of the pre-mining conditions. Directive 2010/75/EU on industrial emissions (IED) applies an integrated environmental approach to the regulation of certain industrial activities (Part A activities). Where the activity involves the use, production or release of relevant hazardous substances, and having regard to the possibility of soil and groundwater contamination at the site of the installation, under Article 22(2), operators are required to submit a baseline report (that fulfils the requirements of the inventory of the pre-mining conditions). The aim of the IED Baseline Report is primarily the assessment of the soil quality at the start of the renewal of the permit of an industrial activity as to establish an initial state. The objective is to provide a basis for comparison upon definitive closure of the activity, as to make possible the application of the “polluter pays principle” on an objective basis.

3.4.2 Structure of a Closure Plan – Design for Closure

In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area[1], BAT is to use the following technique (MWEI BREF):

Design for closure - Relevant for ponds, dams and heaps (permanent and temporary)

- a preliminary identification of the covering techniques;
- a preliminary identification of the techniques to prevent and control water and wind erosion;
- an assessment of costs related to the proposed and alternative closure strategies including a cost benefit analysis;

[1] The MWEI BREF defines waste deposition area as „Any area under the responsibility of an operator where extractive waste is handled, treated, accumulated or deposited whether in a solid or liquid state or in solution or suspension. This includes, but is not limited to, Extractive Waste Facilities, excavation voids where extractive waste is placed back, and areas for temporary storage of extractive waste.”

- an Environmental Risk and Impact Evaluation;
- a specific indication of the closure process to be followed, specifying if the rehabilitation will be progressively carried out during the operation phase or when progressive rehabilitation is not possible, it will be entirely carried out in the closure phase; in the latter case, the initial closure and after-closure planning explicitly states if a dry or wet cover will be implemented and provides details on the final landform and surface rehabilitation;
- a design of the EWF that takes into consideration possible premature closure;
- long-term stability analysis;
- a proposal for the control and monitoring procedures to be carried out during the after-closure phase.

The general structure of a closure plan can be summarised as follows:

1 Scope and Purpose

1.1 Purpose

1.2 Scope

1.3 Phases of mine closure

1.4 Review

2 Project Summary

2.1 Location

2.2 Land ownership

2.3 Mining tenure

2.4 Postal address, site address and contact details

2.5 Project history

2.6 Overview of operations

2.7 Closure domains

3 Closure Obligations and Commitments

3.1 European Legal Obligations Register

3.1 National Legal Obligations Register

4 Stakeholder Engagement

4.1 Stakeholder identification

4.2 Stakeholder engagement register

5 Post–Mining Land Use and Closure Objectives

5.1 Pre-mining land use

5.2 Post–mining land use

5.3 Closure objectives and guiding principles

6 Completion Criteria

6.1 Basis for development

6.2 Development of completion criteria

7 Collection and Analysis of Closure Data

7.1 Climate Observations

7.2 Flora and Vegetation

7.3 Fauna

7.4 Soils

7.5 Hydrogeology

7.6 Hydrology

7.8 Geotechnical assessment

7.8 Socio-economic Situation

7.8 Cultural Heritage

7.9 Characteristics of the resource

7.10 Natural background data for water and soil

8 Identification and Management of Closure Issues

9 Rehabilitation Options and Evaluation in General

9.1 General remarks and unit prices

9.2 Rehabilitation options for mine openings

9.3 Rehabilitation options for waste rock heaps

9.4 Rehabilitation options for buildings and processing plant areas

9.5 Rehabilitation options for tailings ponds

9.6 Rehabilitation options for mine water

9.7 Closure Costing

9.8 Option analysis per object and conclusion of preferred option

10 Closure Implementation

10.1 Closure domains

10.2 Timeline for closure

10.3 Mine openings closure work program

10.4 Waste rock heaps closure work program

10.5 Tailings ponds closure work program

10.6 Infrastructure area closure work program

10.7 Infrastructure area closure work program

10.8 Water and soil management

10.9 Unexpected closure – care and maintenance

11 Closure Monitoring and Maintenance

11.1 Geotechnical monitoring

11.2 Soil monitoring

11.3 Water monitoring

11.4 Biodiversity monitoring

12 Financial Provisioning for Closure

13 Management of Information and Data

14 References

The closure plan should include a Gantt chart, or similar, to show the activities (tasks or events) over the planned timeframe. This provides greater clarity on the sequencing of works/tasks/events and the expected timeframes. The sections below provide details for some parts of the closure plan structure.

3.4.3 Site Investigation and Extractive Waste Characterization

In order to support the identification of potential environmental risks and impacts associated with the extractive waste site and extractive waste management options, BAT is to use all of the following techniques (MWEI BREF):

- Identification of extractive waste site options
- Identification of extractive waste handling/ transport, treatment and deposition options.

In analogy to the provisions given in Environmental Protection Agency of Ireland (2014), following topics need to be addressed in the frame of the site evaluation:

Operator performance, to include information relating to:

- any existing Environmental Management System (EMS) for the activity;
- compliance, enforcement, incident and complaint history; and
- any relevant results of monitoring and/or site investigations carried out, which may include baseline monitoring/conditions that existed prior to the commencement of site operations (where available).

Environmental pathways and sensitivity, to include:

- details on the underlying geology/hydrogeology;
- proximity to surface water bodies, their classification and status;
- proximity to sensitive receptors, including humans;
- details on the nearest natural habitat, Natura2000 and national habitats;
- list of all emission and discharge points, including the quantities of materials (solid/liquid/gas) emitted; and
- neighbouring developments, etc.

The environmental sensitivity should also consider the potential pathways through which the operation may impact on the surrounding environment. It should be noted that much of the preparatory information required for this section will be available from existing information (see above).

Site processes and activities, to include:

- overview of the processes and activities undertaken at the site;
- detailed maps of the site and building layouts (to an appropriate scale); and
- the different process areas, e.g. incoming raw materials, production units, dispatch area, waste handling/storage areas, water/waste water treatment areas.

Inventory of buildings, plant and equipment, to include:

- list of all buildings and major plant and equipment;
- details of any hazardous or potentially polluting components and construction materials, e.g. PCBs, asbestos;
- list of all bunded, secured and protected areas; and
- details of any tests on bunds, pressure tanks, pipelines, etc.

Inventory of raw materials, products and wastes, to include:

- a comprehensive list of all raw materials, products and waste, including non-hazardous and hazardous materials; and
- the quantities of each item identified in the inventory.

Maximum storage capacity for raw materials, products and wastes and maximum storage amount in practice.

Important is the assessment of the baseline situation, as well as the environmental using the source – pathway – receptor model. In case that polluted material is identified, the hot spots of pollution must be subject to rehabilitation planning. The goal of risk-based rehabilitation is to reduce present and future risk in a cost-effective manner through the use of one or more of the following risk reduction techniques:

- Chemical source reduction — Achieved by physical removal or control of hazardous substances.
- Receptor restriction — Land use controls and physical barriers (e.g., concrete caps and site fencing) that prevent the exposure of hazardous substances until source concentrations are reduced below risk levels.
- Chemical pathway elimination — Examples include placing restrictions on excavation or groundwater use to prevent on-site or off-site receptors from making contact with chemicals of concern. Identified polluted hot spots will be considered in the option analysis.

3.4.4 Option Analysis

Scope of the assessment of closure options is to find the best system which meets the requirements in terms of the regulatory requirements and complies with the specific closure objectives for the respective mining site. The purpose of the option analysis is the optimisation process to find the 'best' alternative. In general, after the exploitation of the mines they will be closed because of economic reasons and to ensure public health and safety to reduce negative environmental impacts. The methodology adopted comprises, for each option analysis, the following steps:

1. *Specify design parameters:* targets to be met, relevant unit costs, other relevant parameters
2. *Define and describe suitable options.* This activity includes:
   - summarise base data and general options that are state of the art
   - update strategic options based on new information available
   - cost estimation

In theory there are often many options, but common sense is necessary to screen down the list to a small number of practical robust alternatives which meet the objectives and are not clearly ruled out on grounds of practicality, legality and consistency with local circumstances. Further the very specific objectives which have to be met by the system circumscribe the number of options available.

3. *Define evaluation criteria to identify the best option*. Important criteria are:
   - Cost (investment, O&M costs)
   - Environmental aspects (not only the negative impacts from construction and operation, but also the positive impacts resulting from the environmental improvement);
   - Technical aspects (efficiency (in achieving targets), robustness, technical maturity)
   - Legal aspects (complies with legislation, whether compatible with existing institutional structures);
   - Implementation risks (public acceptance, threatens existing vested interests, time needed to implement)
4. *Identify best option.*
5. *Draw conclusion based on the foregoing.*

The methodology for the identification of the best option consists of two parts: a technical analysis and a financial analysis. Within the technical analysis is analysed the technical feasibility and the applicability of several options and their resulting environmental impacts. In parallel are analysed the cost, taking into account investment cost and operation and maintenance cost. In general, a solution must be applicable from technical point of view first, and in the next step is analysed the cost. The approach depends in each case on the options being compared, and is discussed further when options are being evaluated. The direct cost analysis must consider investment cost as well as operation and maintenance (O&M) cost, and both are used to prepare preliminary estimates for the cost comparison of the closure options. The investment cost and the O&M cost are to be calculated and assessed separately, and finally will be concluded the result in terms of the preferred option regarding cost. The Net Present Value (NPV), a profitability indicator, expressed as sum of the present values of all project cash flows over the first n years, will be calculated in a Financial Analysis for the total system that consists of components which are the result of the preferred option.

3.4.5 Closure Tasks

Closure tasks per objects and per mining typology can be identified from section C of this guidance. In the report shall be detailed the tasks necessary to achieve successful closure and provide a program (Gantt chart or similar) for the entire closure process with all key activities included (Environmental Protection Agency of Ireland, 2014). Details should include (Environmental Protection Agency of Ireland, 2014):

- plant and equipment decontamination;
- plant and equipment decommissioning;
- demolition (if necessary);
- waste facility closure (e.g. landfill and extractive waste facilities);
- raw materials, products and waste disposal and/or recovery;
- contaminated land treatment, removal and/or disposal; and
- programme (Gantt chart or similar) and timeframes for delivery.

Proposals regarding contaminated land treatment, removal and/or disposal should include the following details (Environmental Protection Agency of Ireland, 2014):

- baseline/existing conditions;
- proposed rehabilitation methods and their current status, including details of any agreements reached with the competent authority; and
- monitoring proposals.

For each element the report must contain a detailed rehabilitation work schedule (progressive and after shutdown of mining activities) including the human and material resources involved (Gouvernement du Québec, 1997).

3.4.6 Closure Plan Costing

The elaboration of a closure plan is typically based on the costing stage of conceptual design for the remedial option analysis, and detailed design for the preferred option. Beside the design cost, and according to the International Council on Mining and Metals ICMM (2019), several types of cost estimates are used to characterise the financial aspects of closure, that are illustrated in figure 15.

Figure 15: Closure cost estimate types, Legend: LoA - Life of asset (ICMM, 2019)

Closure cost estimates frequently need to be estimated for the implementation of closure activities many years or even decades in the future. In this context, it is important to be realistic about the achievable accuracy of cost estimates (ICMM, 2019).

3.4.7 Criteria for Successful Closure

In analogy to the Environmental Protection Agency of Ireland (2014) following criteria have been established to set the benchmark for the successful closure of the site (amended):

- plant safely decontaminated using standard procedures and authorised contractors;
- wastes handled, packaged, stored and disposed or recovered in a manner that complies with regulatory requirements;
- relevant records relating to waste and materials management retained throughout the closure process;
- no soil or groundwater contamination at the site, verified using monitoring data;
- and a soil and groundwater assessment at the time of closure (if required);
- hazard and/or risk of environmental pollution is returned to a satisfactory state;
- long term geotechnical stability is ensured, verified using monitoring data;
- sufficient funds available to cover the full cost of closure; and
- Environmental management system in place and actively implemented during closure.

Due to International Council on Mining and Metals ICMM (2019), the ***SMART approach*** (specific, measurable, achievable, relevant, timely) is useful for developing and accessing success criteria. Key considerations for each element of SMART criteria are as follows (ICMM, 2019):

Specific: Criteria should relate directly to closure objectives and individual closure activities. A closure activity or group of closure activities without an associated criterion indicates a gap; a criterion without an associated measure or measures may indicate the criterion is too general.

Measurable: If a criterion cannot be measured, there is no way to stakeholders that it has been met. While the method of measurement is usually obvious for numerical criteria, narrative criteria may require alternative forms of measurement (such as completion of a given task as confirmed through as-built drawings or field inspections). Some objectives may require a combination of qualitative and quantitative measurement.

Achievable: If relinquishment or return of financial assurance is to be attained, realistic criteria are crucial are to be achieved. Unrealistic or poorly defined criteria can delay or prevent relinquishment, or unnecessarily extend monitoring periods.

Relevant: Criteria should ultimately be aligned with closure objectives and the social, environmental and regulatory context of the site.

Timely: Criteria will have a time component, either explicitly or implicitly. Some can be considered completed immediately after implementation of the associated closure activities while others will require a period of monitoring.

3.4.8 Accompanying Documents

In case of water-related structures, it might be required a water management plan including water balance and design flood analysis (Garbarino et al. 2018).

3.4.9 Closure Plan Validation and Audit

This section should detail the environmental monitoring and validation provisions that will be in place, the scope and criteria for the validation audit, the qualifications and independence of the auditor and the nature of the report and closure certification resulting from the audit (Environmental Protection Agency of Ireland, 2014).

3.4.10 Environmental Impact Assessment

Environmental assessment as such is a process that ensures that environmental effects of projects are assessed and taken into account before the decisions of their authorisations are taken. Figure 16 gives a general overview on the existing environmental assessment approaches with respect to mining. Legend: SEA – Strategic Impact Assessment, EIA – Environmental Impact Assessment, EMS – Environmental, Management System, LCA – Life Cycle Assessment.

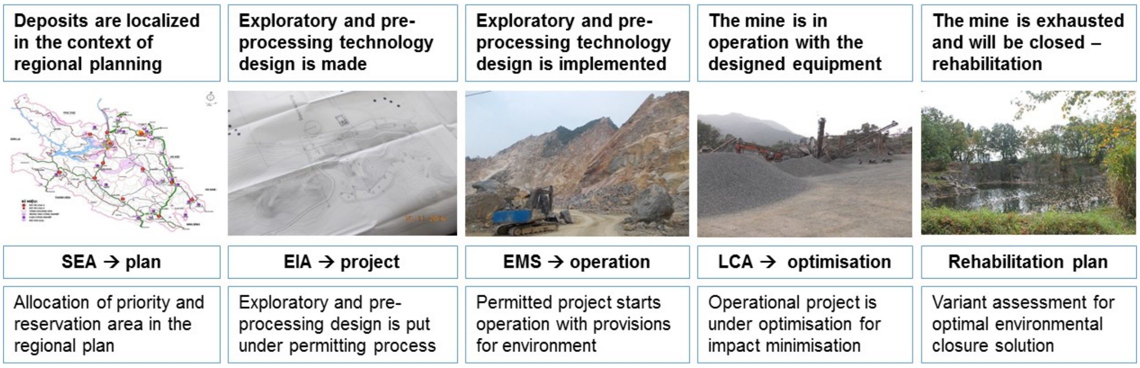


Figure 16: Overview on the existing environmental assessment approaches with respect to mining

Strategic Impact Assessment (SEA) is a legal instrument for the environmental impact assessment of *plans and programs*. With SEA, potential environmental impacts of a planning can be recognized and taken into account before the plan or program is accepted. Typical applications are regional development plans, land use plans, waste management plans, energy concepts, etc. In the European Union, SEA is based on the EC Directive (2001/42/EC) on the assessment of the environmental effects of certain plans and programs.

In the mining sector, SEA plays a major role in regional planning, as reserve areas and priority areas for mining are identified as a result of the localization of ores and mineral resources. In this regard, SEA precedes the Environmental Impact Assessment (EIA). While the EIA is used for the approval of environmentally relevant projects, SEA is already carried out at the planning stage.

Environmental impact assessment (EIA) is a process governed by law. It serves to determine, describe and evaluate in advance the impacts of *projects* on the environment, including human health. Generally, mining operations are subject to EIA, depending on their type. EIAs according to Directive 2011/92/EU as amended by

2014/52/EU are carried out to assess of individual projects in a formalized, systematic and comprehensive process of identifying and evaluating the environmental effects. Impact Assessment has to be done ex-ante with participation of public and relies on multidisciplinary input. Figure 17 shows the flow chart illustrating the EIA process.

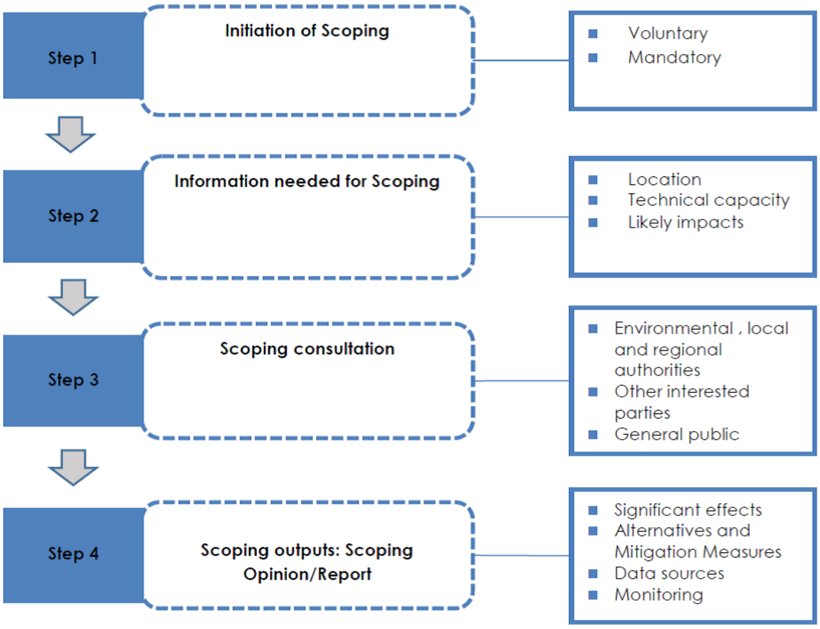


Figure 17: Flow chart illustrating the EIA process (Source: European Commission Scoping Guidance, 2017)

The environmental impact assessment analyses, evaluates and identifies:

1) Direct and indirect impact of a given project on (EIA Directive, Art.3(1)):

a. the environment and the population, including the health and living conditions of people
b. material goods
c. monuments
d. landscape, including cultural landscape
e. interactions between abovementioned elements
f. availability of mineral deposits
g. risk of serious accidents and natural and construction disasters

2) Means and ways to avoid, prevent, reduce and if possible offset the significant adverse effects of project on the environment;

3) Required parameters and duration of monitoring.

Furthermore, the EIA process needs to include an appropriate assessment required for N2000 sites under Art. 6 of the Council Directive 92/43/EEC (Habitats Directive), as its scope and binding conclusion concerning permitting differ from the SEA and EIA provisions. The link with those directives is detailed in the guidance “Managing and protecting Natura 2000 sites” at

https://ec.europa.eu/environment/nature/natura2000/management/guidance_en.htm

Environmental Management Systems (EMS) are part of the overall overarching management system, which includes the organizational structure, responsibilities, formal procedures, and means for the implementation of the environmental policy of a company. ISO 14001:2015 specifies the conditions for an EMS that an organization can use to enhance its environmental performance (Schneider et al. 2017).

Life Cycle Assessment (LCA) is a systematic analysis of environmental effects of *products* throughout the life cycle. The preparation procedure is laid down in ISO 14040:2006. LCA includes all environmental effects during the production, the utilization phase and the disposal of the product, as well as the associated upstream and downstream processes (e.g. production of the raw materials and supplies). Environmental impacts are classified in impact categories and include all environmentally relevant withdrawals from the environment (e.g. ores, petroleum) and emissions into the environment (e.g. waste, CO2 emissions). The overall scope of the assessment is to identify environmental optimization potential in order to achieve a cradle-to-cradle system (Braungart & McDonough, 2002).

Figure 18 illustrates influence and impact by mining phase, and analysis potential impact measures that can be taken to offset impact according to Hofsteenge et. al. (2017).

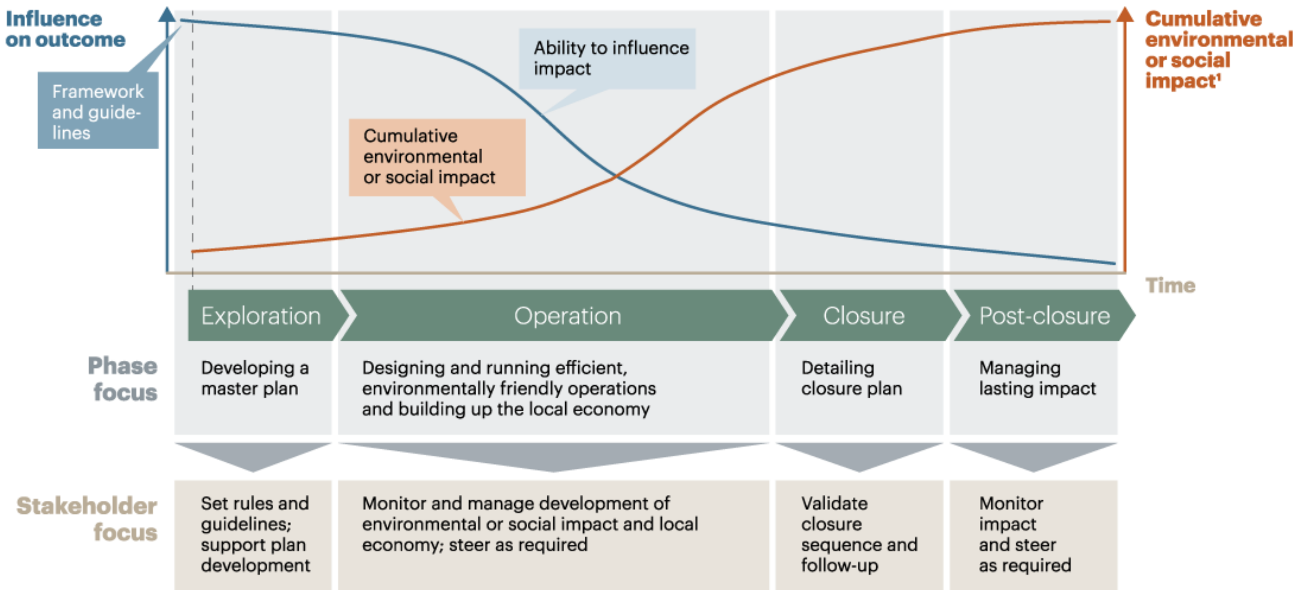


Figure 18: Influence and impact by mining phase. Analysis of potential impact measures that can be taken to offset impact (Hofsteenge et. al, 2017)

The EIA methodology is based on the following criteria:

- Spatial extent of the impact
- Temporal extent of the impact
- Severity of the impact

At least the following criteria will have to be taken into account for the assessment:

- Existing degradation or disturbance of areas or nature

- Proximity of sensitive habitats or specially protected areas, presence of protected species
- Sensitivity of receptors to a given impact
- Area in which disturbances (noise, dust) may be noticed and may have significant nuisance levels
- Impact on water or air so that legal quality standards are exceeded
- Potential of water contamination in case of accidental spills

The severity of impacts is ranked according to the following qualitative scheme that is based on the sensitivity of receptors and magnitude of impacts. It should be noted that the application of the criteria always contains a subjective element. Therefore, the following tables should be used as orientation and need to be applied with a site-specific focus.

Table 4: Definitions of sensitivity levels of receptors

Sensitivity	Description
Low	Areas have already been significantly degraded Non-designated or locally designated sites/habitats Non-sensitive receptor with regards to the impact type (e.g. noise receptors)
Medium	Partially degraded area Regionally designated sites / habitats Regionally rare or endangered species Moderately sensitive receptor with regard to the impact type
High	Nationally or internationally designated sites/habitats Species protected under national or international laws / conventions High sensitivity with regard to the impact type

The significance of the impact is calculated by multiplying the assigned values for magnitude of the potential impact and the sensitivity of the receptor to generate an evaluation matrix.

Table 5: Definitions of magnitude levels of impacts

Magnitude	**Description**
Minor	Reversible Duration < 2 years Will not cause any material change to the value or function of the receptor Emissions comply with regulations Emissions contained within project footprint Local disturbance
Moderate	Potentially irreversible Duration > 2 and < 10 years Causes a change in the value or function of receptor but does not fundamentally affect its overall viability Emissions comply with regulations Emissions reach outside Project footprint Local/Regional disturbance
Major	Mainly irreversible Duration > 10 years Causes a significant change in the environment affecting the viability, value and function of the receptors Unmitigated emissions or other impacts do not comply with regulations and need to be reduced Emissions reach outside Project footprint and may extend to national or transboundary influence

The significance of the impact can be summarised in terms of numerical values as shown in the significance table below, verbally or through a colour key. Higher impact significance reflects a higher severity of impact and requires customized mitigation measures. The EIA procedure considers risks during the rehabilitation works, and the remaining risks after the rehabilitation works.

Table 6: Numerical ranking and verbal category of impact significance

Numerical impacty ranking (impact magnitude x receptor sensitivity)	**Verbal category of impact significance**
0-1	Negligible
2	Minor
3-4	Moderate
6	Major
9	Critical
+	Denotes overall positive

3.4.11 Environmental Management Plan

An Environmental Management Plan (EMP) can be defined as an environmental management tool used to ensure that undue or reasonably avoidable adverse impacts of the construction, operation and decommissioning of a project are prevented; and that the positive benefits of the projects are enhanced. An EMP is based on the principles of Environmental Management Systems (EMS) according to ISO 14001:2015. An EMP is not foreseen in the EWD, however it represents Best Practice in construction works (like an Occupational Health and Safety Plan). Both types of plans might be required by the competent authority. An EMS basically includes 1) the environmental policy, 2) objectives and programs, 3) organization and personnel, 4) impact on the environment, 5) design and process control, 6) environmental management documentation, 7) environmental audits (Schneider et al. 2017). On international scale the most common standardized EMS is provided by ISO 14001:2015. In the European Union further exists the “EU Eco-Management and Audit Scheme” (EMAS), a premium management instrument developed by the European Commission for companies and other organizations to evaluate, report, and improve their environmental performance.

3.4.12 Occupational Health and Safety Plan

A health and safety program is a definite plan of action designed to prevent accidents and occupational diseases, and it is based on a hazard assessment for all activities with risks to health and safety in line with the principles of ISO 45001:2018. It contains provisions for safe working procedures as well as emergency procedures.

3.5 Design of an After-closure Plan

3.5.1 Approach to After-closure

After-closure refers to longer term measures that are necessary where environmental liabilities remain following closure, e.g. contaminated soil and groundwater, landfills, extractive waste facilities, mines, quarries and soil recovery facilities. Measures may encompass activities such as rehabilitation, ongoing emissions control and monitoring (Environmental Protection Agency of Ireland, 2014). The two main circumstances requiring an after-closure plan are:

- soil and groundwater contamination; and
- landform changes, e.g. landfills, extractive waste facilities, mines, quarries and soil recovery facilities

The projection of after-closure monitoring works and the financial assessment of after-closure monitoring costs. The following issues are to be addressed:

1. The monitoring objectives;

2. Data required

2.1 Monitoring the surface stability

2.2 Water monitoring

2.3 Air monitoring

2.4 Monitoring the tailing ponds and the stability of decant ponds structure

2.5 Monitoring the ecosystems and vegetation

3. Quality management

4. Data Management

5. Estimation of costs required for fulfilling the long-term tasks.

6. Models of monitoring and impact mitigation plans.

3.5.2 After-closure Measures and Activities

Examples of after-closure measures include (Environmental Protection Agency of Ireland, 2014, amended):

- maintenance of surface water drainage systems;
- maintenance of green and plantations;
- operation of contaminated soil and groundwater pump and treat systems;
- monitoring (e.g. water, air, gas, leachate, stability, biodiversity);
- maintenance of access to monitoring locations;
- servicing and calibration of monitoring equipment (e.g. continuous water quality monitors);
- Landscape maintenance of grass cover and planting;
- staff resourcing; and
- site security (e.g. inspections/patrols, fencing)

3.5.3 Restoration and After-closure Costing

Both the rehabilitation and after-closure proposals require detailed costing by operators (Environmental Protection Agency of Ireland, 2014).

For sites where significant soil and groundwater contamination is present, the following items should be costed (Environmental Protection Agency of Ireland, 2014):

- site investigation works (e.g. drilling and groundwater well installation) in order to delineate the extent and magnitude of contamination;
- environmental risk assessment in order to determine whether risk is posed to environmental receptors and to devise an appropriate rehabilitation strategy;
- implementation of a rehabilitation programme such as excavation, treatment, environmental verification testing and/or design and installation of in-situ treatment systems;
- maintenance and monitoring costs associated with the site rehabilitation, e.g. costs of maintenance of the treatment plant associated with a pump and treat system or the costs of groundwater monitoring associated with a monitored natural attenuation (MNA) programme;
- staff resourcing; and
- site security (e.g. inspections/patrols, fencing).

For landform changes, the following items should be costed (Environmental Protection Agency of Ireland, 2014):

- restoration measures, e.g. reclamation of excavated areas, seeding and landscaping
- maintenance of surface water drainage systems
- ongoing pollution control measures, e.g. landfill gas extraction and flaring/utilisation, landfill leachate extraction and treatment/disposal
- maintenance of access to monitoring locations
- monitoring (e.g. surface water, groundwater, air, gas, leachate, stability)
- servicing and calibration of monitoring equipment (e.g. continuous water quality monitors)
- landscape maintenance
- staff resourcing; and
- site security (e.g. inspections/patrols, fencing).

A proposal for review of the closure plan should be provided. Typically, restoration and after-closure plans must be reviewed annually and proposed amendments thereto notified to the competent authority for agreement (Environmental Protection Agency of Ireland, 2014). Also restoration and after-closure costing must be reviewed annually, and updated respectively.

3.5.4 Environmental Monitoring Plan

Environmental Monitoring (EM) refers to the observation of scientifically relevant areas of the environment and the documentation of ecological parameters (Schneider et al. 2017). The scientific fields include biology, soil science, chemistry, geography, geology, hydrology, meteorology and physics. The findings can be important for forestry, landscape planning and other environmentally relevant planning tasks and problems, as well as the scientific monitoring of environmental projects. The goal is the long-term recording of environmental and environmental protection-relevant changes in air, soil and water. Impacts on landscape and biodiversity can thus be systematically recorded.

In terms of the implementation of CP strategies in the mining sector, EM plays a role in all design and operational steps. An EM plan needs to be provided by the applicant for the respective EIA project, and will be complemented by an obligatory EM plan through the mine approval by the competent authority (Schneider et al. 2017).

3.5.5 Rehabilitation and After-closure Plan Review

A proposal for review of the closure plan should be provided. Typically, after-closure plans must be reviewed annually and proposed amendments thereto notified to the competent authority for agreement (Environmental Protection Agency of Ireland, 2014).

4. Part C: Overview on Closure Best Practices by Mining Typology

4.1 Best Practices Overview

Best Practice is a technique or methodology that, through experience and research, has been proven to reliably lead to a desired result. Best practices are used to maintain quality as an alternative to mandatory legislated standards and can be based on self-assessment or benchmarking. The further step of Best Practice is the application of the Best Available Techniques (BAT), the most effective and advanced stage in the development of an activity and its methods of operation. In Europe, the Best Available Techniques (BAT) reference documents, the so-called BREFs, are the explanation documents that have been adopted under both the Directive on Integrated Pollution Prevention Control IPPC (2008/1/EC) and the IED Industrial Emissions Directive (IED, 2010/75/EU). BAT refers to operating facilities. Good Operating Practice (GOP) is a strategic management term. The term best environmental practice (BEP) means the application of the most appropriate combination of environmental control measures and strategies. Best available techniques not entailing excessive costs (BATNEEC), sometimes referred to as best available technology was introduced in 1984 into European law with Directive 84/360/EEC. The BAT concept was first time used in the 1992 OSPAR Convention for the protection of the marine environment of the North-East Atlantic for all types of industrial installations.

4.2 BREF for Extractive Waste Management

The Best Available Techniques Reference Document for the Management of Waste from Extractive Industries (MWEI BREF, Garbarino et al. 2018) is a technical document representing the results of the latest exchange of information, organised by the Commission, on Best Available Techniques (BAT) for the management of extractive waste and associated monitoring, based on the developments in the extractive waste management sector since the elaboration of the initial Best Available Techniques Reference Document for the Management of Tailings and Waste-Rock in Mining Activities (MTWR BREF). The MWEI BREF refers exclusively to mine waste management, and not to the closure of other extractive facilities like shafts and opencast mines.

Processes and activities covered by the MWEI BREF BAT Conclusions:

- the management of extractive waste from onshore extractive activities
- the handling/transport of extractive waste (e.g. loading, unloading and on-site transport)
- the treatment of extractive waste
- the deposition of extractive waste
- the activities directly associated with the management of extractive waste.

According to the Terms of Reference of this study, the documentation refers to MWEI BREF for extractive waste management; however, it goes beyond MWEI BREF for further closure techniques like for instance shaft closure.

To apply a design for closure and after-closure approach by including an initial closure and after-closure planning of the extractive waste deposition area (including the EWF) that may contain the following (MWEI BREF):

- a preliminary identification of the covering techniques (MWEI BREF BAT 38);
- a preliminary identification of the techniques to prevent and control water and wind erosion (MWEI BREF BAT 21 and BAT 49);
- an assessment of costs related to the proposed and alternative closure strategies including a cost benefit analysis;
- an Environmental Risk and Impact Evaluation (MWEI BREF BAT 5);
- a specific indication of the closure process to be followed, specifying if the rehabilitation will be progressively carried out during the operation phase or when progressive rehabilitation is not possible, it will be entirely carried out in the closure phase; in the latter case, the initial closure and after-closure planning explicitly states if a dry or wet cover will be implemented and provides details on the final landform and surface rehabilitation;
- a design of the EWF that takes into consideration possible premature closure;
- long-term stability analysis (MWEI BREF BAT 22);
- a proposal for the control and monitoring procedures to be carried out during the after-closure phase (MWEI BREF BAT 3, 23, 40, 48 and 52).

If possible, the closure and after-closure planning of the extractive waste deposition area is integrated into the periodic extraction plans.

4.3 Mining Typology

In general, the term “mining” refers to exploration, extraction and processing of mineral resources from the earth's upper crust using technical facilities and recourses. The extraction comprises of the exploitation of raw materials of mineral and fossil origin as well as the generation of geothermal heating. Additionally, the underground mining is becoming increasingly important. All mining activities are regulated worldwide by the respective mining law within the national legislation. All mining operations require an operation plan, which also regulates the closure and reclamation after the completion of mining works. Depending on the raw material and specific deposit conditions different extraction methods are used. The mining exploitation and processing shall be considered as a mining complex. The extraction of deposits is distinguished between:

- Underground mining
- Opencast mining
- Borehole mining.

Different underground and opencast extraction methods can be used. The mined raw materials can be divided into three major groups:

Element resources (aiming on a certain element): These are aggregates, ores, as well as precious and semi-precious stones, but might include also industrial minerals.

Energy resources: hydrocarbons, coal and uranium.

Property resources (aiming on a certain material characteristics): These include raw materials for metallurgical and chemical processes, as well as salt and fertilizer raw materials.

In terms of technological characteristics, the resources are usually divided in a) aggregates, b) Industrial Minerals, c) ores, and d) energy minerals. The specific characteristics of the groups are considered in more detail below, with a raw material-specific group derived from the groups above mentioned.

It should be noted that the site specific conditions as type of raw material (unconsolidated rock, hard rock, hydro-soluble, sulfidic, type of surrounding rock etc.) and the type of extraction (open-pit as drift mining or slope mining, hard rock, unconsolidated rock, underground mining, borehole mining, solution mining, etc.) are very diverging. Each closure plan is site specific and not transferable to another site. The GD provides a general overview to give guidance on the general steps and conditions to be taken into consideration for the respective mine closure.

4.3.1 Aggregates

The term “aggregate” refers to coarse particulate material such as crushed stone, gravel, sand, clay, and marl. Aggregate is used in the construction of buildings, roads, dams, and other infrastructure as a base material or in composite material such as concrete. In terms of material rheology, the original material for the production of aggregates are divided into coarse rock materials (soil and sandy or clayey materials) and solid rock materials (used for crushed rock and dimension stones). Aggregates (also known as inorganic non-ores), as a component from the group of element raw materials, combine various non-metallic, mineral-abiogenic and mineral-biogenic raw materials. Basically, there are:

Mass commodities: coarse rock (sand, gravel), crushed sand (e.g. basalt)

Binder: Cement, carbonate / limestone, gypsum / anhydrite stone, clay / kaolin, quartz sands

Dimension stones

Industrial minerals for special applications (see point. 4.3.4)

The mining of raw materials takes place predominantly by the opencast method. Whereby a relatively high output (over 60… 90%) is technologically based on a high level of extraction, both in terms of mining and processing technology. Overburden or rock of lower qualities is usually used for the reclamation of excavated areas. After the relevant drilling exploration works, the mining exposure of the deposit is generally carried out in a combination of ramps (exploratory works), berms (pre-processing works) and benches (extraction). Following illustrations show a typical exploratory and pre-processing works as well as extraction activities in an aggregate mine.

Figure 19: Basic illustration of a sand and gravel opencast mine

- Exploratory works
- Pre-processing works (berms)
- Extraction (benches)

The reclamation of excavated areas of opencast mines will be done in parallel to the ongoing extraction works. This mining method results the relatively high output. Figure 20 shows example of manufactured sand processing from hard rock.

Figure 20: View of an aggregates mine (left); aggregates processing plant (right)

According to the respective legislation, the topsoil that occurs during the mining operations has to be used for later reclamation or to be sold as raw material (e.g. as a basis for the greening of mining waste heaps or tailing ponds).

Further extraction and mining possibilities are the dredging within the groundwater levels or from rivers or lakes (figure 21). Large gravel and sand deposits support significantly groundwater resources. With the extraction of gravel and sand, the nature and especially the water balance will be significantly changed. The changes to groundwater system cannot be restored, especially in wet mining. Therefore, frequently it comes to the conflict of interests between extraction of gravel and sand and the protection of the groundwater.

Figure 21: Example of a sand dredging facility

The available BAT document for the aggregates sector is "Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide: Industrial Emissions Directive 2010/75/EU.

4.3.2 Ores

Ores are naturally occurring mineral aggregates of economic interest, from which one or more components of value can be extracted by processing. Most of these are minerals that contain more or less metallic components. From a mining point of view, the distinction based on criteria is the most effective, i.e. ores are distinguished from metal cations.

- Black metal ores: Fe, Mn, Cr, Ti, Ni, Co, W, Mo, V
- Non-ferrous metal ores: Cu, Pb, Zn, Sn
- Light metal ores: Al, Mg, Li, Be
- Precious metal ores: Au, Ag, Pt

The available BAT document for the ore mining sector is "Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metal Industry".

Ore mining takes place in open-cast or underground mining. In-situ leaching (ISL) is a special feature, which can be applied for ore extraction from the rock in both, underground and above ground. The geological, geotechnical and environmentally relevant framework conditions are decisive for the choice of the mining method. Large, surface near mass deposits are usually exploited as open-cast mines, whereby the limit depth (separation of open-cast mining to underground mining) can be defined as approximately 300 m. For the mining extraction, the connection between mining, processing and smelting must be considered. Figure 22 shows the relations.

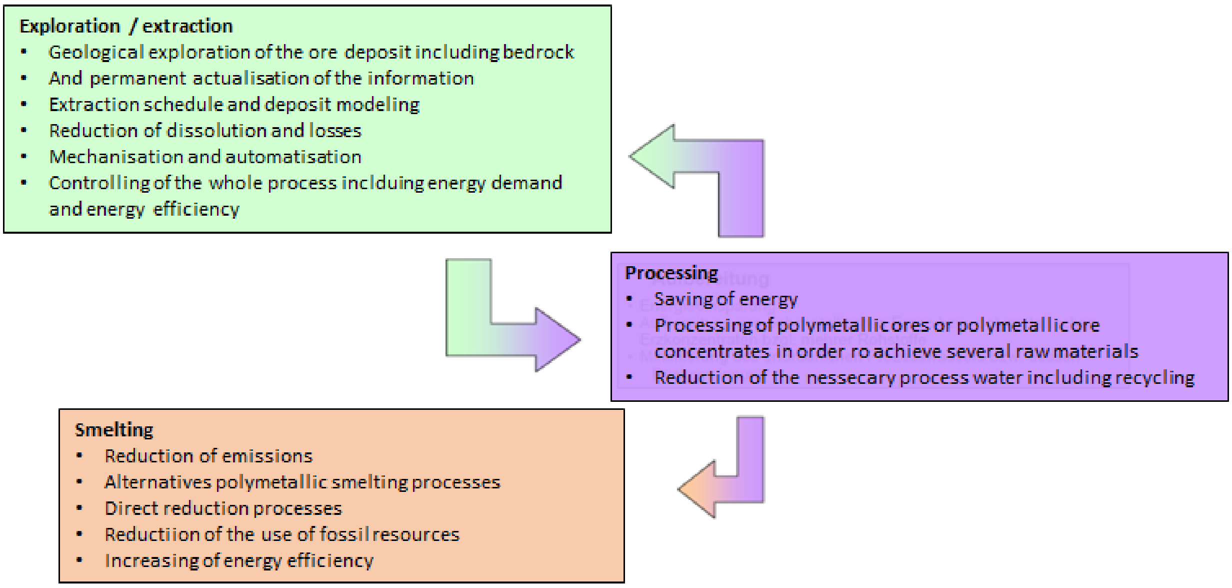


Figure 22: Relation between technologies and requirements for effective deposit utilization

Knowledge of the underground mining methods that may be used are crucial for the subsequent remedial measures. A distinction is made in

- mining process with scheduled reclamation of excavated areas (full or partial reclamation)
- fracture construction method with lowering of the slope layers (longwall construction)
- ridge construction or ridge joint construction method with placing back into remaining open excavation space.

Figure 23: Copper open cast mine in Andalusia, Spain

In addition to costly expenses for subsequent refilling to secure the surface, the expected geotechnical framework conditions, including long-term metrological surface monitoring, are decisive. For this purpose, large above-ground piles of unproductive bedrock were and are still being built, which, despite the increased return of such waste as material to the open underground mine, necessitates long-term above-ground remedial measures. Figure 24 shows a sample of an overall planning model for underground mining.

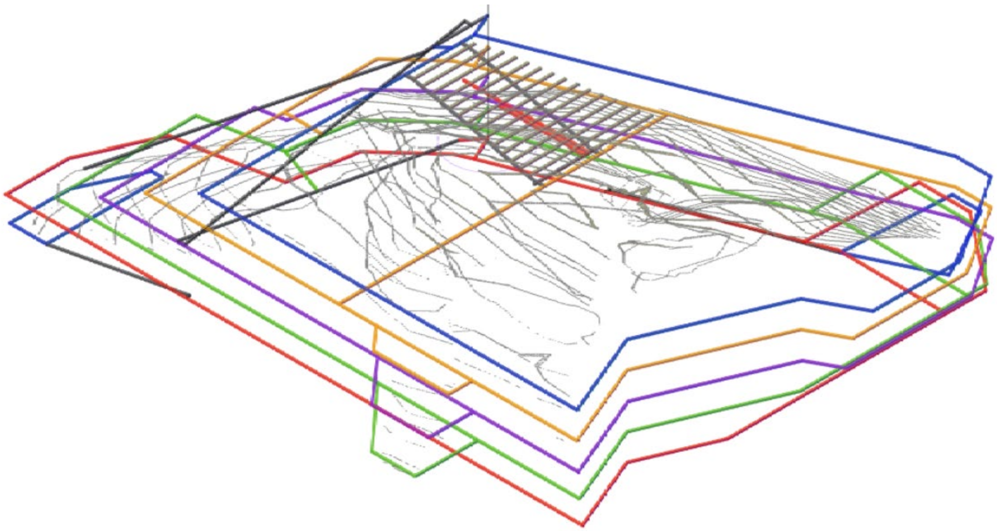


Figure 24: Sample of an overall planning model for underground mining

In terms of underground leaching mining (opening of chambers with interim storage and subsequent leaching) particularly, long-term effects on the entire extraction process, in part the uncalculated time sequences, must be taken into account.

4.3.3 Energy Minerals

A group of energy resources includes hydrocarbons, coal and uranium.

- Hydrocarbons: petroleum and natural gas (associated with natural asphalt, earth wax, bitumen and oil shale)
- Coal: lignite, hard coal and anthracite, peat, sapropel coal (caustobiolites)
- Uranium: raw material for nuclear power generation

The available BAT document for the energy resource mining sector are:

- 2008 BAT Guidance Note for the Energy (LCP) Sector
- 2008 BAT Guidance Note for the Oil & Gas Refining Sector
- 1996 Draft BATNEEC Guidance Note - Extraction of Peat - 14/05/96

Hydrocarbon Extraction

The oil and natural gas resources are extracted exclusively (with a few exceptions) through surface drilling up to a depth of approx. 2,000-3,000 m. Due to inclined drilling for oil and natural gas extraction in the so-called offshore areas the inclined drilling can reach a borehole length of up to 11 km. With regard to the geology of the deposit and the viscosity of the oil and thus ultimately the effort required for oil extraction, conventional deposits are distinguished from unconventional ones. Figure 25 illustrates the reservoir formations of oil and gas deposits (left), oil and gas production facilities (right) according to Devold (2013).

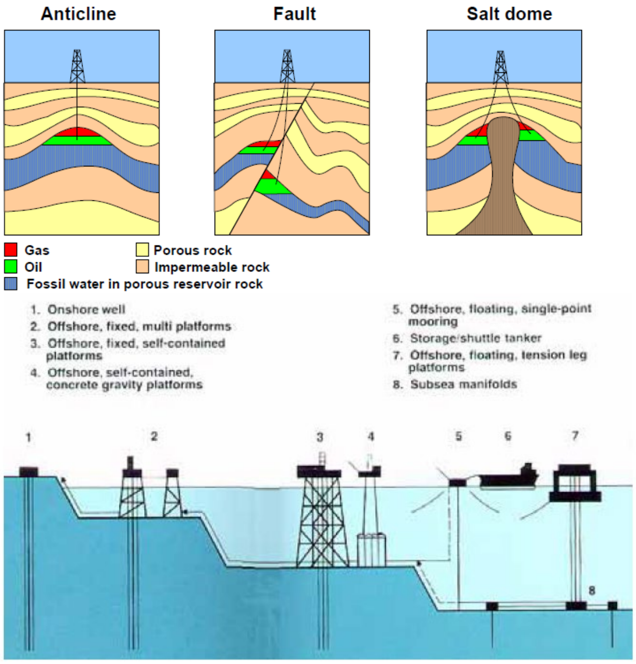


Figure 25: Reservoir formations of oil and gas deposits (left), oil and gas production facilities (right) (Devold, 2013)

Conventional deposits are located in relatively highly porous and permeable reservoir rocks and contain relatively low viscosity oil. Unconventional deposits are located in rather low-pored and impermeable rocks or contain more viscous, bituminous oil, so that the extraction can be only done through increased technical and energy expenditure. The oil exploration takes place in phases:

- Prospection
- Development of oil deposits
- Extraction
    - Primary extraction (the pressure within the deposit drives the oil to the surface)
    - Secondary extraction (If the pressure in the deposit drops in the course of oil extraction, it can be increased by (re)injecting water or natural gas into the deposit)
    - Tertiary extraction (extraction of additional oil from the deposit through special measures such as hot steam, CO_2 or N_2 and others)
    - Offshore extraction

Oil sands and oil shale close to the surface are also mined and extracted directly in open-cast mines. Deep drilling has been made on a larger scale since the mid of 19th century. The state of the art in producing, operating and filling of boreholes and the applicable legal provisions have developed continuously since then and have reached a high standard based on long experience.

The extraction of natural gas resources is also differentiated from extraction from conventional deposits (extraction from salt domes, and from non-conventional deposits (hydraulic fracturing). Figure 26 shows a natural gas fracking example.

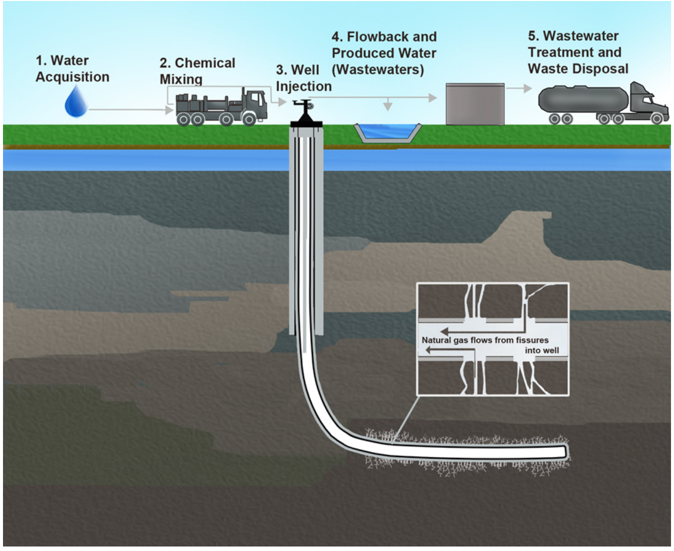


Figure 26: Example of natural gas extraction by fracking (source: U.S. EPA)

Natural gas (methane) also occurs in coal seams or e.g. within potash seams. The extraction takes place onshore and offshore. Figure 27 shows a scheme of oil and gas extraction.

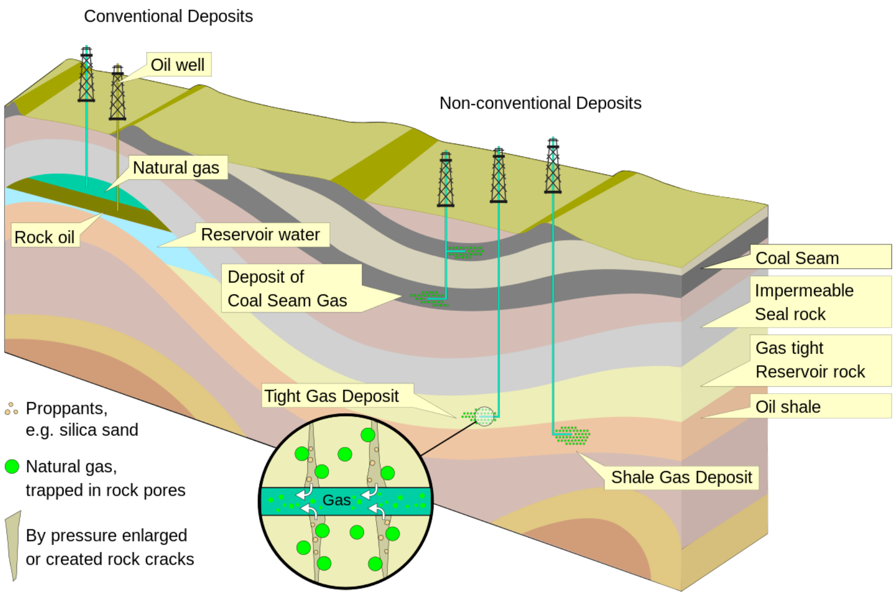


Figure 27: Scheme of oil and gas extraction (source: MagentaGreen, CC BY-SA 4.0)

Oil extraction causes significant damages to the environment. Even with conventional deposits, development and extraction cause adverse interventions in ecosystems, especially offshore plants. In addition, flaring of associated petroleum gas, which is still common under certain circumstances, also damages the environment through emission of carcinogenic particulate, carbon dioxide, sulphur dioxide and nitrogen oxides.

Lignite Mining

Coal deposits are basically divided into hard coal deposits and lignite deposits. Hard coal deposits are mostly mined underground (exceptions Canada, USA, Australia and Russia), lignite deposits are mainly open cast mined. Up to 90% of underground hard coal deposits are exploited upright and horizontal. Caving or room and pillar methods are used as extraction method. The mining depth is usually between 800 m and 1,000 m below surface. In case of caving, load-bearing elements will be systematically thrown to breakage. The disadvantage of all types of caving methods is the significant subsequent damage of the surface, which can cause the subsidence of up to several meters. The impact on the environment in opencast mining is mainly determined by the high land consumption. Further environmental impacts are the lowering of the groundwater level and dust formation. These are mainly large opencast mines for lignite extraction (figures 28 and 29).

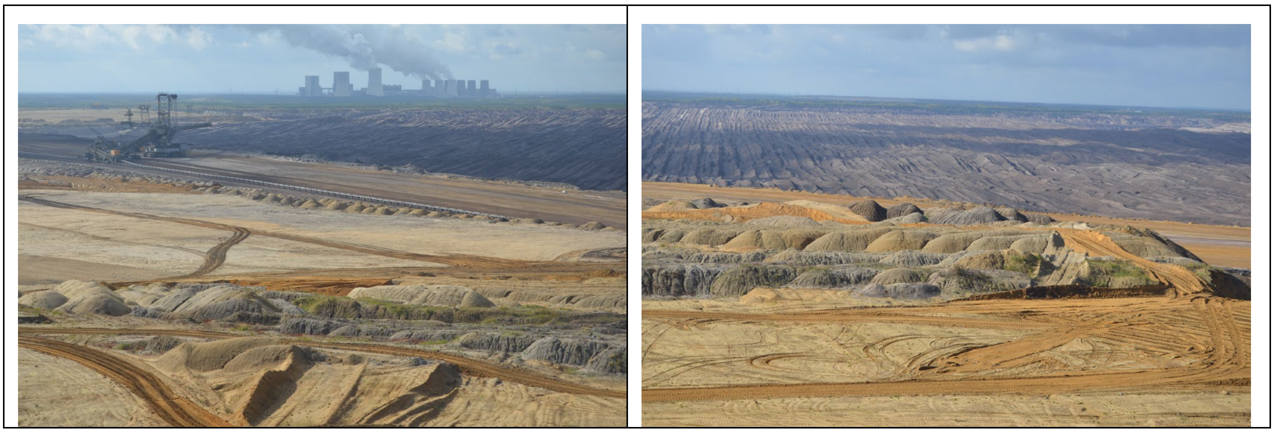


Figure 28: Open cast lignite mining in Eastern Germany

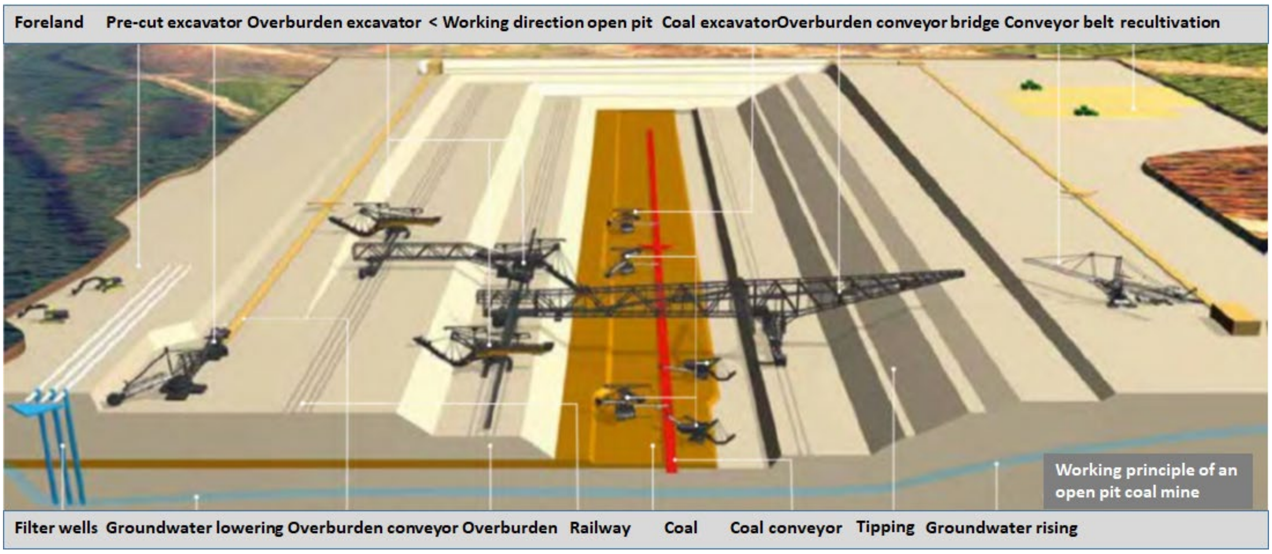


Figure 29: Principle of open cast mining (Tudeshki & Pielow, 2018, translated from German)

In lignite mining, a continuous lowering of the groundwater level in the mining area is necessary. To reach this condition, hundreds of sump wells are often built around the open-cast mine, where the groundwater is sucked off by pumps. However, this lowering of the groundwater often has an effect far beyond the opencast mine and can affect other users. For this reason, various measures have to be taken. The pumped well water is used, for example, to irrigate the surrounding wetlands using infiltration plants. Waterworks ensure the public water supply.

Uranium Mining

The same principles shall apply to the extraction of uranium ores as for the extraction of metal ores. Examples are shown in figure 30. The uranium ore can occur in:

- hydrothermal lode deposits
- sediment deposits as well
- as a by-product in the extraction of other raw materials such as copper, silver, gold or vanadium

In 2017, 4 % of uranium was mined in this way. Another 46 % of uranium were extracted in underground or opencast mining.

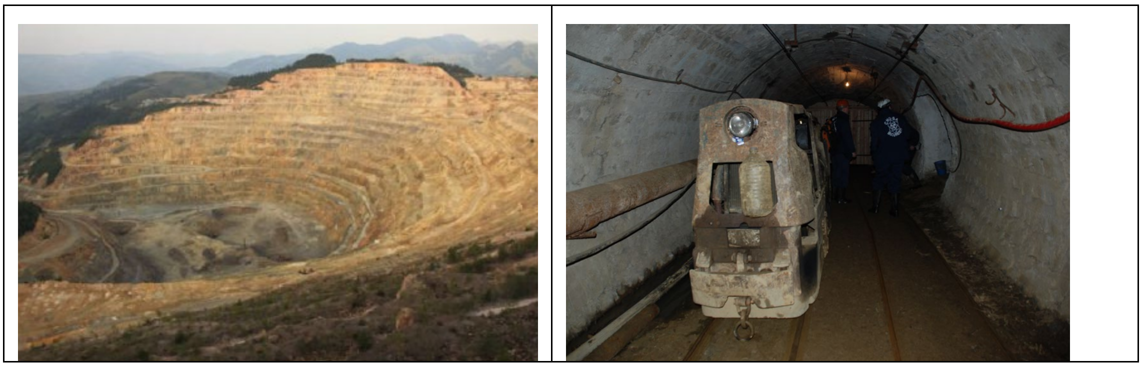


Figure 30: Uranium mining in Romania: open cast (left, figure source: Dima 2016), and underground (right)

However, half of the uranium is now extracted by so-called in-situ leaching (ISL). The uranium is extracted from the surrounding rock using leaching acid, and pumping the leached ore through drill holes. In the underground the interim storage of extracted rock will be done. As a mining method, there is possible a cut and fill caving with and without interim storage of the waste rock and a mine filling extraction method. All uranium mines are under national regulatory supervision. Most of mines apply the international environmental management standard ISO 14001 and are certified accordingly. The mine operators are obliged to protect people and the environment from harmful influences and to restore the natural landscape after finalization of mining operations. The process of certifying the social responsibility of mining companies is in progress.

Uranium ore contains up to 0.1% uranium in the form of oxides. After ore extraction, the first stage of processing is the production of yellowcake. Uranium oxides can be released from the extracted ore using acids. Approximately one kilogram of yellow cake is extracted from two tons of ore mined in uranium mills. It consists of more than 80% uranium compounds. The residues from the extraction of yellowcake (so-called tailings) are still radioactive despite the uranium separation and must therefore be disposed of in an orderly manner. The large quantity and the long half-life of the remaining thorium, radium and uranium isotopes present longstanding environmental problems. Contamination of groundwater resources is particularly problematic.

4.3.4 Industrial Minerals

Industrial minerals refer to non-metallic mineral raw materials for technical use and further processing due to their chemical or physical properties, partly only after appropriate processing. Industrial minerals include salt, barite, fluorite, quartz, feldspar and graphite. In contrast to ores, which are converted into metals by smelting, industrial minerals can be used directly or with provision of small technical effort. Following raw materials further represent industrial minerals:

- potassium and magnesium salts, sea salt, potash, industrial brine, (evaporated salt)
- kaolin, bentonite, special clays, quartz, quartz sand and gravel, phosphorous, diatomaceous earth, silica, molding sand, adhesive sand
- pegmatite sand, fluorspar, barite, graphite, sulphur, bauxite

The available BAT document for the industrial mineral sector are:

- 2008 BAT Guidance Note for the General Inorganic & Alumina Sector
- 2008 BAT Guidance Note for the Glass Sector including Glass Fibre
- 2008 BAT Guidance Note for the Ceramic & Diamond Sector

The extraction approach of the industrial minerals is different. Potash and salt are usually extracted from larger depths (about 500 – 1,000 m and below) and they will be only mined underground. In addition, chamber construction, chamber pillar construction and offset construction (i.e. chamber construction with regularly standing pillars, then displacement of the chambers and subsequent dismantling of the pillars) are used. The last-mentioned mining processes have the least possible influence on the surface environment, since the use of processing waste for construction eliminates the need to transport such waste to the surface. In addition to minimizing the loss from dismantling, a significant improvement in fuse protection can be achieved at the same time and the avoidance of possible rock falls must be ensured.

Potash and rock salt deposits are excavated and installed in a horizontal manner, with the shaft depth also being of particular importance with regard to subsequent renovation. The shafts are largely submerged in the freezing process, which is essential when groundwater resources are encountered. The underground device is designed using diesel or electric LHD technology in conjunction with access ramps to the respective mining levels. The underground extraction takes place depending on the specific host rock conditions

- drilling and blasting work (especially when there is a risk of CO_2 outbreaks) or
- rock-friendly machine extraction (partial cut or full cut machines)

The mining technology used in these deposits is highly productive, but in case of the open chamber construction it means low output with high losses up to 60%. With a combination with offset construction, the deposit losses will be reduced to up to 30%

on one hand, and on the other hand, a significant advantage that the residue is only slightly required to be stored for days. At the same time, productivity is also declining on a larger scale. Salt exploration examples are illustrated in figure 31, potash wastes in figure 32.

Figure 31: Salt exploration

Conventional processing methods such as hot dissolving, flotation, cold pre-decomposition and Electrostatic separation (ESTA) are to be used. As non-conventional treatment processes are to be mentioned gravity separation by hydrocyclones, and nanofiltration. The piling up of the potash and rock salt residues is particularly negative for the environment, especially with regard to the salinization of the groundwater and the receiving water. Extensive ecological measures are required here in the long term (see also section 4.6.).

Figure 32: Surface stockpiling of potash residues

The mining of kaolin, bentonite, special clays, quartz, quartz sand and gravel, diatomaceous earth, silica, molding sand, adhesive sand takes place in the mining industry over days by means of the above-mentioned technologies like in aggregates extraction, i.e. in the form of open pit mines and quarries, depending on the size of the deposits. The berms are set up regularly and the alignment is carried out using ramps. The technology is almost exclusively trackless diesel-powered LHD technology combined with direct extraction by excavators. Drilling and blasting technologies as extraction method are only used in exceptional cases. Thus, ecological challenges are:

- use of space for the mines to be created

- placing back of processing rock and mines to be mined for the renaturation of land, and
- influence in particular on natural water resources including their environmentally relevant pollution

A further type of potash and rock salt mining is brine mining. Salt solution mining means dissolving salt resources and pumping the resulting brine to the surface where it is concentrated or processed to recover the desired chemical products (Warren, 2016). Extraction takes place via drilling (figure 33).

Actual dissolution and recovery methodology is predicated on the solubility of the targeted salt (Warren, 2016), a rough estimation in the solution mining industry is that every 7–8 m3 of freshwater pumped into a cavity will dissolve 1 m3 of halite. Water or undersaturated brine is injected through a purpose-designed well drilled into a salt mass to etch out a void or cavern (Warren, 2016). The resulting “almost saturated” brine is then extracted for processing. The technique usually targets salts at depths greater than 400–500 m and down to 2,000 m (Warren, 2016). The resulting caverns can be used as natural gas storage. Table salt is usually extracted from clean sea water in the immediate vicinity of the coast. Figure 33 illustrates the principle of brine extraction by salt leaching (Warren, 2016).

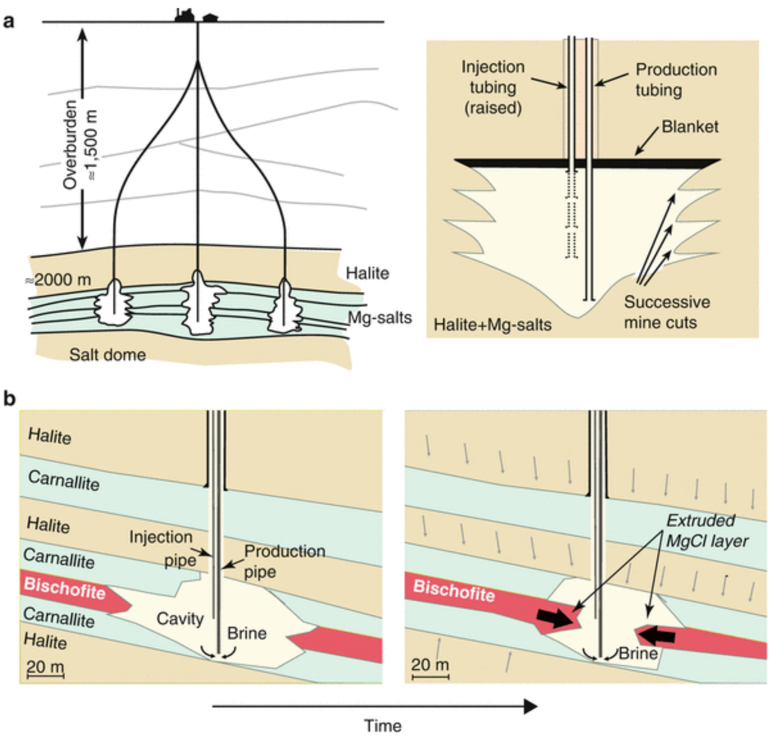


Figure 33: Principle of brine extraction by salt leaching (Warren, 2016)

Figure 34 illustrates kaolin and clay extraction. Fluor spa and barite are usually bound either to veins or sedimentary deposits, which are usually mined in open pits. According to the current state of the art, the removal and device is carried out by means of ramps coming from above. Following the depth, the individual mining levels are connected to each other by means of additional ramps. Extraction technology is drilling and blasting technology, the downstream production processes are carried out using LHD technology. Partial cutting machines are also used for selective mining, taking into account the corresponding rock properties.

Figure 34: Kaolin extraction (figure source: German Federal Institute for Geosciences and Raw Materials)

Both barite and fluorspar are very often associated with other elements, which, however, usually have a low concentration. In the course of a raw material strategy, which requires a complex use of all deposit components, the goal is to use these reserves economically by selective extraction. The preparation is usually done by flotation. The aim is to place back the residues to the pit and to install them there as planned. In contrast to the extraction of raw materials in open-cast mines, the impact on nature and the temporary use of space in underground mines is minimal. Nevertheless, the operation of mines is associated with negative environmental impacts and pollution of the transport infrastructure.

4.4 General Overview on Closure Activities

Generally, closure activities might comprise:

- Dismantling of processing plant and related structures, steel buildings and structures, reinforced concrete buildings and structures
- Rehabilitation of access roads, subsided areas, and overburden and spoils
- Demolition and rehabilitation of electrified railway lines, non-electrified railway lines, housing and facilities
- Opencast rehabilitation including final voids and ramps
- Sealing of shafts, adits and inclines, fencing
- Rehabilitation of processing waste deposits and evaporation ponds
- General surface rehabilitation, including grassing of all devastated areas
- River diversions
- Water management
- Maintenance and after-closure

Table 7 provides a general overview on the closure components applicable for the types of mining.

Table 7: Closure components applicable for type of mine

Main description	**Applicable closure components**			
	Open-cast	**Under-ground**	**Com-bination**	**Oil wells**
Dismantling of processing plant and related structures (including overland conveyors and power lines)	yes	yes	yes	no
Demolition of steel buildings and structures	yes	yes	yes	yes
Demolition of reinforced concrete buildings and structures	yes	yes	yes	yes
Decontamination of buildings, plant and equipment	yes	yes	yes	yes
Rehabilitation of access roads	yes	yes	yes	yes
Demolition and rehabilitation of electrified rail-way lines	yes	yes	yes	yes
Demolition and rehabilitation of non-electrified railway lines	yes	yes	yes	yes
Demolition of housing and facilities	yes	yes	yes	yes
Opencast rehabilitation including final voids and ramps	yes	no	yes	no
Sealing of shafts, adits and inclines	yes	yes	yes	
Rehabilitation of overburden and spoils	yes	yes	yes	yes
Rehabilitation of processing waste deposits and evaporation ponds (alkalinic, salt-producing waste)	yes	yes	yes	yes
Rehabilitation of processing waste deposits and evaporation ponds (acidic, metal-rich waste)	yes	yes	yes	no
Rehabilitation of subsided areas	yes	yes	yes	yes
General surface rehabilitation, including grass-ing of all devastated areas	yes	yes	yes	yes
River diversions	yes	yes	yes	no
Fencing	yes	yes	yes	yes
Water management (Separating clean and dirty water, managing polluted water and man-aging the impact on groundwater, including treatment, when required)	yes	yes	yes	yes
maintenance and after-closure	yes	yes	yes	yes

Closure of underground mines requires a special attention in terms of geotechnical stability of the mining construction and the impact of water pollution with hazardous and radioactive substances.

Surface mines (open pits) need to be evaluated and rehabilitated in order to mitigate the impact on water, air and soil and for safety issues regarding slope stability and mine security.

Geotechnical stability of tailings deposits raises complex problems. The dam and stockpile surface are tightly connected with the water balance, impact on underground water and generation of dust on dry beaches. The rehabilitation works at a tailings pond will complicate even more the situation and this is the reason why it needs a careful planning.

Tailings and salted water ponds may cause problems because of the salt load of the surface and underground waters. In certain situations, it requires conditioning.

Tailing dumps can generate on long term acid water leakage which may create serious water pollution problems. Depending on the tailings material, waste heaps can generate significant amounts of acid infiltrations. A careful planning of the dump cover needs to be conducted considering the water balance.

Salt and salt bearing rock dumps can generate large amounts of salted infiltrations.

Contaminated buildings (such as treatment plants, ore bunkers) require demolition. The wastes resulted need to be managed so that the amount of wastes requiring treatment or special removal methods to be reduced to minimum.

Mine water treatment and management are critical and complex actions because of the time period required for water treatment. The relatively large amount of mine waters treated during long periods of time and the issues associated with discharging the resulted water need to be addressed appropriately. Standards on treating the effluents can offer an efficient rehabilitation solution in terms of costs.

Sudden breakage of rocks and underground landslide are to be expected. They will result in erosion holes and land collapse up to the surface. Moreover, the emission of gas may occur (CH_4, CO_2) and needs to be carefully monitored. These seismic activities associated with mining operations can be detected in due time by very accurate geophysical measurements.

4.5 Closure of Aggregate Mining Sites

4.5.1 Overview

Usually aggregates mining of stable rock is conducted as open pit mining, in case of solid rock called quarry, excavated using one or more horizontal benches. Sand mining from rivers or lakes is subject dredging. Unsustainable sand dredging is often accompanied by massive geotechnical and ecological hazards. The closure technique depends on the type of extraction. Dredging sites are usually left as ponds, maybe a stabilisation of the slopes might be required. The further description refers to the rehabilitation of quarries.

Quarrying activities create changes to topography with ongoing potential to impact the environment long after a quarrying activity has ceased. The restored landscape can be designed as agricultural land, field or meadow, forest, biotope, wetland, waste dispoal site, or left to natural succession without further treatment.

A local agreement may also be required if the proposed final land use changes the land use currently in force for the area or if the area is subject to planning overlaps. Once the final land use has been agreed, the completion criteria can be set. The mine operator must ensure that:

a) the rehabilitated area is left in a stable, safe, non-polluting state;
b) the area is suitable for the planned final use or rehabilitation objective;
c) rehabilitated areas are not excessively affected by erosion;
d) vegetation has to be consistent with the final land use.

The operator must ensure that all obsolete and superfluous installations, vehicles, machinery and equipment are removed from the working area, as well as all temporary and permanent structures, unless they are required for future use. While most part of the rehabilitation works should take place during the working phase of a quarry operation, some areas shall be rehabilitated after completion of the works. Proposed reclamation as contained in a mining plan describes a concept for the final end use of the site. Reclamation end uses are quite variable and may range from basic slope stabilization to wildlife habitat, or even lakeshore residential development. With a concept in mind, mining activities like clearing, stripping, stockpiling, and landform construction are directed towards final reclamation.

4.5.2 Particular Challenges at Aggregate Mining Sites

Usually, aggregates mining sites in the regular case do not contain dangerous waste according to Directive 91/689/EEC. However, it must be ensured that the site does not contain blasting or explosive chemical residues. Further, it must be inspected that no illegal waste disposal took place at the quarry site. A potential risk can occur from the instability of slopes, as a slope failure could lead to a serious accident. Further, aggregates mining sites are usually prone to erosion. A substantial portion of quarries have a convex shape that leads on the mid-term to the accumulation of water (flooding process). In case the final after use option is not an artificial lake, the construction of water diversion channels is necessary. The area should be redesigned to blend in with the landscape as much as possible. Figure 35 shows a flooded aggregate quarry in Sweden and a closed aggregate mining site in an infrastructural landscape in Germany.

Figure 35: Flooding of an aggregate quarry in Sweden (left); closed dry aggregate mining site, included in infrastructural landscape in Germany (right)

4.5.3 Earthworks

A quarry should remain in a stable, free drainage condition. Objective is to reconstruct the landform to be compatible with the surrounding landscape and to prepare the ground for revegetation. The mine operator must ensure that the site is left in a safe and stable condition. The usual closure practice is:

- The reduction of all slopes to a gradient of 1:3 (vertical: horizontal) or less, or application of artificial slope stabilising means like geotextiles, mulch mats or benching to break up the slope
- Once a stable landform has been created, respreads topsoil uniformly over the area at a suitable depth to support revegetation
- Leave topsoil with a rough surface

The main earth works consist of profiling and stabilising works. During the closure works is necessary to ensure erosion prevention, preferably through establishment of vegetation on a stable landform. However, as vegetation establishes, it may be necessary to use other erosion prevention techniques. In order to decelerate the runoff, drainage controls, such as troughs, contour banks and rock filters, must be maintained above the area to be rehabilitated through the covering growing seedlings with surface mulch on steep slopes to reduce erosion, weed formation and soil moisture retention, and to add nutrients to the soil.

4.5.4 Water Management

Aggregate mining typically has less impact on water quality, as this type of mining is carried out without chemicals, and the target raw materials rarely contain oxidizable minerals like pyrite or marcasite (Schneider & Wolkersdorfer, 2021). However, the aggregates mining requires sound water management with a focus on water supply for dust control and sanitation purposes as well as flood control. Therefore, aggregate quarries operators usually maintain a sedimentation basin. These facilities will also have to be put into long term stable conditions during the closure process. Depending on after-closure options, water diversion channels might be required for the long term stable maintenance of the former aggregates site. An example is given in figure 36.

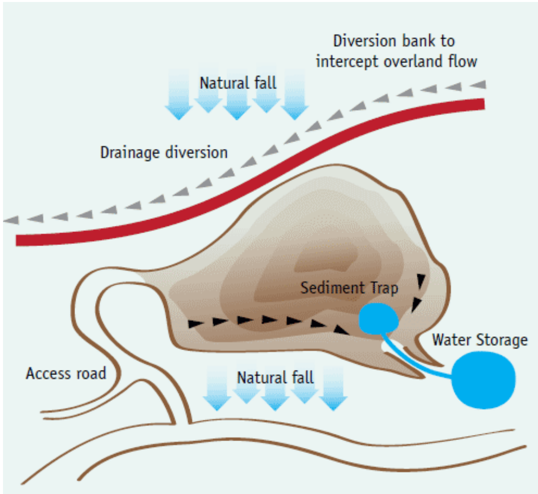


Figure 36: Typical Drainage Plan for water management across a quarry (source: Department of Economic Development, Jobs, Transport and Resources. Code of Practice for Small Quarries, 2010; Adapted from Quarry Code of Practice, Department of Environment and Primary Industries Water and Environment, Tasmania 1999)

4.5.5 Ensuring Long Term Geotechnical Stability

The main task at aggregates mining sites is to ensure the long term geotechnical stability, particularly of the slopes. At river dredging sites, there might also occur a ground failure risk. Aggregates mining sites are often prone to erosion as long as no vegetation is established. Further, in case of quarries, the slopes can have sharp edges or other dangerous structures that require supplementary occupational health and safety installations. On high slopes, fall protection must be ensured. Another type of geotechnical risks are coarse rock zones shall be available for rock sliding.

4.5.6 Ensuring Long Term Environmental Safety

After ceasing the aggregates mining activities, all installations, vehicles, machinery and equipment and the substantial environmental risk decreases shall be removed from the working area. However, the main remaining risk results from geotechnical stability.

Monitoring the rehabilitation works may take some time before it is determined that the works are safe, stable and environmentally friendly. The required level of surveillance may vary depending on site characteristics and the proposed final land use.

4.5.7 After-closure: Revegetation, Flooding, Nature Protection

Establishing a self-sustaining cover of vegetation is the best way to stabilise quarries in the long term. Vegetation also minimises the visual impact of quarries. Generally, the vegetation type which existed before the disturbance, or a similar vegetation type will be regenerated most successfully. Steps to successful re-vegetation are:

- Use the native vegetation originating from the local area, which is selected according to the ecological vegetation class of a location.
- Sow seed or plant tubestock. Use of high quality seeds free from harmful weeds.

Revegetation may take several years to produce a stable, safe and self-sustaining ecosystem. Any damage to rehabilitation should be quickly rectified. The preferable period of species restoration is:

- To carry out the preparatory earthworks is in the drier months.
- To plant plants at a time when growth is most likely (usually autumn or spring). In species susceptible to frost, however, seeds should be sown after the last frosts.

The recommended practice is to inspect rehabilitated areas regularly to assess the health of the vegetation and to check for erosion, pest animal browsing damage and weed infestation. In areas where germination has failed, to carry out enrichment planting of seedlings into unstocked areas or spot sowing by hand sowing of seed into small cultivated patches. The application of fertiliser might be useful if poor growth and yellow leaves indicate nutrient deficiencies. The planting of a variety of species in the vegetation with native vegetation increases the probability of success.

Although quarries change nature and landscape, mining areas can also become ecologically valuable secondary sites for many animal and plant species. Sometimes important sites for species and nature conservation will be developed during the operation. A mosaic of partial and micro habitats of sun-exposed screes, precipices, niches and ledges, old lanes and ponds promotes a high biodiversity and offers space for plants and animals with different survival strategies. Important during the mining operation are suitable accompanying measures that promote biodiversity. Whether managing existing operations or planning the rehabilitation of pits and quarries, there is a wide range of opportunities for the aggregate industry to contribute to the conservation and enhancement of biodiversity, figure 37.

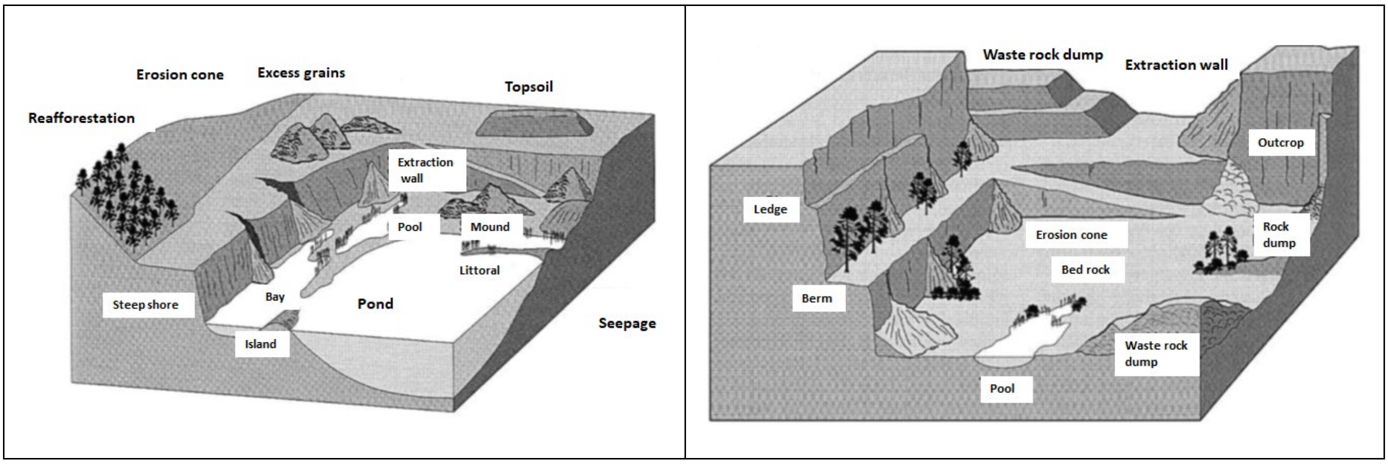


Figure 37: Potential habitats in a) in gravel, sand, clay and clay pits (left), and b) quarries (right) (Trautner & Bruns 1988, modified)

In case of species habitat planning, the following issues are to be considered:

- Is the site within the range of any species at risk or rare habitats? It is reasonable to target the species for which there are recent records within about 20 km of the site.
- Does the site contain suitable biological, hydrological, and geophysical conditions to create the desired habitat? What is the condition of existing habitat features on the site?
- What are the surrounding land uses? Is the site connected to an adjacent natural area and, if so, what kinds of vegetation are found in the intact/reference habitat?
- Are there local genetic stocks of the species at risk readily available?

Animal translocation is strongly discouraged, unless under exceptional circumstances.

4.6 Closure of Ore Mining Sites

4.6.1 Overview

Ore mining can be performed as opencast or underground mining, depending on the depth of the ore below surface. In addition to the geotechnical and hydrogeological site exploration of the extraction site, water management activities during the exploration and site preparation include the planning and implementation of processes for (1) lowering the groundwater level, (2) disposing of groundwater and wastewater, and (3) planning of development of facilities for liquid and solid residues from the site (Schneider & Wolkersorfer, 2021). Technical measures for the closure of ore mining sites are the groundwater rebound after switching off the pumps (mine flooding), the closure and dismantling of the mining facilities, the covering of heaps and tailings facilities and the reclamation of the land used for mining and their landscaping. In addition to mine closure and dismantling of facilities, placing back of excavated material and flooding of the mines may be required. In this case, groundwater recovery management is necessary, probably including water treatment (Schneider & Wolkersorfer, 2021).

For closure techniques particularly in ore mining is to be considered the Best Available Techniques Reference Document for the Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC (MWEI BREF), that is a review of the Reference Document for Management of Tailings and Waste-Rock in Mining Activities. The document presents updated information on the management of waste from extractive industries, including information on BAT. It is published by the European Commission Article 21(3) of Directive 2006/21/EC on the management of waste from extractive industries. MWEI BREF presents data and information on the following:

- General information and key figures on extractive industries in Europe (Chapter 1).
- Applied processes and techniques for the management of extractive waste (Chapter 2).
- Emission and consumption levels resulting from the management of extractive waste (Chapter 3).

- Techniques to consider in the determination of Best Available Techniques (Chapter 4).
- Best available techniques conclusions (Chapter 5).
- Emerging techniques (Chapter 6).
- Remarks and recommendations for future work (Chapter 7).

4.6.2 Particular Challenges at Ore Mining Sites

During the extraction and processing of ores, liquid and solid (such as treatment residues, wastewater), waste is generated for which disposal facilities must be planned. In some cases, the mining residues might be toxic if the extraction or material treatment has been carried out with chemicals (Schneider & Wolkersorfer, 2021), so that TMFs may contain toxic substances.

For example, in the case of gold mining, cyanide is used as a solvent; in the case of metal mining, acid or alkaline solutions are used (Schneider & Wolkersorfer, 2021). For instance, sulphuric acid is used for leaching of copper from oxide ore, and some sulphide ores. The highest volume of bulk inorganic reagents used in mineral processing is lime and sulphuric acid (Pearse, 2005). Lime is used for pH adjustment, coagulation, heavy metal precipitation, causticisation and depression of pyrite in flotation.

Sulphuric acid is also used for pH adjustment but more importantly for the leaching of oxide copper, lateritic nickel, zinc calcine, titanium dioxide from ilmenite and uranium minerals (Pearse, 2005). Further, sodium or calcium cyanide (solvent for gold) and caustic soda (pH adjustment in several processes and for the leaching of alumina from bauxite) are used in large quantities. Many other inorganic reagents are used in the mineral processing industry, even if in smaller amounts than those above. Table 8 gives an overview on inorganic reagents and their primary functions in mineral processing (Pearse, 2005). Those materials may be found in the TMF, depending on the mineral processing methodology.

Table 8: Some inorganic reagents and their primary functions in ore processing (Pearse, 2005)

Reagent	**Primary function**
Sodium cyanide	Pyrite and sphalerite depressant
Sodium silicate	Slimes dispersant
Zinc sulphate	Sphalerite deactivator
Copper sulphate	Sphalerite activator
Sodium sulphite	Pyrite, sphalerite and oxidised galena depressant
Potassium dichromate	Galena depressant
Potassium permanganate	Arsenopyrite and pyrrhotite depressant
Sodium hydrosulphide	Sulphidizer for oxide and weathered minerals
Soda ash	pH adjustment in lead flotation
Ammonia	Nickel solvent
Hydrogen peroxide	Oxidant for gold cyanidation
Lead nitrate	Additive in gold cyanidation
Alum, Polyaluminium chloride, Ferric chloride	Clarification
Sodium hypochlorite	Cyanide destruction
Sodium ferrocyanide	Anti-caking agent

The pollutant-containing suspension is deposited into the TMF's, so that the sediment can settle and thus forms a sediment layer with an excess waste water level (figure 36). A special extraction form is in situ-leaching, where the acid or alkaline solutions are pumped into the rock in order to transfer the target resource into a mobile form and to extract the mineral as solution. In situ-leaching sites require challenging closure techniques as the long term immobility of polluted water must be ensured. Figure 38 provides exemplarily impressions of TMFs in Romania, figure 39 illustrates exemplarily acid mine drainage in Spain.

Figure 38: Impressions of TMFs in Romania

In addition, if necessary, water treatment plants might be necessary, which is particularly the case when mine water with elevated concentrations of potentially toxic elements or acidity is formed during the excavation of the deposit (Schneider & Wolkersorfer, 2021). Usually, this occurs when geogenic iron (di)-sulphides (pyrite, marcasite, pyrrhotite) are oxidized by water and oxygen; in this case, sulphuric acid reacts with the host rocks, forming Acid Mine Drainage (AMD, figure 37) (Evangelou & Zhang, 1995; Nieto et al. 2007; Wolkersdorfer, 2008; Blowes et al. 2014).

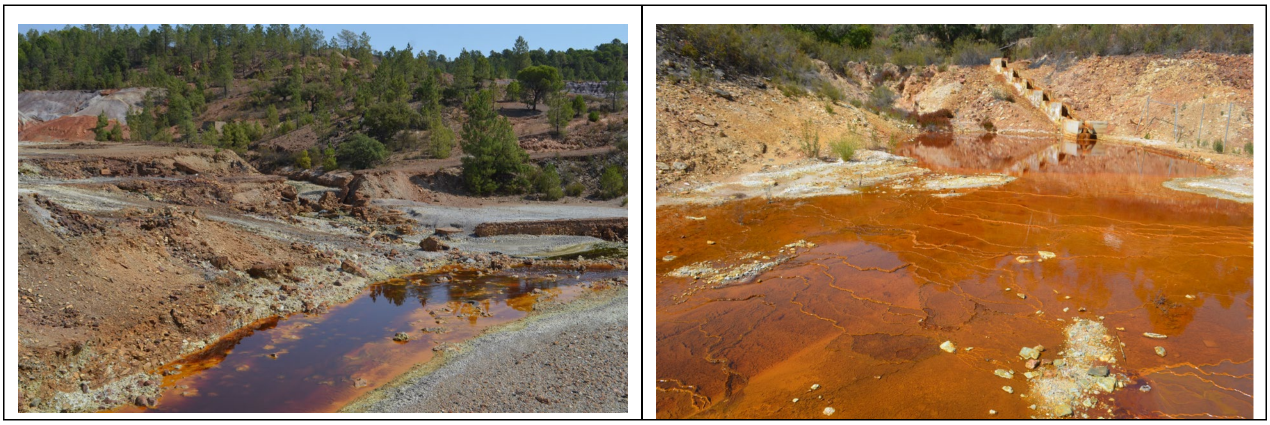


Figure 39: Impressions of Acid Mine Drainage in Spain

A further particular challenge at ore mining sites occurs when the host rock contains geogenic radioactive material that remains as waste during processing. It is about radionuclides of the natural decay series of Uranium-238, Uranium-235 and Thorium-232, which are represent in all rocks and ores as traces. If rocks and ores are used as raw materials, natural radionuclides are also inadvertently introduced into industrial processes. In some industries, natural radionuclides can accumulate in parts of the material streams. These residues are called “naturally occurring radioactive material” (NORM) (International Atomic Energy Agency, 2013). In the long term, this leads to a radioactive pollution of the environment. When using raw materials (for example ores), natural radionuclides are generally introduced into technological processes causing increased radiation exposure and radioactive residues (Technologically Enhanced Naturally Occurring Radioactive Material, TENORM). That material requires particular waste management practices.

4.6.3 Closure of Open Cast Mines

Generally, there are two approaches for the closure of opencast mines:

a) Filling with solid material (placing back extractive waste into excavation voids for rehabilitation and construction purposes)

b) Flooding with water, resulting in a pit lake.

Filling with solid material

Filling with solid material is often selected as solution in case a geochemical barrier of the waste rock is required. The advantages are (Chapman et al. 1998):

- Consolidating diffuse sources (multiple rock piles) into a single location;
- Providing a secure, maintenance free repository for potentially acid generating waste rock;
- Reducing the area impacted and increasing the area of land returned to its original use; and,
- Preventing the development of an exposed acidic pit lake.

Within an open pit, three potential deposition zones can be identified in terms of the potential for continued oxidation of the waste rock, as shown in Figure 34. A secure zone exists below the re-flooded water table as oxygen ingress is severely restricted and thus the saturated anoxic zone represents the zone most suited for placement of waste rock with a high potential for acid generation.

Above water table two additional zones do exist (Chapman et al. 1998). An oxygenated zone (oxidation zone) exists from the surface down. The depth to which oxygenation occurs depends on several factors, including diffusive transport and barometric pumping. Each of these mechanisms depends on such factors such as the physical properties of the fill and the degree saturation (Chapman et al. 1998). The more reactive the waste rock, the more rapid oxygen will be consumed and the shallower the resulting depth of oxygen entry. The third zone, (unsaturated anoxic) is delineated by the lower boundary of the oxygenated zone and the water table. This zone is anoxic and the potential for further oxidation is limited. But, unlike the saturated zone, water flow through this zone generally is unsaturated so that only a small proportion of the waste rock is actually contacted by infiltrating water (Chapman et al. 1998).

According to Paul et al. (2004), the open pit mine to be filled may be subdivided into sections, but it will be difficult to distinguish between their relative effects. Water flow consists of infiltration respectively groundwater recharge in the open pit area (preferentially vertical flow), groundwater flow through higher permeable areas (aeration zone, inside dump) due to hydraulic gradients and despite the hydraulic connection provided by the mine workings, as well as exchange of substances between the well flowed through aeration zone surrounding the open pit and the filled waste rock in the pit. Figure 40 illustrates the conceptual zonation of filled open pit (Chapman et al. 1998) and the practical example of the open pit Lichtenberg, Germany in 2004, that was filled with conceptual zonation. In the foreground are visible hydrological test sites for the final surface cover (Hoepfner & Schneider, 2006).

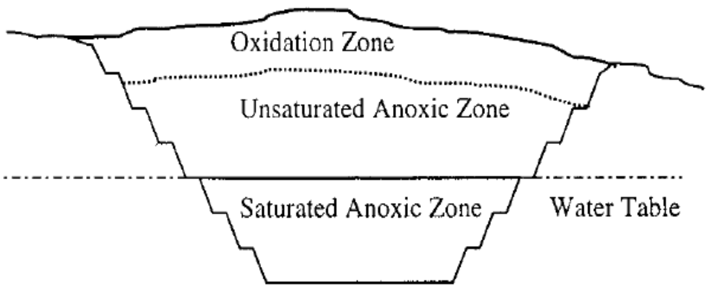


Figure 40: Conceptual zonation of a filled open pit (Chapman et al. 1998) (left); open pit Lichtenberg, Germany (2004), filled with reactive zones (right)

Flooding with water, resulting in a pit lake

The flooding process happens because the drainage wells or dewatering pumps stop to work and the open mining spaces are filled with ground and surface water. Flooding the open cast mine with water means also to allow for precipitation to enter the open case mine, and/or to provide supplementary water from other sources. Usually, in case of solid rock pen cast mines, as sources might be used water diversion channels from natural creeks, in case access water might be diverted. In case of flooding with surface water, protection of the natural water courses according to EC Water Framework Directive must be ensured. Figure 41 shows a sample of a flooded copper mine in Bulgaria.

Figure 41: Sample of a flooded copper mine in Bulgaria (left); water diversion channel upstream the mine (right)

A flooding strategy strongly depends on the after-closure usage scenario and the available water sources.

4.6.4 Closure of Underground Mines

Closure of open mine workings

Two general filling approaches are applied for underground mines, resulting in following closure techniques:

a) Filling with solid material

b) Flooding with water, resulting in a raising groundwater level and a mixture of mine and groundwater. A flooding water level might result in an outcrop. In such a case, adits are necessary for mine water management.

Filling with solid material

Regarding the filling with solid material, there are many requirements in terms of quality because this affects mining cost, performance of the mining equipment and the filling ratio, e.g. binder vs. rocks (Zhang et al. 2019). Further, the selection of materials for filling and its mixture design is essential, as well as a close-by source of the materials (Zhang et al. 2019). Figure 42 provides an overview on engineering demands for selecting materials for filling.

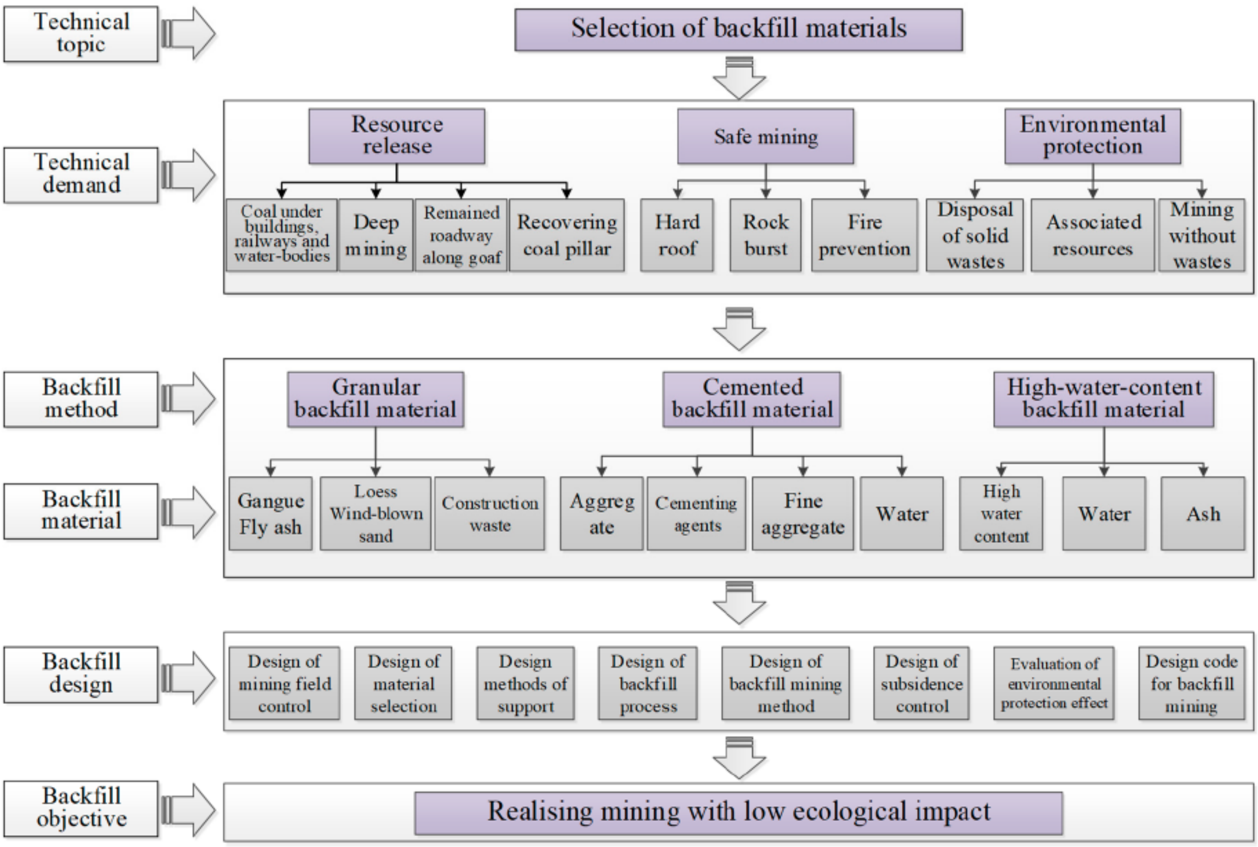


Figure 42: Engineering demands for selecting materials for filling (Zhang et al. 2019)

The provision of filling material is done through an open mine working like a shaft or an adit. Depending on placement and consistency of the fill material, the following types can be distinguished (Konietzky, 2018):

- Pneumatic filling: dry material is placed via pneumatic conveying through pipes
- Hydraulic filling: liquid material is placed via pipes, belts or trucks
- Paste filling: pasty material with high solid content (> 65%) transported through pipes by hydraulic pressure
- Mechanical filling: dry granular material is placed via belts, chutes, pipes or trucks in the excavations (just gravity driven)
- Big bags: filled with dry or only slightly wetted material are placed in the excavations.

There are further differences between cemented and uncemented material (Konietzky, 2018). The first one can be transported and placed by gravity or pumping, the second one by pneumatic or slinger stowing.

Flooding with water

Flooding in underground mines is usually controlled. These types of mines are not directly influenced by surface waters, so it is mainly underground water that plays a role in the flooding. One of the main reasons to let an underground mine be flooded is to avoid disulphide oxidation and thus, avoid acid mine drainage. In case flooding with water takes place, stable bedrock is a precondition. Flooding means to cut off the operation of the pumps that keep water out of the mine and to allow groundwater to rise. Shafts and other mine workings act as preferential flow paths in this case, and the permeability is much higher than before the mining activities. Flooding of mines requires a comprehensive mine water management. The controlled flooding of underground mines usually follows these guidelines:

- Removal of potential water hazards
- Fill the surfaces that might collapse during or after the flooding process
- Install water diversion systems
- Install, at both the surface and underground, a system to monitor hydrogeological and geotechnical aspects
- Make a projection of hydrological and hydrogeochemical development of mine waters

Figure 43 shows a mine flooding scheme, illustrated at the Schlema-Alberoda site, Germany (Schneider et al. 2005).

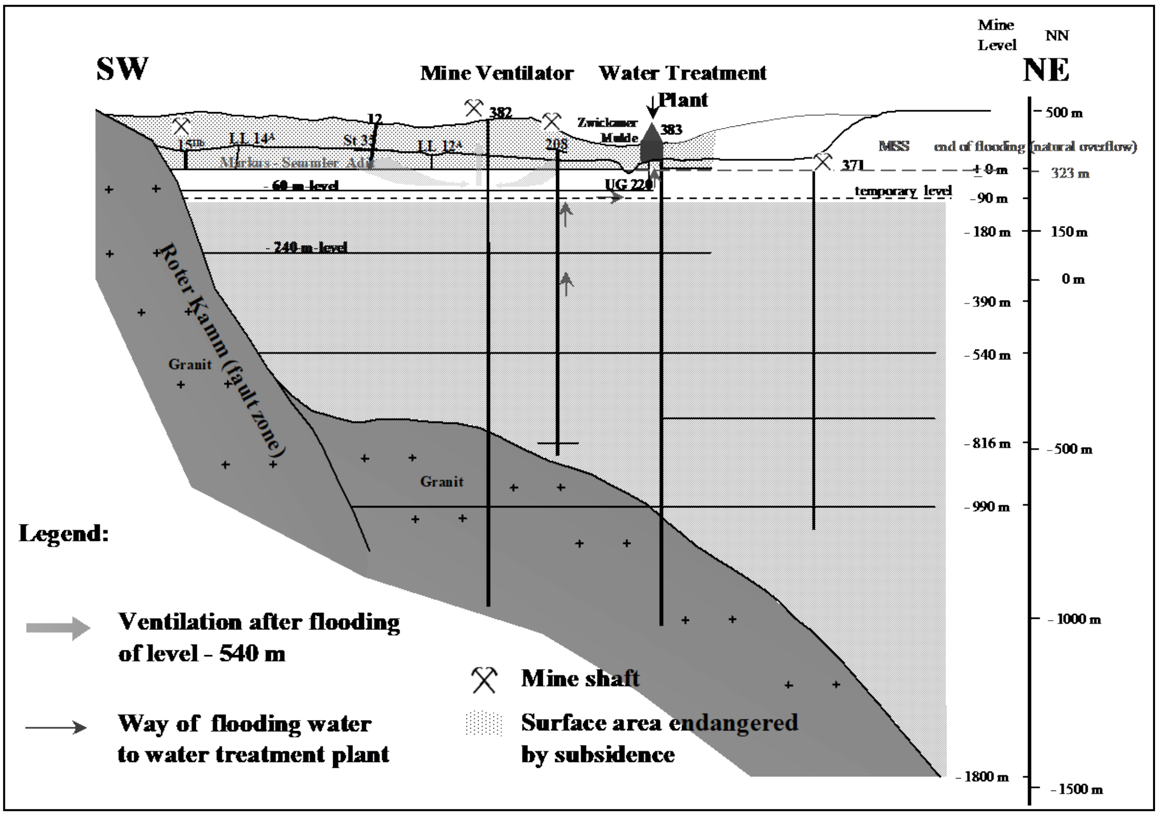


Figure 43: Mine flooding scheme of the Schlema-Alberoda site, Germany (Schneider et al. 2005)

Closure of mine openings

Mine openings must be kept permanently and securely at the end of their useful life to avoid damage to the surface of the day and in the interest of public security. A distinction is made:

<u>Ensuring permanent safety</u>

Permanent safety measures over a limited period (years / decades) eliminate or significantly reduce the risk to public security. Periodic inspections or monitoring are an integral part of these rehabilitation measures (e.g. plumbing the fill level and, if necessary)The inspection by the competent authority will be continued all the period.

<u>Definitive final long term closure</u>

Permanent, effective and maintenance-free measure to prevent adverse effects on the surface of the site and rehabilitation of existing damages. The scope and type of measure must be adapted to the existing or planned use of the site surface. The closure design must ensure an efficiency of more than 100 years. The inspection by the competent authority will end after a certain period after approval of implementation.

Visible mine openings include shafts, adits and sinkholes. Abandoned and unsafely secured mine openings are an acute hazard to people. Shafts have to be stabilised and inadvertent access prevented to avoid danger to the surface and to ensure public safety when mining activities have ceased. Figure 44 illustrates samples of shafts, adits, and sinkholes before rehabilitation.

Figure 44: Sample of shafts (left); adits (centre) and sinkholes (right) before rehabilitation

Before planning and executing shaft safekeeping, preliminary examinations must be carried out to determine the type of safekeeping:

- Analysis of the mine survey documents and the technical information
- Analysis of mining damage
- Geological and geotechnical surveys
- Hydrological studies

Shafts contain two parts that must be closed: the shaft hole (drilling hole) and the mine opening (shaft mouth). Generally, shafts have to be stabilised by total or partial filling (waste rock, crushed rock or cohesive material). Shafts, that are located in predominantly or completely in the coarse bed rock or in the non-stable solid rock must be filled to their full depth. Shafts in the stable, solid bed rock must be rehabilitated by partial or full filling according to the specific conditions.

<u>Shaft hole</u>
Depending on the site setting, the following materials are generally permitted for the filling of shafts:

- Broken bedrock: crushed stone, grit
- Non-cinder coarse rock: gravel, sands
- Industrial mineral waste products: waste rock material, slags, ashes
- Cohesive filling material: erosion and position-stable hydraulically setting cement-bound materials (concrete, hardening mix using cement and officially approved brown coal filter or power plant ash as a binder)

All internals that prevent the intended filling sections from being completely filled and which can break when the filling material is introduced must be taken out beforehand, provided that they have no expansion function. The permissible fall heights for cohesive contents are to be determined depending on the material properties (consistency, grain size of the additives). Figure 45 shows general option for shaft hole closure.

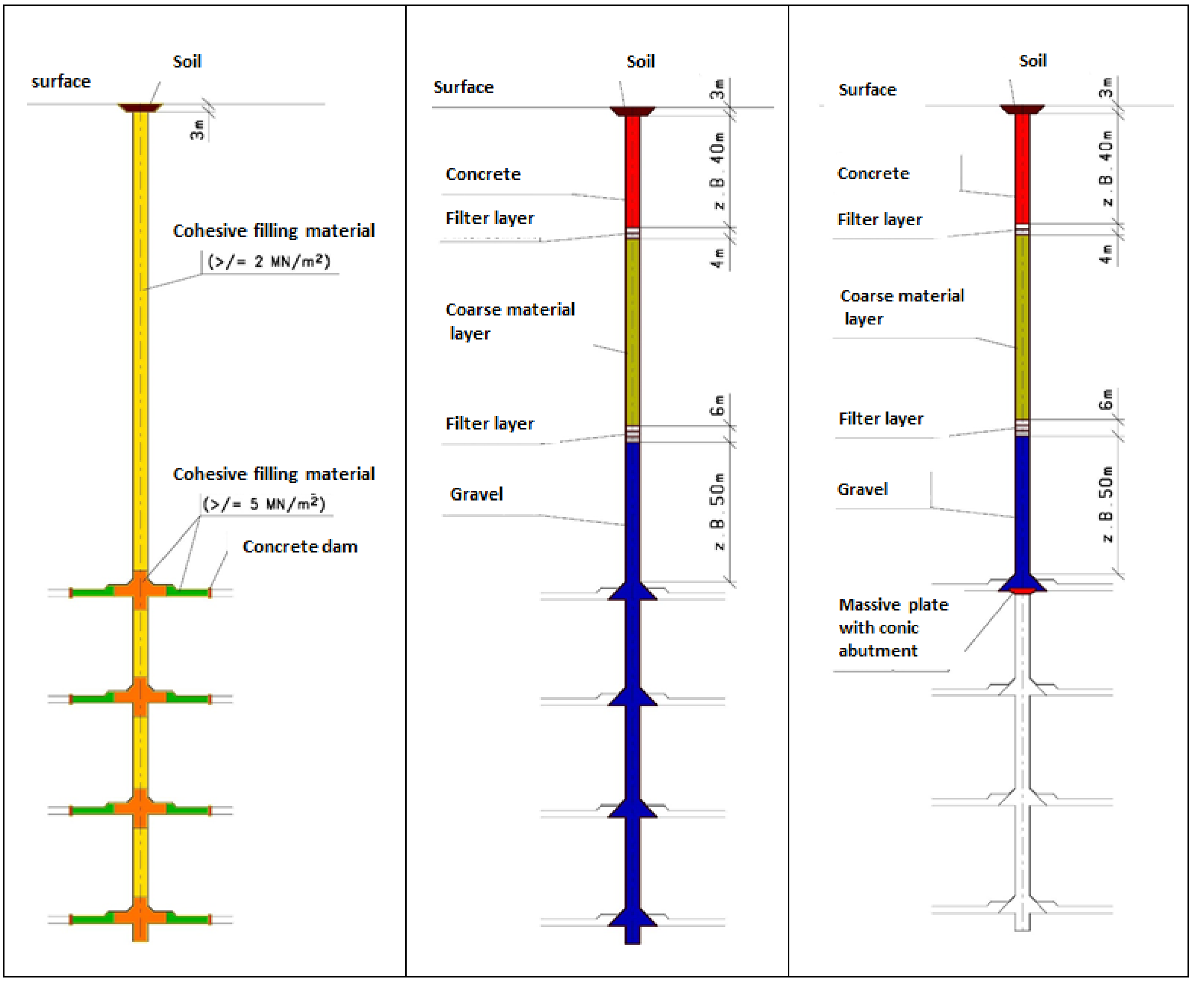


Figure 45: Shaft closure: a) full filling: cohesive filling column (left); b) full filling: coarse rock filling column combined with cohesive filling column section (centre), and c) partial filling: sealing and coarse rock filling column combined with cohesive filling column section (right)

In order to avoid settlement of the filling column, sands with approx. 5%, waste rock with approx. 15% as well as flotation piles and ashes with approx. 30% water content should be added to the dry batch volume if there is no water in the shaft to the appropriate extent or if it is filled into water.

Strength requirements:

Filling columns reaching from the deepest of the shaft to the surface: Compressive strength of the filling material after 28 days $\sigma_D \geq 2$ MN / m² as a minimum requirement, stipulations of $\sigma_D \geq 5$ MN / m² have proven successful for the filling column sections in the area of filling locations and $\sigma_D \geq 2$ MN / m² for the filling column areas in between..

Cohesive filling column sections: Definition of the required quality features according to the following criteria: length or height of the filling column, shaft cross-section, size of changes in cross-section of the shaft with depth, type and properties of the shaft extension or rock, strength properties of the shaft expansion and rock, load size on the filling column.

Filling columns must always be permanently secured against leakage into unfilled shaft areas, filling point or other shaft exits. The Best Practice of securing coarse rock filling columns is:

1. Sealing

Use as partial filling, applicable in stable bedrock, not applicable in active subsidence areas, as well as in areas affected by mining and with water inflows >1 m³/min.

Types: Sealing in the shaft pipe (e.g. concrete single shear plug, concrete double shear plug), sealing in one filling location (e.g. solid filling location double seal, massive filling location single seal, solid plate with conical abutments in connection with filling location embankments made of gravel or with other shut-off devices)

2. Shut-off devices in filling locations

Fully offset zones, explosive fracture zones, dams made of masonry or concrete

3. Filling locations

Shut-off devices in filling locations to secure the filling column can be omitted if it is possible to pour filling location embankments out of gravel. Ballast must be made of weatherproof and water-resistant material. As a guideline, a grain size of 80 mm should be aimed for (e.g. crushed stone 56/80).

The prerequisite for this method is that the shaft be blocked off at the level of the shaft outlet in question by means of a solid plate or that the part of the shaft pipe underneath is filled and that the height of the ballast column height can be reliably verified during and at the time the ballast insertion is completed

<u>Shaft entrance</u>

According to the current state of the art, following methodologies are used for closure of abandoned shaft mouths

- walling of the immediate mouth area
- filling if an approx. 10 m long section in the mouth area
- closing the mouth hole by blasting

If sinkholes occur in the surrounding of the adit, the relevant areas must be secured as soon as possible without any voids. A common method is the introduction of concrete offset through holes.

The following rehabilitation measures can be applied:

- Excavation of a building pit, stabilisation of the shaft by infilling rock material and sealing with a reinforced concrete plate,
- Construction of a concrete shear plug inside the shaft, secured against slipping, within reach of the shaft surface, followed by filling of the upper part of the shaft with crushed rock up to the surface.

The option of fencing-in an object and installing hazard warning signs should be considered a temporary measure. This is a rapid but unsustainable hazard prevention with minimum budget. The method of shaft sealing with a reinforced concrete plate is illustrated in Figure 46.

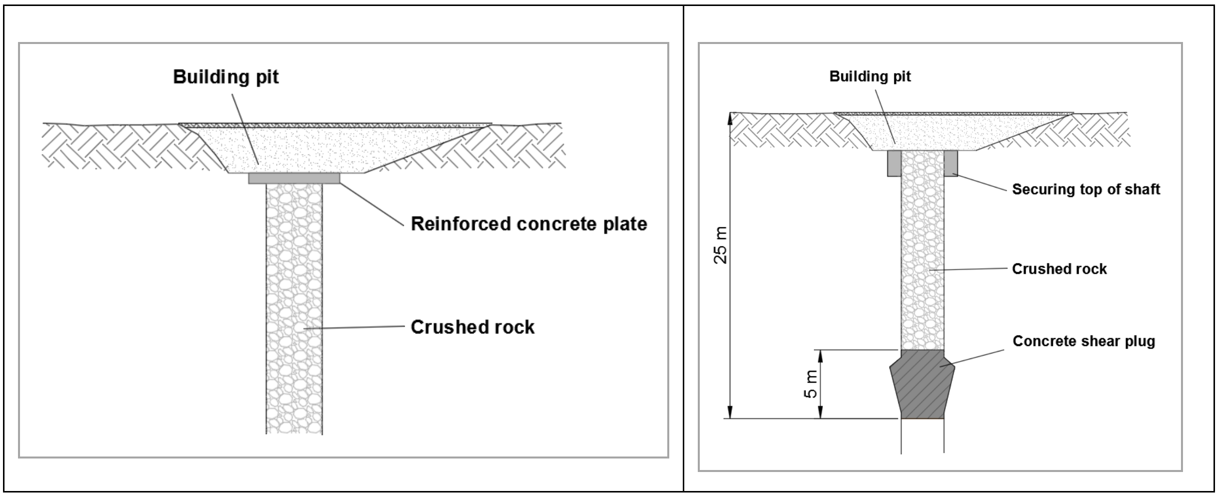


Figure 46: Shaft mouth sealing with reinforced concrete plate (left); shaft sealing with concrete shear plug (right)

Horizontal mine access structures, ***inclines, adits and shaft entrances***, are usually sealed soon after closure for reasons of public safety. The applicable closure technology depends on:

- location of the adit with reference to the surface,
- geological and hydrogeological setting,
- adit function, and
- general state of the adit in terms of stability and accessibility.

If the adit serves or may serve as a mine water conduit, special attention has to be paid to a stable water discharge. Following settings are typical situations in terms of adit or shaft mouth closure:

- adit or shaft entrance open, no seepage water drainage
- adit or shaft entrance open, seepage water drainage
- Open adit, no water leakage, sinkholes along the adit route
- broken or filled up adit, seepage water drainage

The closure technology is illustrated in figures 45 and 46.

For closure of adits the following measures are in compliance with applicable international standards, guidelines and best practice:

- construction of a solid brick or concrete wall at the entrance of the adit (possibly followed by crushed rock/soil filling in the front section)
- blocking of a 10-50 m long section immediately behind the adit portal with cohesive fill
- filling of the complete adit and closure of the mouth of the adit by blasting
- gravel filling at the adit portal

The method of adit sealing with a brick wall and filling with crushed rock and soil is illustrated in Figures 47 and 48. The standard construction measures include:

- Excavation of soil in front of the adit if necessary,
- Install a brick wall of 0.5 m thickness and install a drainage pipe if necessary,
- Filling crushed rock and soil in front of the adit.

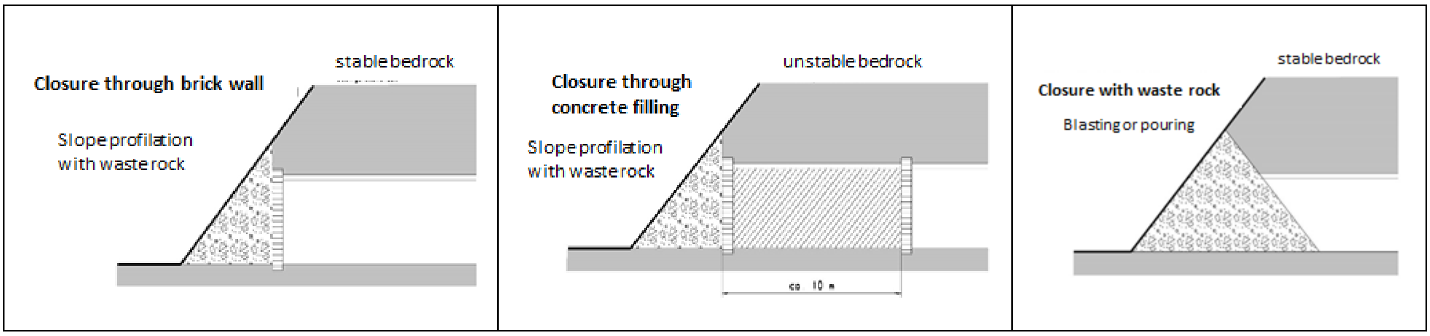


Figure 47: Adit sealing with a) brick wall and filling with crushed or waste rock (left), b) with fluid concrete (centre), and c) blasting or pouring with waste rock or crushed roc.

In case of water flow, the solutions displayed in figure 47 need to be equipped with a drainage pipe to ensure dewatering from the mine workings (figure 48).

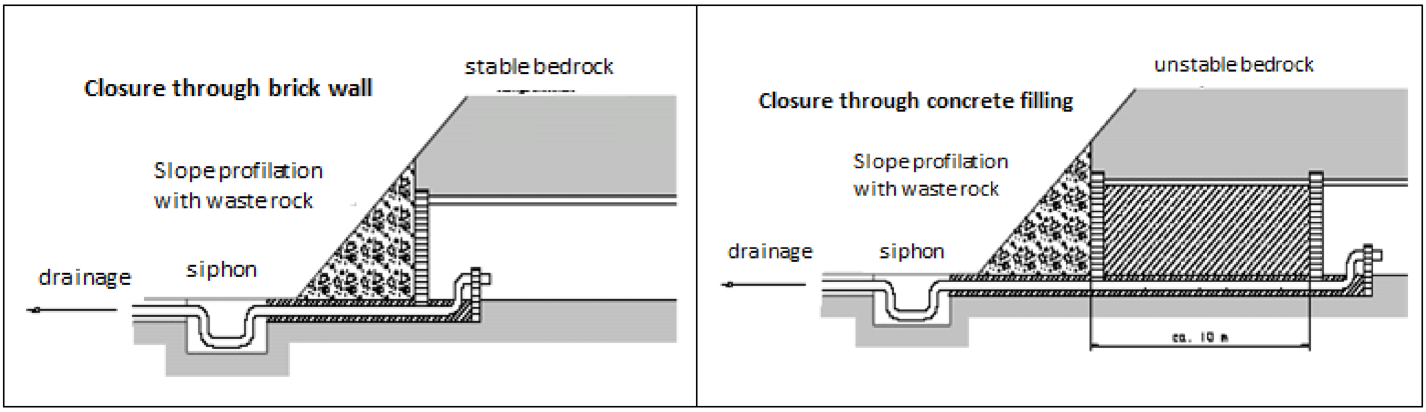


Figure 48: Adit or shaft mouth closure with brick wall and drainage pipe with siphon (left); adit or shaft mouth closure with fluid concrete and drainage pipe with siphon (right)

Sinkholes are caused by collapsing underground mine workings. Sinkholes should be filled and stabilised in order to prevent people from falling in. Long-term stable solutions should be applied to prevent underground workings from continued caving in. Information about the underground mine workings are helpful to ensure proper closure. The following options are applicable for securing sinkholes:

- Fill with waste rock
- Construction of a concrete plug at the surface of a sinkhole

The concrete plug close to the surface is best practice of sinkhole rehabilitation in hard rock. Loose material is excavated down to the level of hard rock. Then abutments are inserted into hard rock to establish holding forces for the concrete plug. The void above the concrete is filled with natural soil. A sketch of this option is presented in Figure 49.

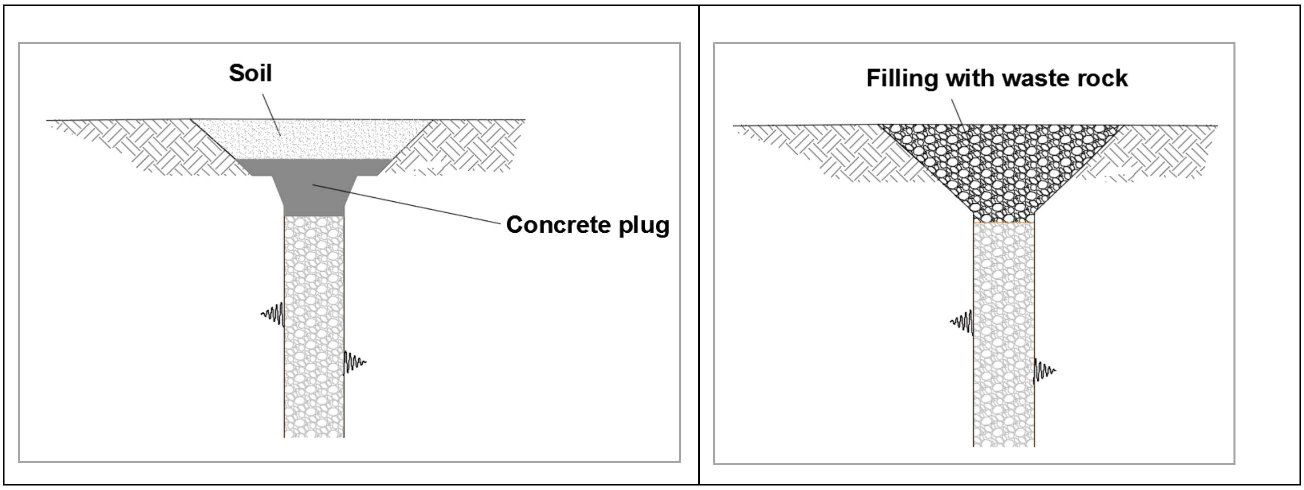


Figure 49: Sinkhole sealing with concrete plug close to the surface (left); filling with waste rock (right)

4.6.5 Management of Solid/liquid Control of Extractive Waste

In order to help ensure the physical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF):

- Mechanical screening - Relevant for extractive waste from excavation and extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds
- Hydro-cycloning - Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds
- Thickening and clarifying - Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds; particularly relevant for extractive waste from alumina refining (red muds)
- Dewatering by means of a pressure gradient or a centrifugal force - Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds; particularly relevant for extractive waste from alumina refining (red muds)

4.6.6 Extractive Waste Stabilisation

In order to help ensure the physical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF):

- Preparing cemented coarse extractive waste to be placed back into excavation voids
- Preparing extractive waste slurry (uncemented and cemented) to be hydraulically placed back into excavation voids
- Preparing paste extractive waste to be placed back into excavation voids

4.6.7 Compaction, Consolidation and Deposition of Extractive Waste

In order to help ensure the physical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF):

- Thickened/ paste extractive waste subaerial deposition - Relevant for extractive waste from mineral processing
- Wet or dry filter cake deposition (or dry stacking) - Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from alumina refining (red muds)
- Placing extractive waste back into excavation voids - Relevant for non-hazardous extractive waste
- Mud farming - Relevant for extractive waste from alumina refining (red muds)
- Co-disposal of fine and coarse fractions of extractive waste - Relevant for extractive waste from excavation Relevant for extractive waste from mineral processing.

4.6.8 Prevention or Minimisation of Pollutant Leaching

In order to help ensure the chemical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF):

- Reduction of extractive waste alkalinity - Relevant for extractive waste with high alkalinity; particularly relevant for extractive waste from alumina refining (red muds)
- Compaction, consolidation and deposition of extractive waste - Relevant for non-inert extractive waste
- Progressive rehabilitation - Relevant for non-inert extractive waste
- Temporary covers - Relevant for non-inert extractive waste

4.6.9 Prevention or Minimisation of Acid Rock Drainage (ARD)

In order to help ensure the chemical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF):

- ARD management system - Relevant for Potentially Acid Generating (PAG) extractive waste
- Segregation of PAG and Non Acid Generating NAG extractive waste by sorting and selective handling/ deposition - Relevant for PAG extractive waste
- Desulphurisation - Relevant for PAG extractive waste
- Blending with buffering materials - Relevant for PAG extractive waste

Furthermore (Relevant for PAG extractive waste):

- Impermeable natural soil basal structure
- Impermeable artificial basal structure
- Progressive rehabilitation

- Temporary covers
- Impermeable and low-flux dry covers
- Oxygen consuming dry covers
- Free water covers
- Wet covers

4.6.10 Prevention or Minimisation of Self-ignition of Extractive Waste

In order to help ensure the chemical stability of extractive waste, BAT is to reduce the combustible matter content, to compact the extractive waste using appropriate mechanical equipment and/or to carry out landscaping and geomorphic reclamation (MWEI BREF).

4.6.11 Reduction of Dangerous Substances in Extractive Waste

Measures for reduction of dangerous substances in extractive waste might refer to the reduction of the cyanide concentration in ponds or to the reduction of hydrocarbon concentrations in drilling extractive wastes (MWEI BREF).

4.6.12 Minimisation of Groundwater Status Deterioration and Soil Pollution

In order to prevent or minimise groundwater status deterioration and soil pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF, amended by the authors):

Basal structures and physical barriers

- Impermeable natural soil basal structure - Relevant for ponds, dams and heaps Relevant for non-inert extractive waste
- Impermeable artificial basal structure - Relevant for ponds, dams and heaps Relevant for non-inert extractive waste
- Seepage barriers - Relevant for ponds, dams and heaps Relevant for non-inert extractive waste
- Lining the surface for temporary storage of drilling muds and other extractive wastes - Relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water
- Temporary storage of drilling muds and other extractive wastes in containers /tanks - Relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.

Water streams management

- Diversion of water run-off systems
- Drainage systems for ponds and dams
- Drainage systems for heaps

- Landscaping and geomorphic reclamation

Covering

- Progressive rehabilitation - Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back
- Temporary covers - Relevant for ponds, dams and heaps, for excavation voids where extractive waste is placed back and for temporary storage
- Vegetative covers - Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back
- Permanent dry covers
    - Permeable dry covers - Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back, Relevant for covering non-hazardous extractive waste
    - Impermeable and low-flux dry covers - Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back, Relevant for covering non-inert extractive waste
    - Reactive covers - Relevant for ponds, dams and heaps
    - Oxygen-consuming dry covers - Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back, Relevant for covering PAG extractive waste
- Permanent wet covers
    - Free water covers - Relevant for ponds and dams and for excavation voids where extractive waste is placed back, Relevant for covering PAG extractive waste
    - Wet covers - Relevant for ponds and dams and for excavation voids where extractive waste is placed back, Relevant for covering low-PAG extractive waste or low paste PAG extractive waste

4.6.13 Closure of Tailings Management Facilities

General considerations

TMF rehabilitation is a challenge during the whole mine closure process, as the fine sediments are not always settled after the mine due to strong pore water pressure. In most cases, tailings consist of fine-grained material (a few micrometres to sand grain size) that has been disposed of in slurry form above ground. For tailings dams, the standard engineering aspects (dam stability, water diversion) as well as chemical aspects have to be considered. Figure 49 shows a typical TMF to be closed.

The planning of tailings dams is carried out according to the recommendations of the International Commission on Large Dams (ICOLD) that issues the bulletin on dam safety management. ICOLD is an international non-governmental organization aiming to the sharing of professional information and knowledge of the design, construction, maintenance, and effects of large dams (any dam above 15 m in height), and leads in setting standards and guidelines to ensure that dams are built and operated, having presently 30 Technical Committees. ICOLD Technical Committees are issuing bulletins, that are a “state of the art” with recommendations for engineers for ensuring geotechnical and environmental long-term stability, also for tailings pond dams (Bowles et al. 2007). Depending on the dimension of the mining site and extension of the processing activities, TMFs can reach a dimension of up to several hectares and a thickness of several tens of meters. They contain the processing sludge that is undergoing sedimentation and thus get separated into a solid and a liquid phase, which is called pore water or interstice water and, usually, polluted through processing residues.

From geotechnical point of view, the dam structure of the ponds needs to be assessed as well as the function of water diversion channels, which might be dilapidated after decades. From the knowledge of the current state remedial options can be elaborated. The following general remedial options for tailings ponds are:

- In-situ rehabilitation: Dams need to be stabilized to withstand all hydraulic or seismic conditions. A proper water discharge has to be installed. After dewatering a properly engineered cover has to be installed onto the tailings.
- Offsite rehabilitation: This option includes the excavation of tailings, dams and contaminated ground. The material must be transported to a suitable site and installed there. At the storage site the same measures are necessary as needed for in-situ rehabilitation.

Figure 50 shows a typical TMF to be closed, a sample of a copper mining site in Bulgaria.

Figure 50: Typical TMF to be closed; sample of a copper mining site in Bulgaria

Usually, before any closure activities can start, the tailings body must be consolidated and dewatered to ensure geotechnical stability.

Geotechnical stabilisation – Dewatering

To ensure long term safety of tailings ponds, a methodology using verticals drains has been developed. It is usually necessary to be applied before the establishment of dry covers in case the settling process of the tailings is not finalised. In most instances, the first step in the reclamation of TMFs is to drain the pore water from the tailings and to cover the waste and tailings storage facilities. Polluted pore water is treated in a waste water treatment plant. Figure 51 provides an overview on an active tailings pond, and a tailings pond under forced consolidation through subaquatic fill of extractive waste through hopper barge. Figure 52 illustrates the application of vertical drains through drilling and the TMF stabilisation through geogrid, underlain by geofabric and drain mats.

Figure 51: Overview on active tailings pond (left); tailings pond under forced consolidation through subaquatic fill of extractive waste through hopper barge (right)

Figure 52: Application of vertical drains through drilling (left); TMF stabilisation: geogrid, underlain by geofabric and drain mats (right)

TMF Covering

After geotechnical stabilisation of the tailings material, the tailings pond can be covered. In terms of in-situ rehabilitation, and according to MWEI BREF, permanent wet or dry covers can be applied. A dry cover is a cap-and-cover solution to cover extractive waste with a single soil layer or a layered structure of numerous soils, natural and/or artificial materials (such as geosynthetics). A wet layer is a permanent water cap. The applicable covers according to MWEI BREF are given below:

Permeable dry covers: consists of covering the extractive waste with a single layer or multiple layers of soil or equivalent materials permeable to water and oxygen, while ensuring that the use of such a layer or layers does not lead to any additional adverse environmental or human health impacts (MWEI BREF).

Impermeable and low-flux dry covers: consist of covering the extractive waste with multiple functional layers in order to inhibit the oxygen influx, to limit the meteoric water infiltration, and the degassing of pollutants like radon (in case of uranium mining) (MWEI BREF, amended by the authors). This type of covers includes mineral sealing layers, geomembranes, bentonite mats, and asphalt (Kudla et al. 2009) sealing layers. Recent investigations underline that the only sealing systems that impermeable for (radioactive) gas convection are quality assured systems with geomembranes or bitumen, respectively asphalt.

Oxygen-consuming dry covers: consists of using organic materials for covering PAG extractive waste to consume oxygen and reduce its infiltration (MWEI BREF).

Free water covers: is a closure method where extractive waste is covered by a free water layer in order to isolate contaminants and reduce erosion, dusting and oxygen infiltration (MWEI BREF).

Wet covers: consist of allowing water to infiltrate the extractive waste, thus forming a wet cap on the top, and adding organic matter, to enhance the establishment of wetland vegetation in the pond (MWEI BREF).

4.6.14 Closure and Covering of Waste Rock Heaps

The rehabilitation approach of waste rock heaps depends on the pollution potential. While sites with lower pollutant potential are often not surface sealed (Ludwig et al, 2003) and, as a preferred solution, are often left to be rehabilitated by natural plant succession (Sweigard et al. 2017), waste rock heaps with higher pollutant potential or in close proximity to protected areas usually need to be covered (Sweigard et al. 2017). A further after-use for biomass production might also be taken into consideration for sites with a small pollution potential that are left to natural plant succession (Bungart et al. 2000). For sites that require a mineral sealing, this sealing may involve a hydraulic barrier (mineral sealing layer with a permeability coefficient of $< 1 \times 10^{-9}$ m/s and a thickness of about 50 cm), or pure mineral layers, which form a gas and dust barrier and serve as root space for plants. A special solution for waste rock hepas with a very high pollutant potential can be reactive horizontal barriers (Schneider et al. 2002).

Waste rock hepas often consist of a plateau area (close to a shaft or adit) and a slope area with the natural angle of repose. Geomechanical risks may occur if such heaps slopes are located very close to residential areas which might be affected by e.g. rockfall. However, in the most cases mine waste heaps are relatively stable objects consisting of coarse material. From a radiological point of view waste rock dumps pose only in rare cases a risk to human. Independent of the risks, the general remedial options for waste rock heaps are:

- Fencing areas in and warning signs
- In-situ rehabilitation with sub-options such as:
    - Local measures against rockfall

- Local geomechanical strengthening of the waste rock heap
- Local measures against water erosion
- Reshaping/flattening parts of the waste rock heap
- Covering the waste rock heap

- Relocation of waste rock to a more appropriate area and potentially covering of the new disposal site

- Covering: typically, permeable dry covers, Impermeable and low-flux dry covers, or Oxygen-consuming dry covers (MWEI BREF) are designed, depending on the extractive waste type and its hazard potential. Often mineral sealing layers are applied, sometimes in combination with geomembranes.

Figure 53 Illustrates a mineral sealing layer on waste rock heaps, and the concept of a reactive horizontal barriers (Schneider et al. 2002). Reactive barriers might be also used for the closure of PAG waste heaps.

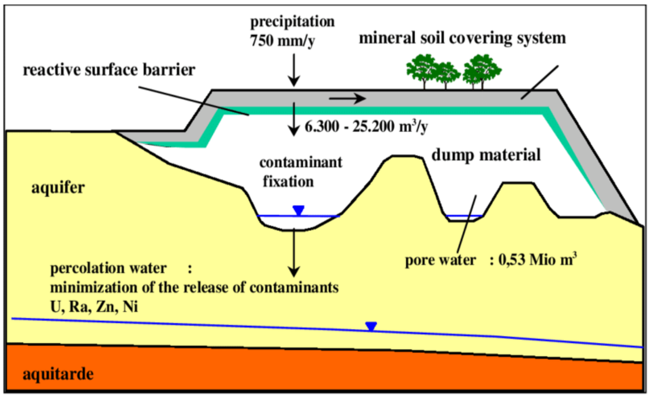


Figure 53: Mineral sealing layer on waste rock heaps (figure source: Wismut GmbH, left) and a reactive horizontal barriers (right, Schneider et al. 2002)

Further new developments in terms of base and surface sealing elements include Tektoseal, a reactive lining system that is amended with active geo-composites like sodium bentonite granules or active coal.

4.6.15 Groundwater and Soil Pollution Remediation

In order to minimise groundwater status deterioration and soil pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF, amended by the authors):

- Permeable Reactive Barriers (PRBs) - Relevant for PAG extractive waste or for extractive waste with metal leaching potential

- Funnel and Gate - Relevant for PAG extractive waste or for extractive waste with metal leaching potential

- Phyto-Technologies - Relevant for PAG extractive waste or for extractive waste with metal leaching potential

- In-situ Chemical Oxidation (ISCO) - Relevant for PAG extractive waste or for extractive waste with metal leaching potential
- In-situ Chemical Reduction (ISCR) - Relevant for PAG extractive waste or for extractive waste with metal leaching potential
- Anoxic Limestone Drains / Reducing and Alkalinity Producing Systems (RAPS) in shafts and adits - Relevant for PAG extractive waste or for extractive waste with metal leaching potential
- Bioscreens, Bioventing, Biosparging - Relevant for PAG extractive waste or for extractive waste with metal leaching potential

4.6.16 Surface Water Pollution Remediation

In order to prevent or minimise surface water status deterioration, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF, amended by the authors):

- Oxidation-based systems
  - Aeration and active chemical oxidation - Relevant for Extractive Waste Influenced Water (EWIW) containing Total Dissolved Substances (TDS)
  - Active aerobic biological oxidation - Relevant for EWIW containing biologically oxidisable TDS
  - Aerobic wetlands - Relevant for EWIW containing TDS
- Reduction-based systems using bacterial activity
  - Anaerobic wetlands - Relevant for EWIW containing TDS, particularly relevant for treating ARD
  - Anoxic BioChemical Reactors (BCRs) - Relevant for EWIW containing TDS, particularly relevant for treating ARD
- Chemical precipitation
  - Hydroxide and carbonate precipitation - Relevant for EWIW containing TDS, particularly relevant for EWIW containing dissolved metals
  - Sulphide precipitation - Relevant for EWIW containing TDS, particularly relevant for EWIW containing dissolved metals
- Co-Precipitation
  - Co-precipitation with chloride or sulphate metal salts - Relevant for EWIW containing TDS, particularly relevant for EWIW containing radium-226
- Adsorption
  - Adsorption - Relevant for EWIW containing TDS
- Ion exchange
  - Ion exchange - Relevant for EWIW containing TDS
- Filtration of dissolved substances

  - Nanofiltration - Relevant for EWIW containing TDS
  - Reverse Osmosis - Relevant for EWIW containing TDS
  - Membrane Biorector (MBR) - Relevant for EWIW containing TDS
- Neutralisation of EWIW prior to discharge - Active treatment
  - Active neutralisation - Relevant for acidic or alkaline EWIW
- Neutralisation of EWIW prior to discharge - Passive treatment
  - Oxic Limestone Drains (OLDs)/Open Limestone Channels (OLCs) - Relevant for acidic EWIW
  - Anoxic Limestone Drains (ALDs) - Relevant for acidic EWIW
  - Successive Alkalinity-Producing Systems (SAPS) - Relevant for acidic EWIW
  - Anaerobic wetlands - Relevant for acidic or alkaline EWIW

4.6.17 Prevention or Minimisation of Dusting of Extractive Waste

In order to prevent or minimise air pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list (MWEI BREF):

- Water or water-based solutions spraying - Relevant for exposed surfaces of extractive waste
- Wind protection systems - Relevant for exposed surfaces of extractive waste
- Landscaping and geomorphic reclamation - Relevant for exposed surfaces, relevant for NAG extractive waste
- Progressive rehabilitation - Relevant for exposed surfaces
- Temporary covers - Relevant for exposed surfaces
- Vegetative covers - Relevant for exposed surfaces
- Permanent wet covers - Relevant for exposed surfaces

4.6.18 Decommissioning of Buildings and Processing Plant Areas

Remedial options for the buildings and areas comprise the following options:

- Fencing the buildings or processing areas in and install warning signs
- In-situ rehabilitation with demolition of the buildings and local disposal of the debris
- Offsite rehabilitation with demolition of the buildings and transport of debris to a proper disposal site.

The second and third options comprise only demolition of buildings, surface structures, pipes and cables that are dangerous to human health and safety. All buildings and surface facilities and structures are to be demolished and crushed to pieces of a size of no more than 30 cm. Demolishing is usually done using excavators with a grab and picker arm or similar grabbing/picking devices.

Demolition debris may comprise scrap metal (steel), plastic, wood, pipes, cables, organic contamination (oil, etc.). Uncontaminated materials and contaminated materials and wastes should be separated as far as possible and reasonable applicable, to reduce the amount of wastes for disposal. Scrap metal is cut into proper pieces for transport. The contamination of steel and other scrap metal should be measured in order to decide about the disposal procedure. Clean metal may be released while contaminated metals need to be buried in a disposal cell. Contaminated scrap metal should be cut and disposed in disposal cells which shall be filled with concrete to fix the metal. This allows a safe and stable disposal and also reduces the risk of looting by scavengers.

If needed, excavation holes or underground cavities (cellars, basements, bunkers) need to be back-filled in order to avoid unacceptable danger to the public as part of the following site rehabilitation. Figure 54 illustrates typical mining facilities structures to be demolished.

Figure 54: Typical mining facilities structures to be demolished

4.6.19 Water Management and Treatment

The term mine water describes all water that circulates in the mine, comes into contact with the underground or open pit host rocks or raw material. It does not include the processing water, and it is not necessarily polluted. Water management activities during the extraction process include groundwater and mine water management, the operation of water supply and disposal, disposal of liquid processing residues in tailings dams and mine flooding protection (Schneider & Wolkersorfer, 2021). These facilities must be closed as well. Furthermore, flood protection measures must be planned for all mining facilities.

Usually, mine water with the highest environmental relevance is Acid Mine Drainage (AMD), which is mine water with a pH below 5.6 (Younger & Wolkersdorfer, 2004; Wolkersdorfer, 2008). It forms when iron (di)-sulphides in the rock are oxidized and not enough buffering minerals exist. The acidic environment in the mine water provides optimal conditions for the solution of metals and metalloids from the surrounding rock. As a result, acid mine water is usually highly mineralized (Younger & Wolkersdorfer, 2004; Wolkersdorfer, 2008). If it is not treated and is not prevented from spreading large amounts of acid mine water can into nearby rivers or pollute the groundwater. Both, the extracted pore water and the supernatant water do usually need treatment.

Approaches used entail mechanical, chemical, or biological methods or a combination of these (Johnson & Hallberg, 2005; Trembley & Hogan, 2000). Due to the site size and the lengthy time required for the mine water treatment, the extractive industry often employs passive water treatment methods which are based on a combination of aeration and biological treatment (e.g. with microorganisms (Neculita et al. 2007; Gazea et al. 1996; Baker & Banfield, 2003, Kleinmann et al. 1981; Trembley & Hogan, 2000; Martinez et al. 2019). These mine water treatment methods are designed to occur in open basins (e.g., constructed wetlands) and are located at the bottom of the mine water outlet (Younger & Wolkersdorfer, 2004; Wolkersdorfer, 2008). Further chemical treatment options for metals include the use of reactive materials (Schneider et al. 2001).

4.6.20 Ensuring Long Term Geotechnical Stability

The priority of all closure methods is to ensure geotechnical stability, in particular the closure of the tailings ponds, shafts and open-cast mines. Most of these closure methods are combined with other geotechnical stabilization methods as well as geotechnical monitoring to ensure long term safety of the site.

4.6.21 Ensuring Long Term Environmental Safety

AMD represents a major challenge in mining practice, because 1) it is heavily polluted and 2) there are mining sites where it is produced in large quantities (Schneider & Wolkersorfer, 2021). A classic method for treating AMD is liming (i.e., neutralization by means of calcium carbonate, calcium oxide, calcium hydroxide or sodium hydroxide). This method of treatment results in potentially dangerous residues that must be disposed of appropriately.

4.7 Closure of Energy Minerals Mining Sites

4.7.1 Overview

Energy minerals mining comprises lignite, hard coal, hydrocarbons and uranium. Uranium ore mining and closure is not separately discussed in this section as uranium in terms of material is a metals, and thus operated and closed like metal mines. The closure technology for uranium mines can be seen from section 4.3. The focus in the present section is on lignite and hard coal mining as well as hydrocarbon extraction, respectively their closure. The majority of solid energy minerals is mined in open cast mines: lignite and hard coal. The open cast mine is a substantial impact on nature: a huge hole is created, which continues to move as it is mined (figure 55). The resulting pit is usually only as large as the so-called deficit, the amount of brown coal that was excavated. The remaining holes are prepared accordingly for flooding: Since a steep front would always break open, the embankments are to be flattened.

Figure 55: Open cast lignite mining: in operation (left); in closure through open pit flooding (right)

The impact on the environment in open-cast mining is mainly determined by the high land use. Further environmental impacts are the lowering of groundwater and the development of dust. In civil engineering, the main effects are the mining damage caused by subsidence. These consist of damage to buildings in built-up areas and the need to mount the flowing water to ensure the flow. Furthermore, areas for heaps and day facilities are used during the operating time of a mine.

Hard coal mining takes usually place underground. Access to the miners' underground workplace is through the shaft, like in ore mining. In it, a conveyor basket transports people and materials. The individual shafts are connected to each other by routes that also allow access to the individual mining areas. The actual mining of hard coal takes place today with modern conveyors in the longwall, where the coal is extracted from the seam that is the coal layer that lies between layers of rock. The environmental impact of hard coal mining can be divided into two groups: land use and mining damage.

4.7.2 Particular Challenges at Energy Minerals Mining Sites

Most lignite mining sites that require landscape rehabilitation are large as open cast mines consume huge regions of land including the existing land use like settlements. The challenge in closing open cast mines of lignite mining are the size, and the needed material volumes. Another challenge is the special planning particularly for the after-closure period. As hard coal mining often takes place underground, the landscaping issues are not that pressing. However, there are challenges in terms of the closure of the underground structure that are comparable to re mining sites. Coal mining sites are usually decades in operation, and further decades are needed to close them. This situation causes socio-economic challenges to the regions that must be considered in the closure approach. Both, lignite and hard coal mining sites are prone to AMD generation and often need mine water treatment. As lignite mining takes place in coarse rocks, it is often subject to land subsidence. Hard coal mining mainly takes place underground, so stability problems do not happen with a priority like in lignite mining.

Particular challenges exist also with the other energy minerals mining sites. As uranium is a radioactive element, uranium mining requires particular radiation protection measures, not only during the operation but during the closure and rehabilitation of the site as well. For that reason, a radioactive pollution potential of rock heaps and tailings ponds of uranium mining requires particular radiation protection measures in terms of water and gas migration path. But not only uranium mining can cause radiation hazards. Also hydrocarbon mining, particularly oil exploration and production, often produces radioactive residues. These materials are considered as NORM waste and must be treated accordingly (Doyi et al. 2016).

4.7.3 Closure of Open Cast Mines

Usually, the use of the area for mining has had a substantial effect on the regional water balance system, as water regulating vegetation may have been removed and natural watersheds drained. The stage of mine closure and rehabilitation provides an opportunity to restore ecosystems and aquifers (Heikkinen et al. 2008; McHaina, 2001; McKenna, 2002; Slingerland & Wilson, 2015; Sheoran et al. 2010), though rehabilitation of most mining sites requires decades of restoration work (Slingerland & Wilson, 2015; Sheoran et al. 2010). For that reason, large scale soil stabilisation activities are necessary before closure can take place. Open pits, particularly those resulting from lignite mining, due to their size and the missing material volume, often will be flooded (Best practice). In the frame of mining site rehabilitation, flooding refers to the cut-off of the drainage systems in order to allow the natural surface and ground water to enter the mine (Melchers et al. 2019). Closure of open cast lignite mines means in particular to solve the following tasks:

- Stable design of the remaining embankments and provision for the necessary load-bearing capacity of the tipping surfaces,
- development of water management conditions, that is design and construction of water transporting systems like water diversion channels, siphon pipes, groundwater pumping systems etc.
- Optimization of the water-land distribution in the area to be redeveloped, including upgrading of already recultivated areas,
- Creation of conditions for the assigned after use including integration of the post-mining landscape into the surrounding landscape as well as conservation of habitats for endangered animal and plant species,
- Treatment / disposal of potentially contaminated areas.

Figure 56 shows the main reclamation steps of open cast energy minerals mining sites according to Tudeshki & Pielow (2018). The details of the main steps are explained in the following figures.

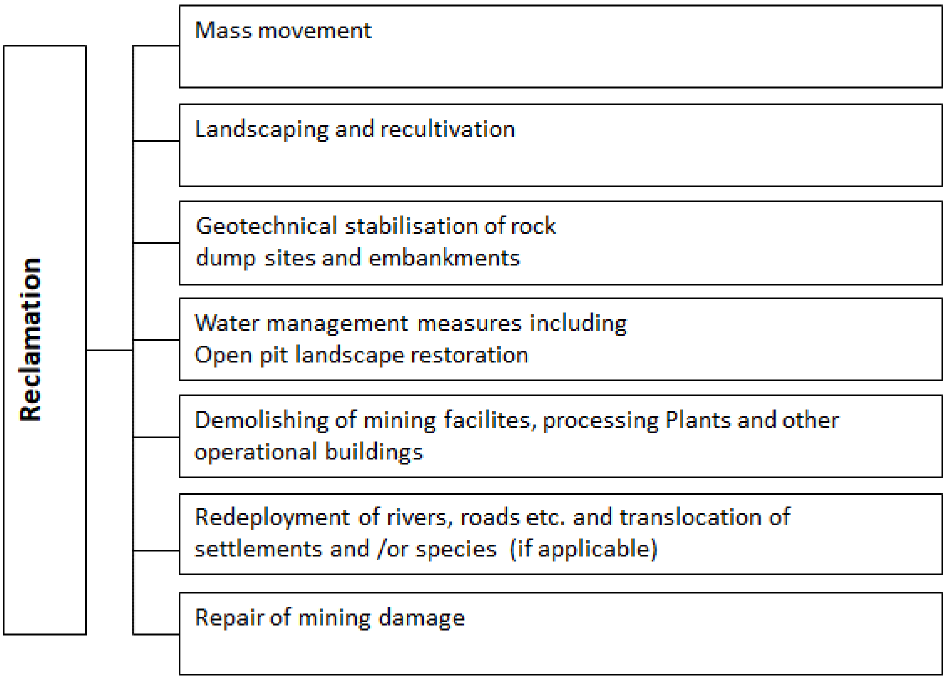


Figure 56: Main reclamation steps steps of open cast energy minerals mining sites according to Tudeshki & Pielow (2018), amended and modified by the authors

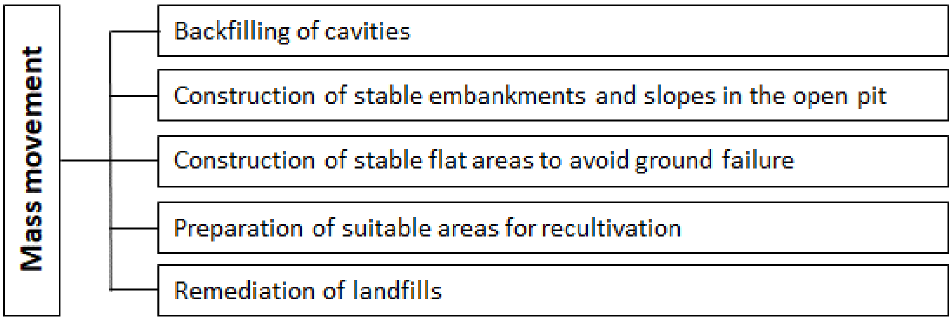


Figure 57: Activities in terms of mass movement in open cast lignite mine closure (Tudeshki & Pielow, 2018)

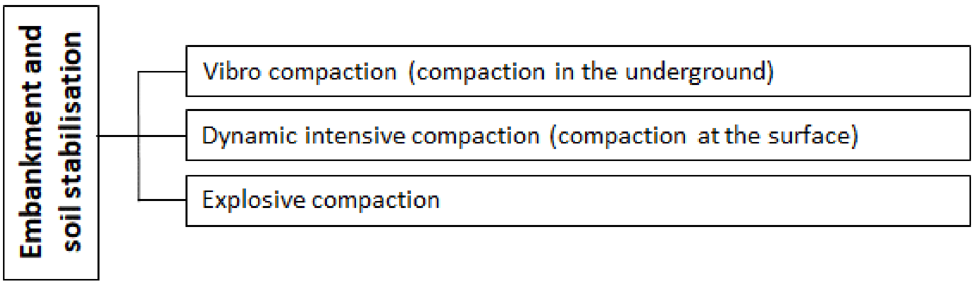


Figure 58: Activities in terms of embankment and soil stabilisation in open cast lignite mine closure (Tudeshki & Pielow, 2018; amended by the authors)

Lignite mining leaves behind ecotopes that can be described as extreme locations for physical soil, chemical and biotic reasons. With the design of the post-mining landscape, the prerequisites for diverse and ecologically stable areas of life must be created. The newly created landscape elements (e.g. lakes, ponds, shallow water areas, ditches, vestibules, meadows, fields, forests and forest fringes) significantly improve the level of equipment in the redevelopment area. Reclamation takes place on the former tipping areas, the deposited and compacted waste rock.

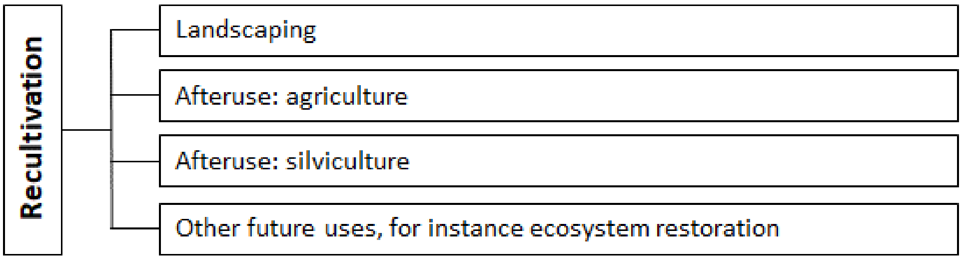


Figure 59: Activities in terms of embankment and soil stabilisation in open cast lignite mine closure (Tudeshki & Pielow, 2018; amended by the authors)

Mine flooding is a rehabilitation activity that can take several years or even decades. Large volumes of water are necessary that would then be unavailable for other purposes during the flooding period (Figure 60). Flooding measures are closely connected to other geotechnical measures that are necessary (e.g. the stabilisation of the embankments of the future lakes). In addition, a chemical stabilisation might be required in case AMD is generated during the flooding process (Johnson & Hallberg, 2005).

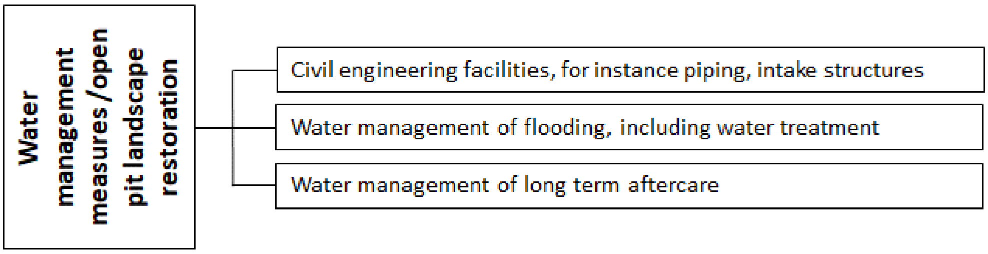


Figure 60: Activities in terms of water management measures including open pit landscape restoration (Tudeshki & Pielow, 2018; amended by the authors)

The process of demolishing of mining facilities, processing plants and other operational buildings includes facilities and equipment in the open cast mine as well as facilities and infrastructure outside the open pit.

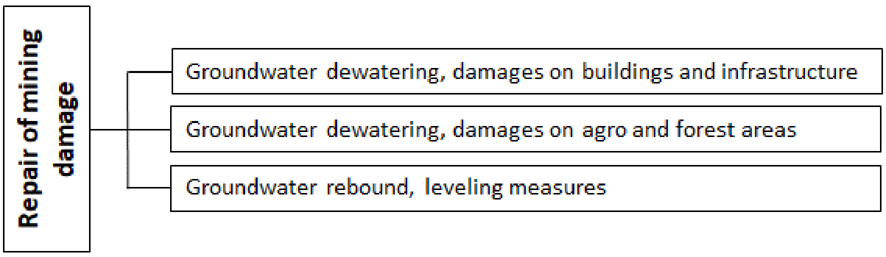


Figure 61: Activities in terms of repair of mining damage (Tudeshki & Pielow, 2018)

4.7.4 Closure of Underground Mines

Technically speaking, the closure of underground mines for energy mineral resources is practised like for ore mines, as describes in section 4.3.3.

4.7.5 Water Management

In addition to damaging nature and the landscape, lignite open cast mining often affects both, water quantity and quality in the catchment area (Schneider & Wolkersdorfer, 2021). Water resources are subject to competing usage claims as a result of mining activities. Strict control on the amount of water withdrawn for mining should be enforced by a water management authority.

Lignite extraction has had a particularly profound and lasting impact on the region's water balance. To extract almost up to 190 million tons of brown coal per year in Lusatia, for example, around 1.2 billion cubic meters of water had to be lifted at the same time. As a result, a billions of groundwater deficit had arisen up to 1990, whereby the groundwater was partially lowered to a depth of 100 meters. Mine closure is assigned to close such deficits. Technical means are groundwater retention, pumping systems, vacuum systems and connecting pipes. In case of groundwater leakage, a retaining wall might be necessary to ensure the groundwater level on a regional scale. Figure 63 shows a groundwater retention wall and the sealing wall cutter its construction.

Water management during closure and rehabilitation work in lignite open cast mining typically requires groundwater retention as well as the construction of water diversion channels. This is especially the case when several mines on a mining site are undergoing rehabilitation at the same time, as in the case of the “Lusatian Lakeland” in Germany. In this area, water was diverted to flood open-cast mines, developing them as lakes into a tourist area. The diversion channels used to flood the mines were also used to support recreational use of small boats by tourists (Lintz et al. 2012).

Figure 62 shows common water management practices: the flooding of a former open cast lignite mine, the construction of water diversion channels, the construction of water level regulation facilities, and mine water management by water keeping through a retaining wall. In the direct open-cast mine area, the natural geological structure is irretrievably devastated. This might lead to a "hydraulic short circuit", which means that pollutants can spread unhindered from previously existing protective separating layers to great depths. The drainage of the deep aquifers also creates a new pressure distribution: If balanced pressure conditions prevailed between the groundwater levels before the large swamps were set in, a pressure difference now arises. This leads to an extensive leakage of the clay horizons from the upper aquifers.

Figure 62: Water management practices: flooding of a former open cast lignite mine (above left), construction of water diversion channels (above right), construction of water level regulation facilities (down left), mine water management, water is kept through a retaining wall (down right)

On the one hand, this so-called leakage effect in the upper groundwater aquifer reduces the groundwater supply, on the other hand, near-surface groundwater contaminated with other pollutants (for instance from agriculture) can now penetrate into the next lower aquifers. With the high pressure differences (greater than 20 meters) between the aquifers, there are also serious water losses due to infiltration into deeper groundwater levels. Leakage can be avoided through sealing with a groundwater retention wall (figure 63). Further, the lowering of the groundwater level in the built-up areas will be necessary if the buildings shall not be removed from the revitalisation area. This can only be achieved by continuing the groundwater management on the long term.

Figure 63: Water management practices: groundwater retention wall (left); sealing wall cutter for construction of a groundwater retention wall (right)

Figure 64: Water management practices: groundwater management (left); cascade outflow of siphon pipe for water level controlling (right)

A groundwater quality deterioration results often from the overburden dumps. With the destruction of the natural layer sequence by the open-cast mine, sulphides bound in the soil reach the surface. If these easily releasable sulphur compounds react with oxygen and if the tip of the waste heap body is flooded with rising groundwater, a constant stream of pollutants flows into the underground. Various measures were examined to minimize the discharge of material from the inner tip. These range from "tipping management", i.e tipping of the acid-sensitive masses, preferably with the exclusion of oxygen, to the addition of power plant ash and lime as an acid buffer. Ultimately, these measures could only reduce pyrite weathering by around four percent in absolute terms. A relative minimization of the acidification of the groundwater by a maximum of one third can be achieved, which means that two thirds of the acidification potential remains.

Water management and ecological problems after the open pit closure do not only result from acidification. There might be also problem resulting from deposited power plant ash containing concentrated heavy metals. There is therefore a risk that these pollutants will be released as the groundwater slowly rises again. Therefore, water treatment might be necessary. Water treatment methods may comprise flooding water management, mine water treatment by active or passive treatment methods, inlake treatment (liming of the flooding lake), groundwater treatment by active or passive treatment methods and/or a conditioning of the waste rock tipping. Respective methodologies are provided in the MWEI BREF, and comprise pump and treat (if necessary biologically supported), that means active groundwater treatment, or reactive walls / funnel and gate, that means passive treatment. Active and passive treatment methodologies might be also applied for polluted surface water. The respective treatment methods are conventional waste water treatment, preferably through active carbon, or passive treatment through biologically activated wetlands or Reducing and Alkalinity Producing Systems (RAPS/SAPS), that might be designed as open limestone cascades (Trembley & Hogan, 2000).

4.7.6 Ensuring Long Term Geotechnical Stability

With coal extraction, a large amount of waste is extracted and tipped, starting from the heap and later into the carburized hollow form of the open-cast mine. The extraction and transport technology of the clearing masses has a decisive influence on their soil physical properties. Depending on the technologies used, overburden conveyor tipping, skip tipping and in some cases directly tilted masses are created (Geß, 2009). With the individual technologies, differently mixed soils are created, which differ according to their geological origin in the cinderial ratio.

The main difference between the tipping floors and the grown mountains is their loose storage and the associated high deformation potential. The deformation is determined by grain composition and water content of the soil (Geß, 2009). Different deformation potentials occur in the individual tipping areas, which are subdivided into self-settling (by compressibility of the loosely poured debris), sagging (occur due to the rise or fluctuations in groundwater in the waste rock heap or through seepage and infiltration of precipitation), and loading (caused by the weight of a building). The deformation behaviour of the tipper dumps is influenced by the position to the edges of the tipper. A distinction is made between open pit embankment areas with the technologically determined edge hoses, inner tipping areas, tipping edge areas and tipping embankments. The embankment and edge areas are particularly critical here, since considerable settlement differences can occur at short distances (Geß, 2009).

A wide variety of methods can be used to control the effects of the high settlement and movement potential on lignite dumps, which differ in their mode of action. These include methods for increasing the rigidity of the floors, reducing subsidence through stress redistribution or technical solutions on the planned building and foundation (Geß, 2009). The following methods can be used to increase stability: preloading, vertical drainage under preload in water saturated areas, material exchange, embankment stabilisation through compaction (vibro compaction, dynamic intensive compaction, explosive compaction, falling weight compaction), and solidification injections.

Methods to ensure stress redistribution are geogrids and tensile geotextiles, reinforcements or improved floor plates. Figure 65 illustrates technical solutions to ensure geotechnical stability in lignite mine closure.

Figure 65: Ensuring geotechnical stability in lignite mine closure: slope stabilisation of former open cast that is under flooding (above left), profiling of slopes (above right); stabilisation of underground instability of coarse rock through injection (down left), vibro compaction for ensuring ground stability (down right)

Further, bioengineering approaches are applied for erosion protection and stabilisation of embankments. Bioengineering methods are an effective method of sustainable and nature-near hydraulic engineering. They have their origin in protective water engineering and are used as handicraft techniques for securing water banks and embankments. In mine closure, for example, live fascines on bush layers, spreaders with live fascines for embankment protection as foot protection, and live fascines in combination with protection mats made of natural fibre fabric can be used. Important is also to ensure a long term stable vegetation on long term stable embankments. Bioengineering is a method to use biological methods to a) ensure geotechnical stabilization and b) greening through ecologically stable vegetation that ensures further a sound water balance as well as an ecological balance that is in line with the ecological setting of the region. Figure 66 illustrates ecological engineering stabilisation and erosion protection for water related structures, figure 67 for earth structures. Feasible types of live stakes are for instance Black Willow (Salix nigra), Silky Dogwood (Cornus amomum), Interior Willow (Salix longifolia), Pussy Willow (Salix discolor), Streamco Willow (Salix coltetti), Arrowwood (Viburnum dentatum), Buttonbush (Cephalanthus occidentalis).

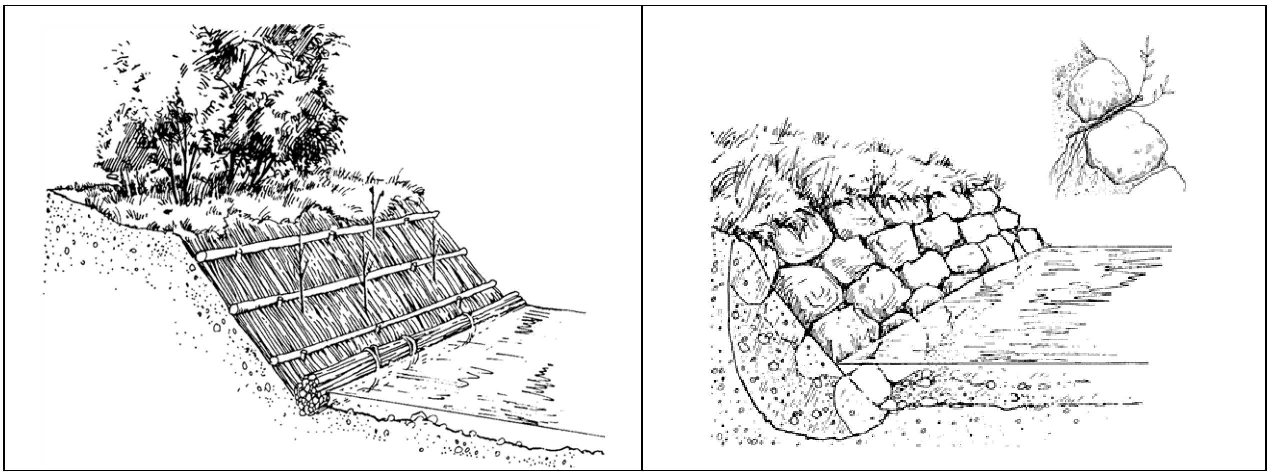


Figure 66: Ensuring geotechnical stability in lignite mine closure: bioengineering stabilisation and erosion protection for water related structures, here: spreaders with live fascines for embankment protection (left); use of water engineering rocks from natural material combined with live stakes for stabilisation and greening (right)

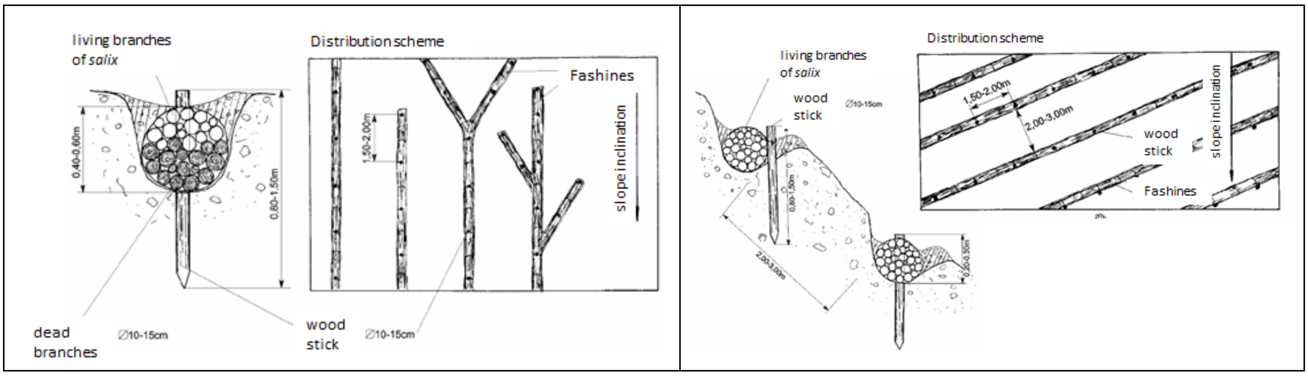


Figure 67: Ensuring geotechnical stability in lignite mine closure: bioengineering stabilisation and erosion protection for earth structures, here: Living branches of Salix are arranged as fascines for slope stabilisation with drainage function.

If the areas for forestry were left to their own devices, a distinction must be made as to whether there are tertiary acid soils or pleistocene soils. A colonization of tertiary soils by plants can take many decades due to the sometimes extremely low pH values. If forest areas are to be established, these soils must be thoroughly limed beforehand, in particular to ensure the ecological stability of the stands. Mining areas to be closed can also be left to natural succession. Figures 68 and 69 illustrate bioengineering measures for ensuring geotechnical stability in lignite mine closure, particularly for stabilisation and erosion protection of embankments. Bioengineering methods are very effective in open cast lignite mining closure as the areas are that huge and conventional technological methodologies are very costly. Planting of trees will further contribute to the long term stability. Suitable plants that are naturally occurring in the rehabilitation region support the reclamation process. To select feasible plants information on the naturally occurring vegetation should be collected. Preferably local seeding material should be used as this seeding material is adapted to the local climate.

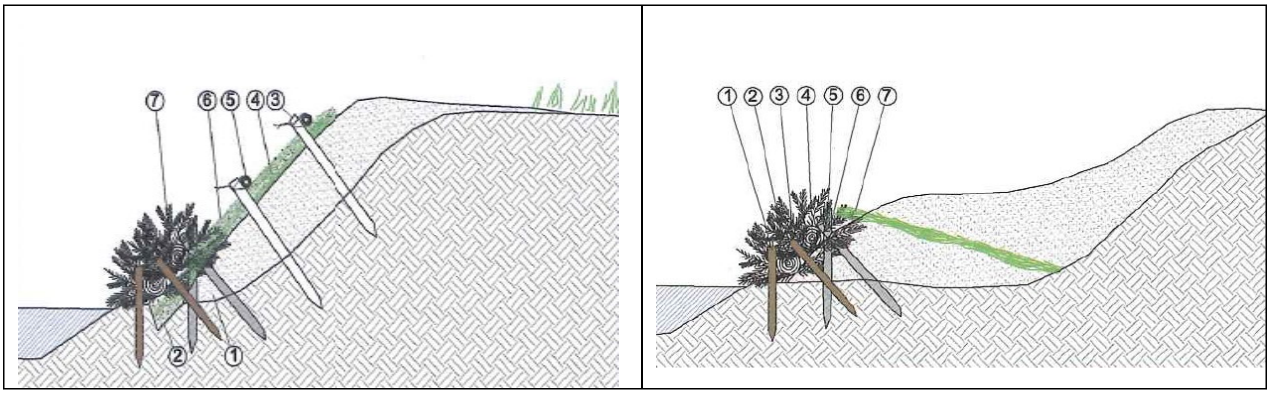


Figure 68: Ensuring geotechnical stability through ecological engineering (Dittrich & Stowasser, 2010)

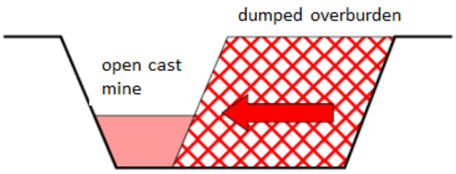
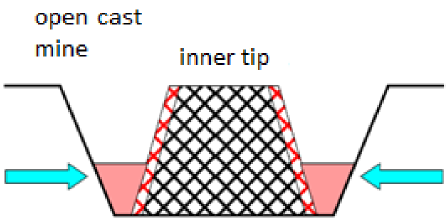
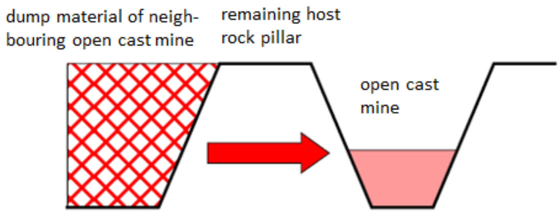
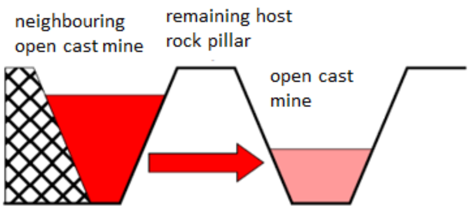
Figure 68 provides a schematic diagram of willow spreader layer with pruning trees as slope protection (left): (1) soil placed back, (2) trench below the low level water line, (3) wooden sticks for stabilization of the spreader layer, (4) expansive willow branches, (5) transom for fastening the willow branches on the embankment, (6) over-grounding of the willow tree (max. 2 to 3 cm), (7) embankment foot protection by two layers of pruning trees. Schematic diagram of bush layer with pruning trees as foot protection (right): (1) pilot pole, (2) first layer of pruning trees, (3) pliers for fastening the first layer of pruning trees, (4) second layer of pruning trees, (5+ 6) viable pastures for fastening the second Location of pruning trees, (7) bush location for rooting the poured earth.

Figure 69: Ecological engineering stabilisation and erosion protection of opencast lignite mining, here: slopes of flooded mine (left); planting of trees for reclamation and erosion protection purposes (right)

4.7.7 Ensuring Long Term Environmental Safety

The main thread to long term environmental safety in lignite mining closure is acidification. Rehabilitation of AMD forms a challenge due to the large volumes, several types of origin of acidification, as well as the different flow paths to arrive in the open cast mine (table 9). Depending on the geological setting must be designed the closure strategy, that may include retention walls, water diversion channels (in combination with RAPS if applicable), as well as groundwater extraction well galleries. Often a subsequent AMD treatment is needed that might comprise inlake liming, geochemical barriers or water extraction. Up to now doesn't exist a feasible solution for a circular use of AMD.

Table 9: Typing of acidic open-cast ponds according to the origin of the acidification (Nixdorf et al., 2000)

Type of open cast mine acidification	**Origin of acidification**	**Dominating process**
	autochthone	Exfiltration of pore water from the deposited overburden
	autochthone	Leaching of the slopes of the deposited overburden
	allochthone	Overflow of pore water from the deposited overburden from neighbouring open cast mines
	allochthone	Overflow of water from the neighbouring open cast mines

4.7.8 Closure of Hydrocarbon Boreholes

Oil and gas are explored and extracted through boreholes / drilling (figure 70). Up to a vertical depth of 5,000 m, a usable diameter of 450 mm can be achieved in a cased borehole using standard drilling methods. If the resource is located at a smaller depth, a larger diameter can be achieved with the technology used today, e.g. at 2,000 m depth, this is approx. 650 mm. In the past, larger diameters have been realized in scientific and military drilling projects. A standard bore with a diameter of 375 mm and a depth of 5,000 m arrives to a cost of approx. € 30 million (pure drilling costs as of the end of 2015). The costs increase disproportionately with the diameter. The equipment for the operation of an oil or gas drilling is shown in figure 70. There are different types of host rocks for hydrocarbon deposits. Often they occur in salt host hock.

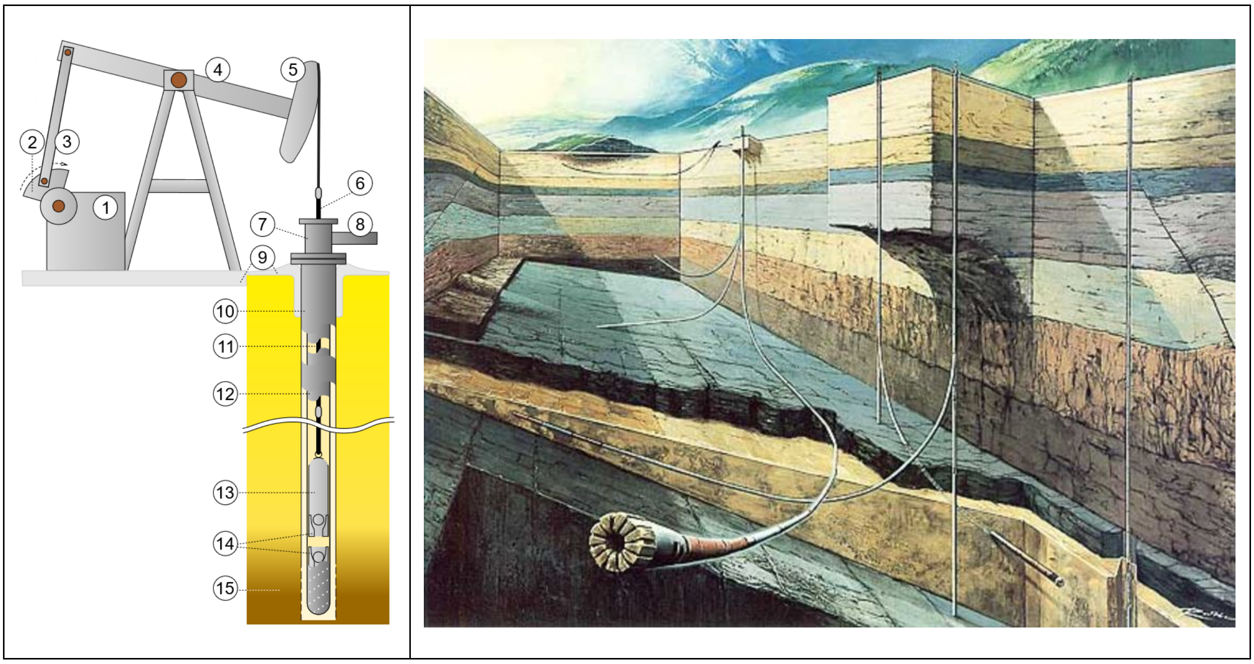


Figure 70: Principle of exploration and extraction: Oil well with pumpjack scheme (left. legend: 1. driving motor 2. counterweight 3. connecting rod 4. balancer 5. horse head 6. piston rod 7. Seal as part of the eruption cross 8. Pipe 9. concrete filling of the bore-hole 10. outer borehole piping 11. pump rod 12. inner borehole piping 13. deep pump 14. pump valves 15. oil-bearing rock layer). Principle of oil and gas exploration using intelligent drilling (right, figure source: Bohrtechnik © 2018 BVEG - Bundesverband Erdgas, Erdöl und Geoenergie e.V).

Closure of oil and gas boreholes

The main closure technique is filling. In principle, the following principles can be assumed:

- Extraction boreholes shall be filled in such a way that burglaries on the surface of the earth are avoided and subsequent use of the subsurface for the extraction of mineral resources and water or for deep storage is not impaired.
- Filling must be carried out in such a way that, based on all experience, a liquid- and gas-tight seal is achieved and adverse changes in the groundwater are avoided.
- The borehole must be filled completely. The areas of usable oil, natural gas and salt deposits, of usable storage and water horizons as well as of pressurized horizons with inflows (collectively referred to in this guideline as deposit), liners, interfaces of pipes, pipes and annular spaces as well as the pipe shoe of the deepest pipe tour, further partially uncased borehole as well as the area below the earth surface are to be sealed by special filling lines.
- In areas where difficulties have arisen during drilling or conveying, special filling sections may also be required. The special filling sections must be filled with suitable cement or other suitable solids, if necessary in connection with mechanical seals. Appropriate measures must be taken to ensure that the solids adhere well to the pipe or borehole wall.

- The materials used for filling the drilling or related lines shall not be aggressive to the host rock, the piping or the materials of the special filling lines.
- Special filling levels should range from 50 m below to 50 m above the abandoned deposit. This can be done using pressure cementation or mechanical sealing.

There is no need for a continuous fill route within large dimension salt layers. At least in the hanging and lying areas, special filling sections of at least 100 m in length in salt and 50 m in bedrock must be introduced. The borehole is to be filled with a special fill line from the surface of the earth to a depth of 100 m.

In the case of borehole closure, after the effectiveness of each closure mechanism (cement plug, salt, mechanical barriers) in the area above it should be monitored - before the next closure is implemented. In case of occurrence of NORM waste material, that material must be disposed of in a feasible disposal site (Doyi et al. 2016). The material might be treated, however in such a case the radioactive material must be disposed of separately. For the rest of the dismantling activities (e.g. demolition of processing facilities) apply the closure provisions provided in the sections above.

4.8 Closure of Industrial Minerals Mining Sites

4.8.1 Overview

industrial minerals are any rock, mineral, or other naturally occurring material of economic value, excluding metals and energy minerals. Typically, they are large volume with low value commodities. They are extracted from surface and underground mines like the other resources that have been already discussed. Industrial minerals are of several genetic types, and of several structural characteristics. The main types of industrial minerals are:

- Metallurgical additives: limestone, barite, fluorspar
- Mineral chemical raw materials: fluorspar, limestone, boron, barite, gypsum, talc,
- Agrochemical raw materials: salt rocks / potash, phosphates
- Raw materials for glass production: glass sand, feldspar, limestone
- Raw materials for ceramics: kaolin, feldspar
- Isolation materials: chromite, magnesite, sillimanite, asbestos (asbestos is not anymore permitted for industrial applications in the EU)
- Decorative and precious stones: diamond, ruby, emerald etc.

For the majority of the mentioned materials apply the closure methodologies described before in aggregates, ore or energy minerals mining, depending on their properties (solid rock, coarse rocks). Comparable closure techniques apply:

- Like aggregate mining, solid rocks: limestone, barite, fluorspar, gypsum, feldspar, chromite, magnesite (in case of open cast mining)
- Like aggregate mining, coarse rocks: glass sand, kaolin (in case of open cast mining)

- Like ore mining, solid rock: limestone, barite, fluorspar, bauxite (in case of open cast mining)

For a minority of the industrial minerals are needed chemicals for the processing (see 4.6.2). Some of them have special properties that require special closure techniques. These are particularly salt rocks / potash and phosphates. In this section is focused on these materials in order to consider their particular properties in terms of closure. Salt rocks / potash are usually explored and extracted underground or through deep drilling to dissolve the brine. However, due to their chemical properties, particular closure aspects must be respected. Phosphates do also have special properties, and after processing to obtain some types of raw materials result tailings ponds (so called phosphogypsum ponds, figure 70) that have comparable properties to ore mining tailings ponds. Further, phosphogypsum ponds often contain metals or radionuclides as residual by-products of the phosphorous ore processing (Papaslioti et al. 2018). The main challenges in the closure process of industrial minerals are

- underground cavities with corresponding effects on the surface (underground mining);
- open or flooded shafts (underground mining);
- only limited usable areas in the vicinity of the shaft systems (underground mining);
- Enclosed space mostly not or only partially usable industrial buildings;
- large residue dumps, e.g. with piled-up salts and the dissolved salts that flow out of them, which transport a substantial salt load into the receiving rivers.

Several of the industrials minerals are not inert, that means chemically relevant during closure.

Figure 71: Sample of phosphogypsum ponds in Andalusia, Spain

4.8.2 Particular Challenges at Industrial Minerals Mining Sites

Table 10 gives an overview on inorganic reagents and their primary functions in industrial mineral processing (Pearse, 2005). Those materials may be found in the sedimentation ponds, depending on the mineral processing methodology.

Table 10: Some inorganic reagents and their primary functions in industrial mineral processing (Pearse, 2005)

Reagent	Primary function
Sodium silicate	Slimes dispersant
Sodium fluorosilicate	Fluorite and silicate depressant
Sodium hydrosulphide	Sulphidizer for oxide and weathered minerals
Sulphuric acid	Fatty acid collector removal in phosphate flotation
Alum, Polyaluminium chloride, Ferric chloride	Clarification
Zinc dithionite	Bleaching agent

Other challenges result from salt / potash mining and phosphates, as these sites might typically have a large dimension. Further, salt and potash minerals are highly soluble resulting in a quite fast material transport into the environment. Salt and potash minerals in higher concentration are toxic to several aquatic animals.

4.8.3 Earthworks

The main earth works are profiling and stabilising works. During the closure works is necessary to ensure erosion prevention, preferably through establishment of vegetation on a stable landform. Earthworks for industrial mineral mine closure are comparable to those described in 4.3.4.

4.8.4 Water Management

Applicable water management activities depend on the type of industrial mineral and the processing technology that means if additional chemicals are used in the further processing. Thus, as water management approaches depend on the resource properties and the type of mining, they are comparable to aggregates (see section 4.3.1) and ore mining (see section 4.3.2). In case of chemicals use, water treatment is usually necessary.

Salt / potash mining requires a special water management strategy as the resource is highly soluble and can lead to salt intrusion in surface and groundwater. In case of salt leaching and brine extraction, highly concentrated salty solutions (brines) are generated that can be pumped up to the surface. However, the mineral solutions are typically also corrosive to the host rock and form caverns that can be hardly stopped to further dissolve salt. Brines can create huge caverns that deep drilling to dissolve the brine. Figure 72 shows brine caused caverns and their geotechnical impacts (Warren, 2016a).

In contrast to other mining branches the prevention of water inflow into the abandoned potash or salt mine is also required during the post-operational phase to prevent hazards to the surface above the mines and to guarantee safe ground. Water-tight shaft or drift sealing, therefore, is one focus of mine closure in mineral salt mines.

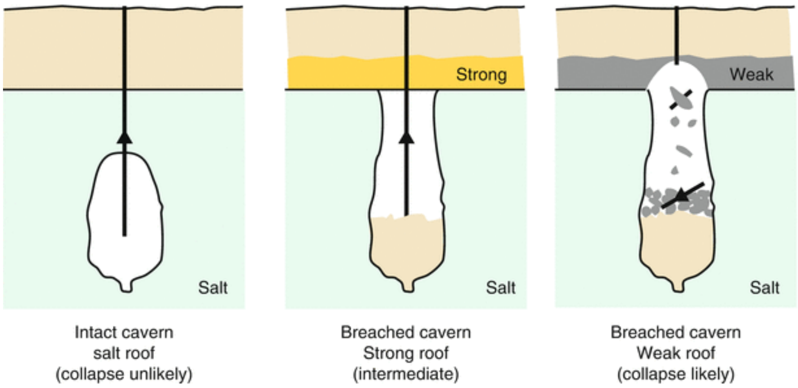


Figure 72: Brine caused caverns and their geotechnical impacts (Warren, 2016a).

4.8.5 Ensuring Long Term Geotechnical Stability

A breached cavern with a weak roof can likely lead to a collapse (figure 72, Warren, 2016a). Geotechnical stabilisation methods focus on hydraulic filling of caverns or other mine workings. Salt usually seals, but sometimes leaks (Warren, 2016a). To minimize subsidence, to avoid rock bursts and to maximize mineral extraction, special hydraulic fill is used in potash and salt mining (e.g. Fliß et al. 2011). Filling of salt and potash mines may take place during underground extraction or after production shutdown. Figure 73 illustrates the hydraulic filling process of filling long chambers.

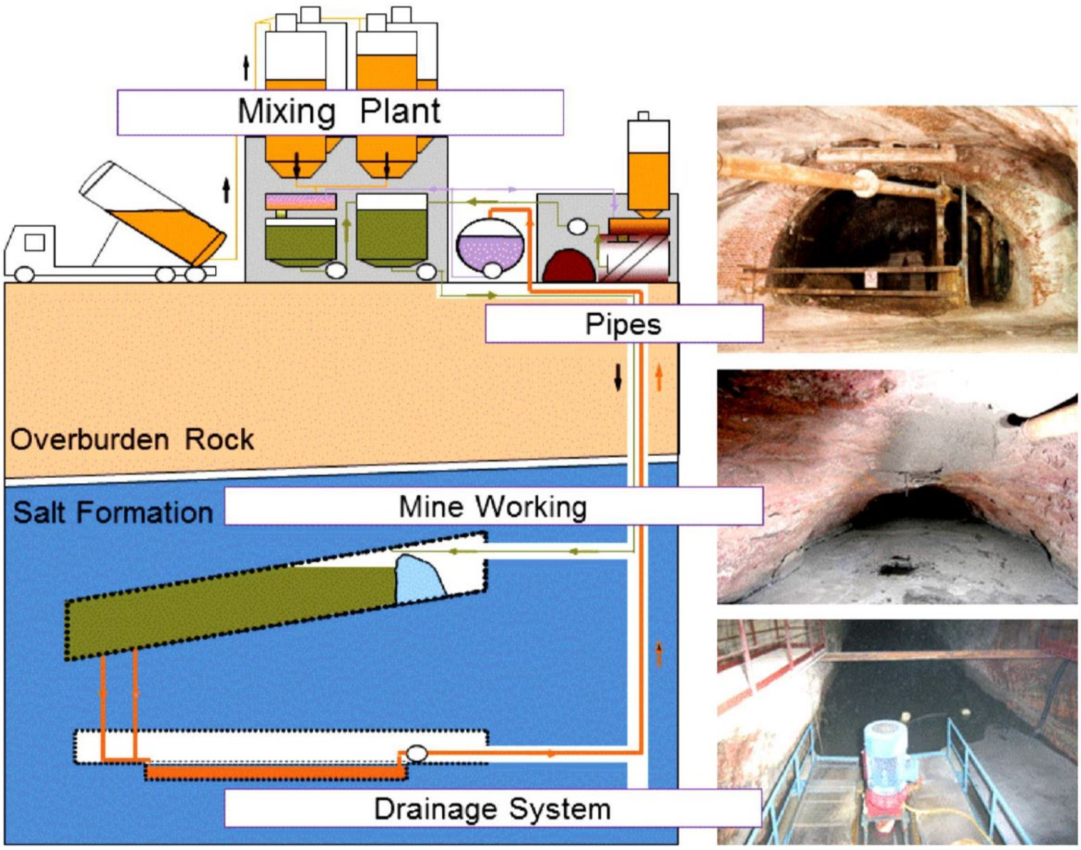


Figure 73: Principle sketch of hydraulic filling in potash mining industry
(Fliß et al. 2011)

Caverns can be filled in a similar way, and in a second step the remaining pillars can be excavated, so that the fill acts as stabilizing material (Fliß et al. 2011). In potash and salt special attention has to be paid to the fluids to minimize dissolution processes (e.g. drainage, water management, chemical composition, use of saturated brines etc.). Hydraulic fill with high content of rock salt with $MgCl_2$ brine leads to a long-term stable fill (Fliß et al. 2011). Crushed salt is the most used fill material in salt mines. Long-term stable fill for potash mines with MgCl brines is the so-called Sorel-concrete or MgO-concrete, based on Mg-Si-hydrates (Walling & Provis, 2016). Figure 73 illustrates the principle of hydraulic filling in potash mining industry (Fliß et al. 2011). Figure 74 shows concepts for shaft stabilisation in potash mines (Zschiedrich et al. 2017).

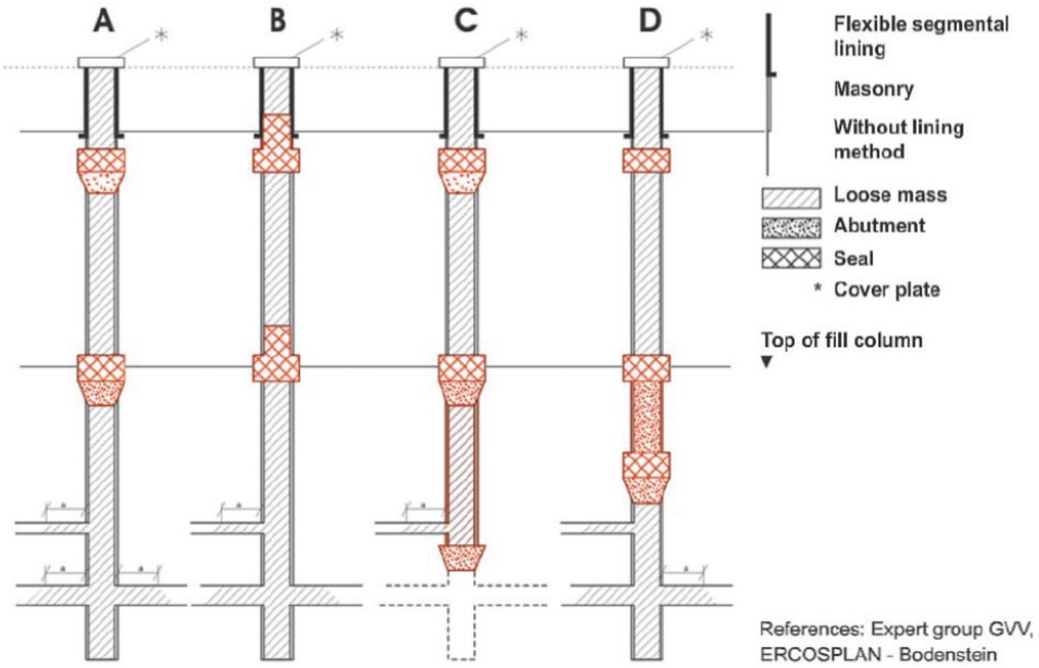


Figure 74: Concepts for shaft stabilisation in potash mining (Zschiedrich et al. 2017)

4.8.6 Ensuring Long Term Environmental Safety

Salt mining leads to the release of saline solutions. The EU Water Protection Laws require that salinization of the continent's rivers be greatly reduced. This is a challenge, particularly in low level water situations, which can lead to a discharge stop. Thus, closure measures need to take into account appropriate dewatering systems, with groundwater protection measures if applicable. Fish, macrozoobenthos and phytoplankton are particularly vulnerable to high salt concentrations. Further, high salt concentrations are highly aggressive to concrete structures. Thus, all closure piping must be done through plastic pipes.

The closure of mine waste heaps requires a particular attention. The main measure for ensuring long term environmental safety of salt and potash mine waste heaps are surface covers that serve further the long term landscaping. Figure 75 shows the systematics of surface sealing / covering at salt and potash dumps (Palm & Kockx, 2018). Some of the mine waste heaps are needed to be profiled or flattened in order to ensure geotechnical stability. Depending on the surface permeability of the waste heap sites, cover systems might be needed (Palm & Kockx, 2018). The main scope of cover systems is to reduce the salt or potash mobility and to avoid precipitation infiltration into the mine waste heap and to ensure surface greening. Also capillary-breaking layers might be applied. Figure 76 shows a stabilisation concept for potash mining waste heaps (Zschiedrich et al. 2017).

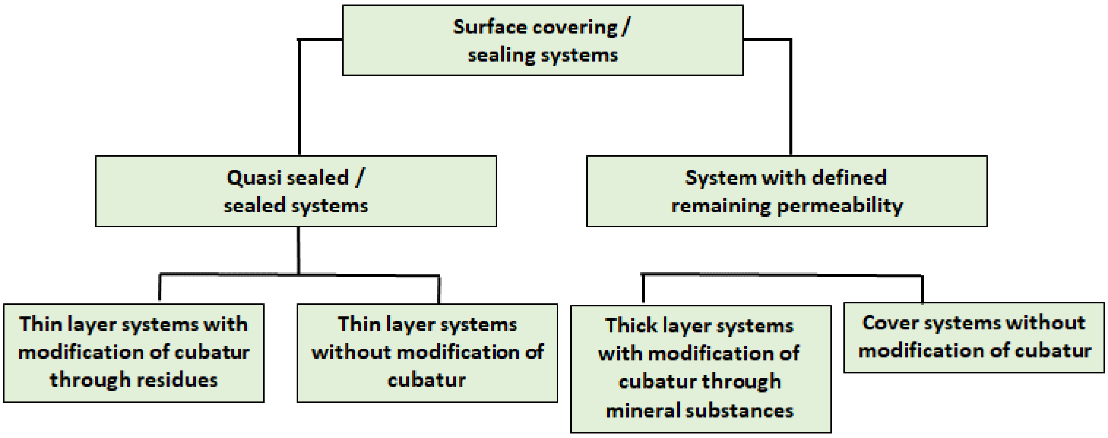


Figure 75: Systematics of surface sealing / covering at salt and potash mining waste heaps (Palm & Kockx, 2018)

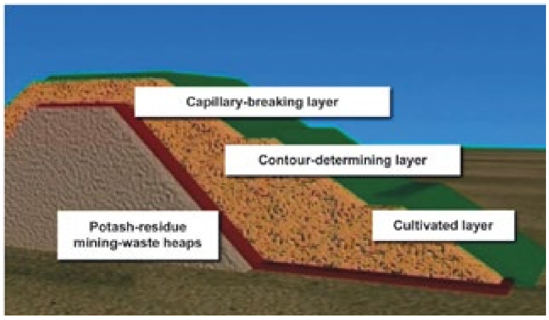


Figure 76: Concept for surface cover of potash mining waste heaps (Zschiedrich et al. 2017)

4.9 Mine Closure Show Cases

4.9.1 Aggregates Mining

The aspects of operation and closure strategies and related closure cost in aggregates mining are illustrated at the limestone company Ostrauer Kalkwerke GmbH in Germany. As already mentioned, aggregates mining usually does not produce hazardous substances. Typically, the only hazardous substances that are used in the operation process are explosives. It is necessary to underline that aggregates mines that are operated according to Best Practice are in a permanent and continuous process of operation and parallel closure of exhausted rock zones. The operation and closure of gravel and sand opencast mines usually includes locations with average annual production volumes with lifetimes of more than 40 up to about 80 years. The limestone plant Ostrau with an average annual output of 250.000 to 300.000 tons is a typical example.

Since the extraction takes place in the open-cast mine and the geology of the deposit ensures the greatest possible lossless mining, all residual materials (overburden, selectively obtained particular soil layers) are returned as filling to the exposed areas. The filling takes place in such a way that the former mining areas are prepared without any further reclamation effort for a future after-use either for forestry or agriculture.

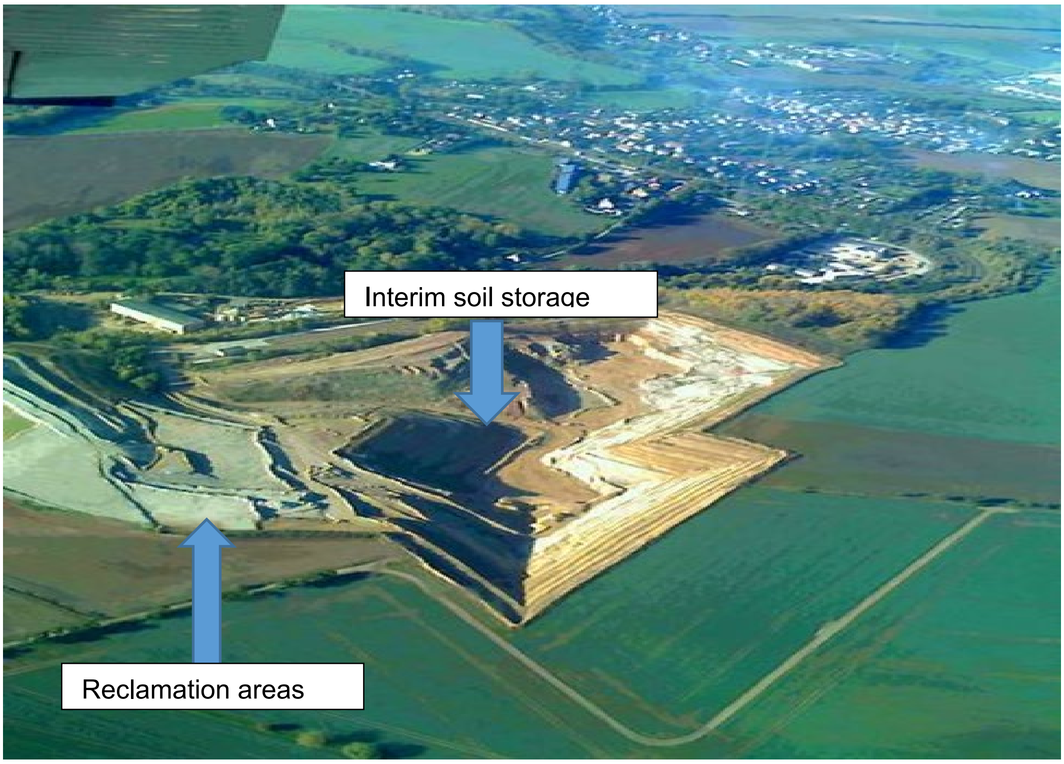


Figure 77: Aerial view of Ostrauer Kalkwerke GmbH

Any topsoil that arises when the future extraction areas are excavated is either reinstalled as a covering layer or sold. This means that the operating result is not burdened due to additional provision costs and, in addition to environmentally friendly resource extraction, the final product is less financially burdened.

The extracted resource is dolomite limestone that is mined through stroke construction methodology. The extraction is conducted through drilling and blasting technology, while the loading technology takes place through LHD technology and large tipper. The company works very efficient: until the resource processing, there is already an extraction efficiency of approx. 90%, means very small resource losses. The main products are fertilizer, filling materials, and road construction material.

Geologically, selective extraction with regard to different rock qualities is required. The operation is managed according to basic economic aspects in the form of an operating point settlement (cost centres) and an annual profit and loss account. The company is under the supervision of the mining authority, i.e. work is carried out consistently according to the submitted and confirmed operating plans. Due to the continuous use of the overburden for reclamation means that no provisions are required for subsequent reclamation.

Figure 78: Extraction scheme and further SEE direction of excavation (left); preliminary exploration with subsequent extraction (right)

The waste resource ratio at Ostrauer Kalkwerke GmbH is 2: 1 (i.e. 2 tons of overburden must be managed in advance for the extraction of 1 ton of limestone). The open cast mine is filled during ongoing operations leading to the situation that the recovered land is usable again immediately after closure. Some seeding and greening cost and some subsequent monitoring cost might be required up to five years after closure. However, due to the application of state-of-the-art technologies and Best Practices during operation, the costs for reclamation purposes are therefore minimal (less than 10.000 € per year).

4.9.2 Ore Mining

The show case for ore mining comprises a polymetallic ore including uranium ore mining from Bulgaria. Uranium mining is a special case as it belongs to the energy minerals; however, it is also an ore and extracted using ore mining technologies.

Polymetallic ore including uranium ore mining

The show case illustrates the “Remediation Programme for the Uranium Mines in Southern Bulgaria” (financed through EuropeAid/113349/D/SV/BG) that was conducted in the period 2004 to 2005. It was financed by the Ministry of Regional Development, Republic of Bulgaria, using funds of the European Commission. Background of the project is the Buhovo ore deposit where past ore exploration was performed with different methodologies (Gitzinger et. al. 2011). As a result of these explorations, 39 ore deposits were identified and developed on the territory of Bulgaria (Gitzinger et. al. 2011). The show case presents the closure of shafts and adits under different geological conditions. An overview on location of the shaft and adit system is given in figure 79.

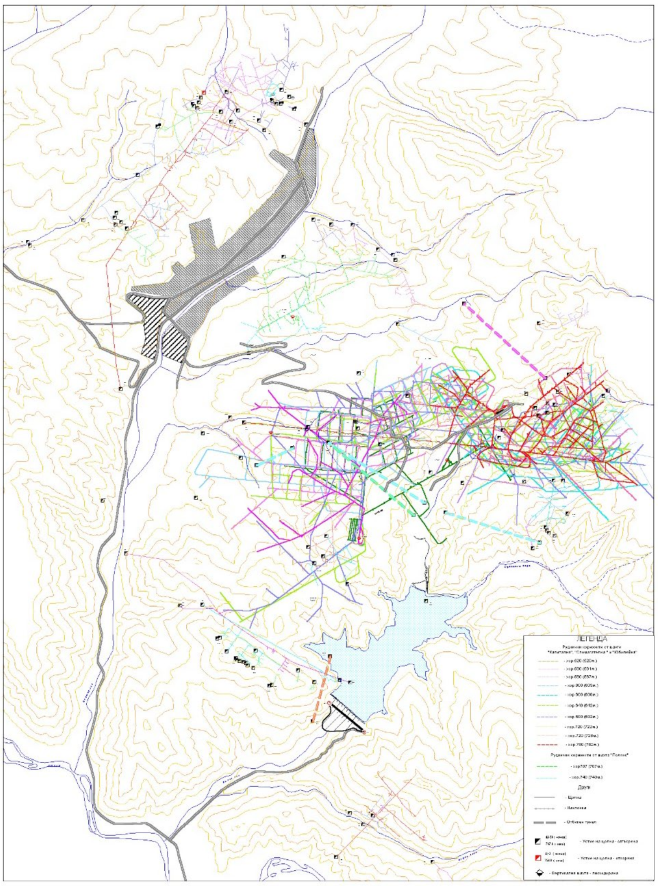


Figure 79: Overview on the location and the shaft and adit system to be closed

The main ore deposits for underground extraction are: Buhovo near Sofia, Eleshnitsa, Senokos and Simitli in South-West Bulgaria, Vinishte and Smolyanovtsi in North-West Bulgaria, Sliven in Central Bulgaria, Smolyan, Dospat and Selishte in the Rhodope Mountains. Deposits exploited via classical mining methods have a complex geological structure and are situated mainly in mountain regions (Stara Planina, Rhodope massive, East Sredna Gora). The mean surface of the ore beds is between 250 m² and

20.000 m², occurring at a depth of about 500 m and a low metal concentration. Under favourable conditions of the ore beds, the ISL method (In Situ Leaching) was applied (Gitzinger et. al. 2011). Beside radionuclides, other by-products resulting from uranium ore production and processing may be detected (Gitzinger et. al. 2011). These are sulphates (SO_4), carbonates (CO_3) and bicarbonates, nitrites, organic solvents and other reagents stemming from the uranium extraction and processing as well as metals (Fe, Mn, Cu, Zn, Co, Ni, Cr, As, Hg, etc.) from poly-metallic and sulphide-poly-metallic mineralisation accompanying the uranium ores (Gitzinger et. al. 2011). The description below illustrates the closure approach.

Shafts in the non-stable rocks of the Eleshnitsa, Dospat and Simitli regions

The safekeeping measures that had been taken in the past by the closure of the former uranium-tungsten ore shafts in the Eleshnitsa, Dospat and Simitli regions were proven to be not feasible as the shafts were leaking. The former closure method was filling of the shaft with coarse materials and covering the entrance to the shaft with a concrete slab. There had been observed geotechnical damage in the filled shafts constantly that was attributed to the leakage of the coarse masses. So, the shafts were closed again according to state of the art and best practice. The state of the art is to fill shafts in the non-stable rocks before the start of flooding along their entire depths from the sump up to surface with hydraulically hardening and non-washable material with a minimum compressive strength of 2 N/mm². Shafts whose entrances are only covered with a concrete slab are to be classified as temporarily (provisionally) closed. Since the existing situation could only be changed with unreasonably high technical and economic expenditure, the securing measures for these shafts are essentially limited to a dimensionally and quality-appropriate execution of a sealing construction at surface. For the shafts whose entrance were only covered with a concrete slab, measures were taken to ensure the long-term safekeeping of the shaft pipe under the given conditions. Framework projects were developed for the different geotechnical and geological conditions at the locations, which were designed in such a way that they could easily be transferred to other locations as pilot projects.

Summarized the following framework projects were realized:

Securing the existing entries by means of stable ballast barriers, further filling also by means of gravel sections, remaining filling up to the surface using cohesive filling column made of lean concrete.

Figure 80: Overview on the location and the shaft and adit system to be closed

According to the state of the art, partial closure methods can be used for shafts in the continuously stable rock, such as:

- Installation of a massive reinforced concrete seal in the onset close to the surface, residual filling with gravel up to surface
- Installation of a concrete shear plug in the shaft area close to the surface, residual filling with gravel up to surface
- Installation of a cohesive filling column section made of hydraulically hardening material with a minimum compressive strength of 5 N/mm²), residual filling with hydraulic hardening material with a minimum compressive strength of 2 N/mm² up to the surface

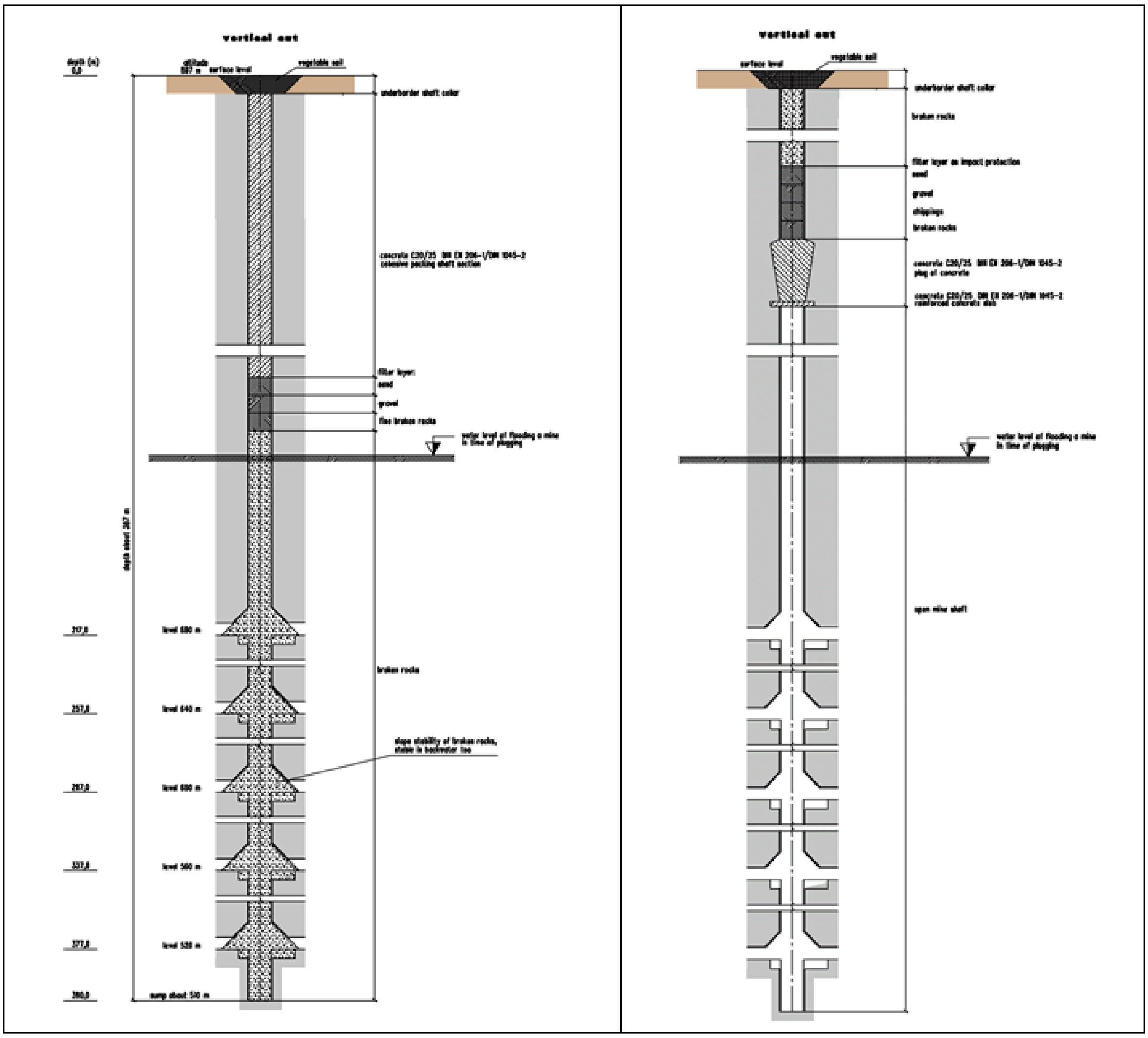


Figure 81: Ensuring geotechnical stability in underground ore mine closure: complete filling of the shafts. The section above the flooding level to be expected in the future must be installed as a drainage layer before the cohesive filling column reaching to the surface layer (left); partial filling (right)

The installation of a shear plug requires a detailed geotechnical and geological surveys of the sites. These sections may need to be re-injected.

Figure 82: Break out of shaft, preparation for plugging

Measures for provision of public safety in the area of abandoned adits in the Eleshnitsa and Senekos regions

According to best practice, the following method for the closure of entrances of abandoned adits was applied:

- Walling the immediate entrance area
- relocation of a circa 10m long section in the entrance area
- Closure of the entrance by blasting.

If surface breaks occurred in the course of the route, the relevant adit areas were shifted as soon as possible free of voids. A common method is the installation of cemented hydraulic fill by drillings. The rehabilitation objects located in the Eleshnitza and Selekos regions can be classified into the following categories according to the initial situation (figure 83):

- Adit open, no water discharge
- Adit open, water discharge
- Adit open, no water discharge, surface breaks in the route
- Adit broken or filled up, water discharge.

The shafts were closed according to the methodology described in section 4.5.

Figure 83: Adit open, no water discharge (left); adit open, water discharge (right)

Closure cost

The closure costs were calculated separately for each shaft and adit. Cost for the long term stable closure of the entrances (shafts and adits) added up to around 1.2 mill euros. The costs for each shaft depend on the type of provided custody works, the shaft depth and the requirements of the responsible supervisory authorities. The compilation is shown in the following tables.

Table 11: Sample of cost calculation - shafts and adits in Elesnitsa region (in EUR)

Shaft	Construction of site facilities	Preparatory works	Shaft plugging		Shaft covering			Concluding works	Overall costs (net amount)	Overall costs (gross) incl. 10,7% Additional charge 20,0%
			Bulk material	Cohesive material (concrete)	Earthworks	Cast-in-place concrete bored pile wall	Concrete works			
Kapitalna	6,425€	5,310€	3,470€	64,032€				8,894€	88,131€	115,187€
Spomagatelna	6,425€	5,040€	16,349€	26,413€				7,753€	61,980€	81,007€
Ventilationa	6,425€	5,040€	2,616€	42,688€				18,489€	75,258€	98,362€
Ubilejna	6,425€	5,796€	94,202€	53,360€				8,810€	168,593€	220,351€
Poliane	3,200€	10,070€			51,0534€	190,020€	78,890€		333,233€	435,536€

Adit No.	Construction of site facilities	Custody works		Concluding works	Overall costs (net amount)	Overall costs (gross) incl. 10,7% Additional charge 20,0% Supervision
		Construc-tion- and montage works	Concrete works			
9	6,425€	11,905€	4,640€	2,820€	25,790€	33,707€
29d	6,425€	11,755€	4,640€	2,820€	25,640€	33,511€
37d	6,425€	20,935€	5,280€	2,820€	35,460€	46,346€
42	6,425€	21,085€	5,280€	2,820€	35,610€	46,542€
42a	6,425€	41,440€	18,180€	3,551€	69,596€	90,961€
53	6,425€	41,440€	18,180€	3,551€	69,596€	90,961€
54	6,425€	20,935€	5,280€	2,820€	35,460€	46,346€

4.9.3 Energy Minerals Mining

The aspects of operation and closure strategies and related closure cost of lignite mining are illustrated with an abstract from the study “Assessment of Rehabilitation Measures in East German Lignite Mining” (Tudeshki & Pielow, 2018) as this recent publication illustrates the challenges related to stepwise financial provisions and the dimensions of lignite mine closure. This show case refers to a number of lignite mines to be closed in Eastern Germany, the measures for the provision of reuse options and the related costing. The study was supported by the Regional Agency for Mining, Geology and Raw Materials Brandenburg, the competent authority for the mine closure project. Even the project documentation doesn’t contain absolute closure cost, but absolute closure cost, it is an interesting show case for the FG calculation methodology and regularly update. Scope of the study was an assessment whether the applied practice corresponds to the legal requirements and can be regarded as technically, economically and legally "practicable". Following steps were taken:

- Systematic analysis of data from Lausitz Energie Bergbau AG
- Validation of data with regard to its technical content and their assignment to one another
- Detailed plausibility verification of the structure and the assignment of the measures to the respective focal points of the reusability
- Validation of the methodology for the creation of financial provisions
- Checking the quantity framework of each individual measure of reusability and the associated unit prices
- Checking the cash flows by evaluating the existing and already created provisions with regard to their adequacy and adequacy
- examination of the development of mining and tipping as a guideline for the cash flows.

On the basis of the verified BoQ frameworks and unit prices, taking into account the factors that have an effect on financial mathematics, calculations of the cash flows were made and the net present value of the relevant measures was calculated. This is the precondition to ensure that the financial provisions can be reliably checked and assessed. The assessment subject is mining-related financial provisions of Lausitz Energie Bergbau AG as of December 31, 2016, which are related to the operating units listed below:

1. Jänschwalde open cast mine

2. Welzow-Süd open cast mine

3. Nochten open cast mine

3.1. Hermannsdorfer See

3.2. Landscape structure Spreyer Höhe

4. Reichwalde open cast mine

5. Cottbus-Nord open cast mine
6. Industrial landfills
6.1. Landfill Jänschwalde I
6.2. Landfill Jänschwalde II
7. Central railway operation area
8. Black Pump industrial site
8.1. Technical services area
8.2. Refinement area
9. Head quarter mining.

The total of closure measures comprises 332 measure types with 528 closure activities. The total closure costs add up to 1.38 billion euros. Following types of closure measures were designed: mass movement, landscaping and reclamation, geotechnical stabilisation of waste rock heap sites and embankments, water management measures including open pit landscape restoration, demolishing of mining facilities, processing plants and other operational buildings, redeployment of rivers, roads etc., resettlements and translocation of species, and repair of mining damage.

Methodology of financial provision calculation and verification: In order to assess the stock of reclamation obligations, the areas used by the open pit and not yet reclamation were determined from the current survey data. There are also areas in the rear area that have not yet been reclaimed. These are e.g. areas for day facilities, coal bunker systems, open pit exits, etc. The maps of the planned end of reclamation status form the basis of the allocation of the areas to the reclamation goals of forestry and agriculture, e.g. from the final operating plan or, if not yet available, from the general operating plan / brown coal plan.

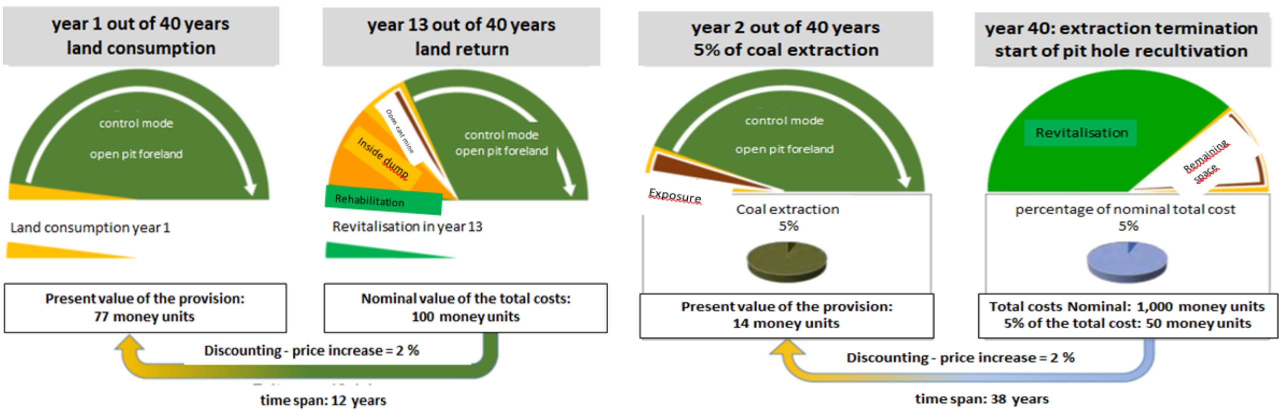


Figure 84: Methodology of financial provision calculation (Tudeshki & Pielow, 2018)

The terrestrial re-use of the open-cast mining areas takes place both in agriculture and forestry, and in the form of other uses, e.g. conservation or military training area. Starting from the lignite plan, the level of detail of the reuse was increased via the framework of operating plans up to the final operating plans, the specifications of which are implemented with a strict focus. Figure 58 shows the schematically accounting for the inventory. The reclamation target for the entire mining area can be recognized within the black mining boundary using the different colours. The basis for accounting for the future re-cultivation of open-cast mine areas is the timely planning of the open-cast mine development with extraction and tipping levels. Due to the long running times of lignite opencast mines, the planning accuracy for medium and long-term periods must be differentiated.

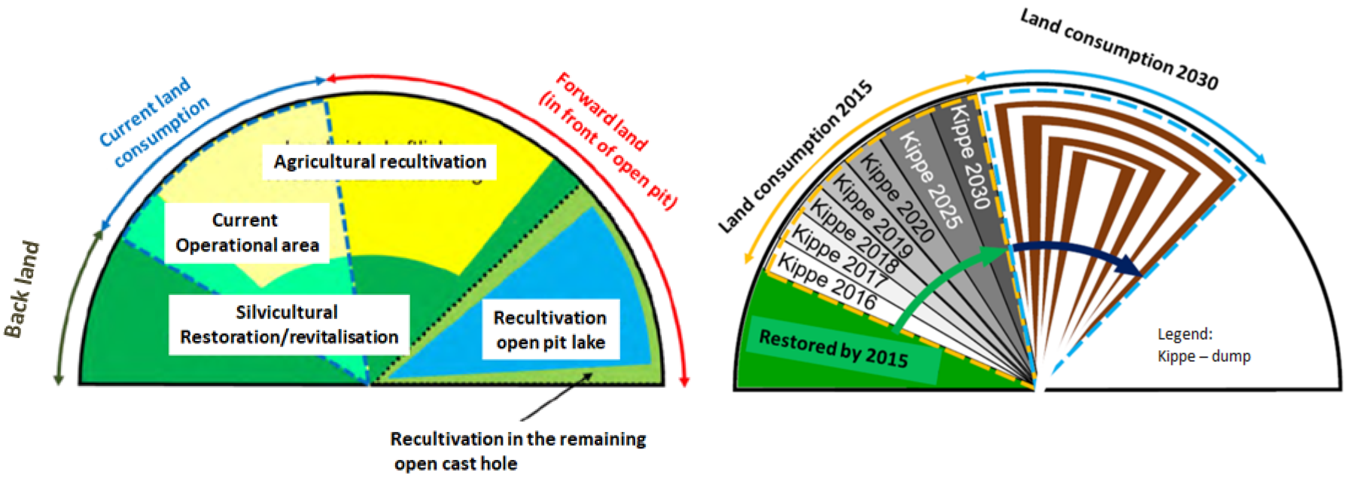


Figure 85: Methodology of financial provision verification: Distribution of the closure cost due to objectives (left. Legend: OC open cast, IL – industrial landfill), FG allocation due type of activity (right) (Tudeshki & Pielow, 2018)

Results of financial provision verification: Figure 86 shows the distribution of the closure cost due to objectives and the FG allocation according to activity type. For development of the open pit hole is needed the largest part of the budget, at over 50%. Reclamation and relocation, each have a share of around 12% of the total cost, while geotechnical protection followed by dismantling and the collective category "rehabilitation of landfills, disposal of contaminants and archeology" sum up each with around 8%.

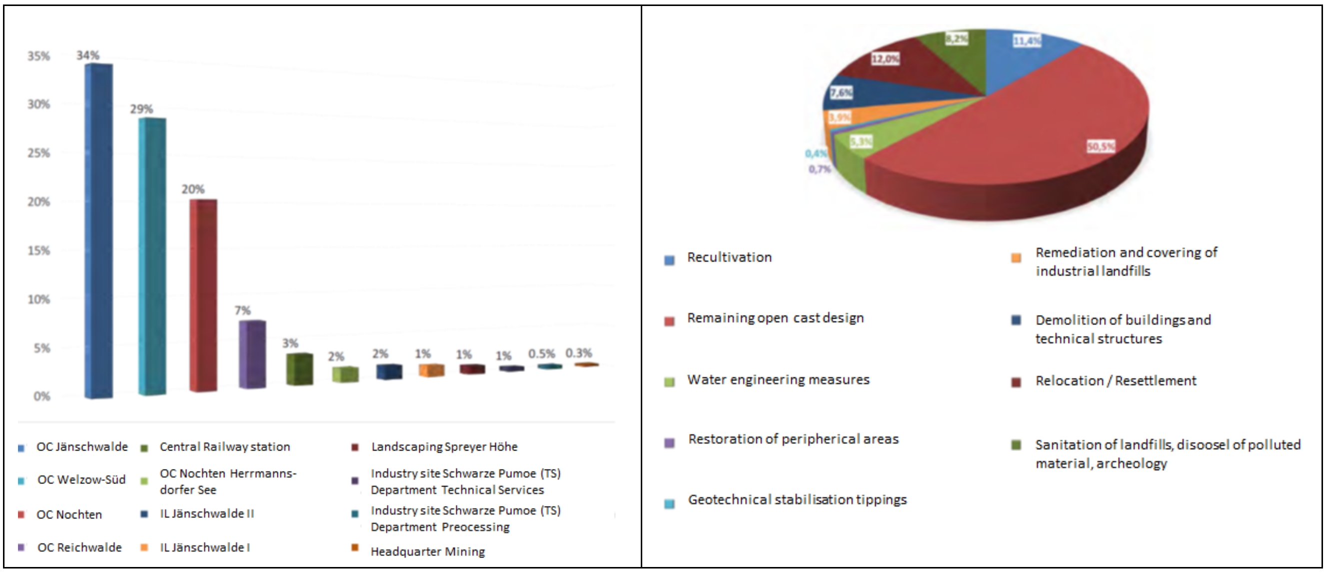


Figure 86: Distribution of the closure cost due to objectives (left. Legend: OC open cast, IL – industrial landfill), allocation of the financial provisions due type of activity (right) (Tudeshki & Pielow, 2018)

Assessment results and conclusions: The mining-related financial provisions are to be formed taking into account the real development of the open-cast mine and to be used or consumed at the appropriate time. As a result of the need to use the raw material ahead of time to excavate the resource and, at the same time, to create the basis for reclamation and reuse, which is technologically necessary, the creation of the financial provisions at the time of use must be started to secure financial resources for the subsequent reuse.

Decisive for the amount of the provision formation is not quality and quantity of the land and infrastructure used, but rather quality and quantity of the reusability, which is to be created at the exact same point by the development of the open-cast mine. These result primarily from the lignite plans with their binding goals of spatial planning for the main features of the type of reuse and the mining law permits in line with these requirements in the form of framework, main and final operating plans according to the Federal Mining Act of Germany.

Summing up the results, following conclusions apply:

- The overall result of the plausibility and completeness verification confirms that the measures on which the financial provisions of the operator are based are overall plausible and complete
- The methodology used by the operator to calculate the required amount of mining-related provisions was assessed to be valid.
- The level of the mining-related financial provisions for the recovery was assessed to be viable.

Finally, the sensitivity analysis and critical examination of the practice of current provision accounting was carried out.

The financial provision made on a legal basis in accordance with the German Commercial Code shows a permanent deficit between the nominal funds required at a certain point in time and the available cash value,

- The design of the remaining extraction hole is a process downstream to open-cast mine operation. The deficit in the design of the residual space arises due to the accumulation of the degree of carbonization. The deficit is greatest shortly after starting the extraction. The closer the dismantling approaches the planned end of mining, the smaller this deficit becomes.
- Reclamation services are already implemented during operation. In the case of reclamation, the basis for the formation of provisions is the complete obligation on the respective balance sheet date. The deficit therefore only results from discounting.

Finally, the following general statement was made: “The sensitivity analysis shows that there is a disproportionate increase to over 100% if the duration of the open-pit mining is extended by only 25%. This also means that open-cast mines with longer extraction phases have higher deficits. The impact of increasing the cost of the design of the remaining extraction hole is enormous. Staggered reclamation measures and the change in the adjusted interest rate play a relatively minor role in relative terms."

4.9.4 Industrial Minerals Mining

Show cases for industrial minerals mining comprise salt mining and fluorspar mining examples.

Salt mining

The case study concerns a salt mine with an attached plant for the production of potash fertilizer salts and for the extraction of industrial and table salt in Morsleben, Germany. It was operated from 1897 until the 1990s and then closed. The salt mine is reused as a repository for radioactive waste. Based on extensive investigation programs, a decommissioning concept for the site was developed, which takes into account the complicated geological, geotechnical, mining and long-term security requirements. It is designed in such a way that the protection goals are maintained over long periods (at least 1 million years).

The long-term safe closure of the radioactive waste from the biosphere is to be achieved with the concept of the extensive filling of the mine and the seals in the vicinity of the storage areas west-south field and east field. For this purpose, around 75 percent of the cavities are to be filled, 22 seals are to be built and the Bartensleben and Marie shafts are to be sealed and filled.

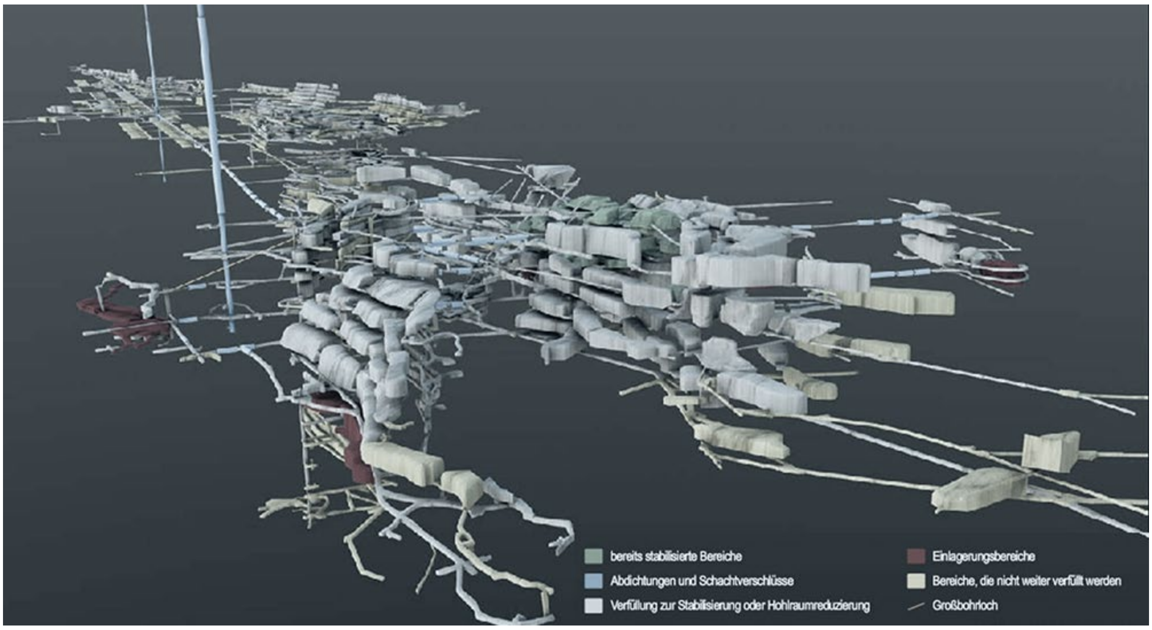


Figure 87: Underground closure of Morsleben salt mine type (Bundesgesellschaft für Endlagerung, 2016)

The seals delay the access of solutions to the storage areas and the radioactive decay of the solution until the radionuclides, and in particular those with short disintegration times, will then have largely disintegrated. The direct connections to the top, the Bartensleben and Marie shafts, are sealed with particularly high-quality seals. The principle diagram shows the following figure:

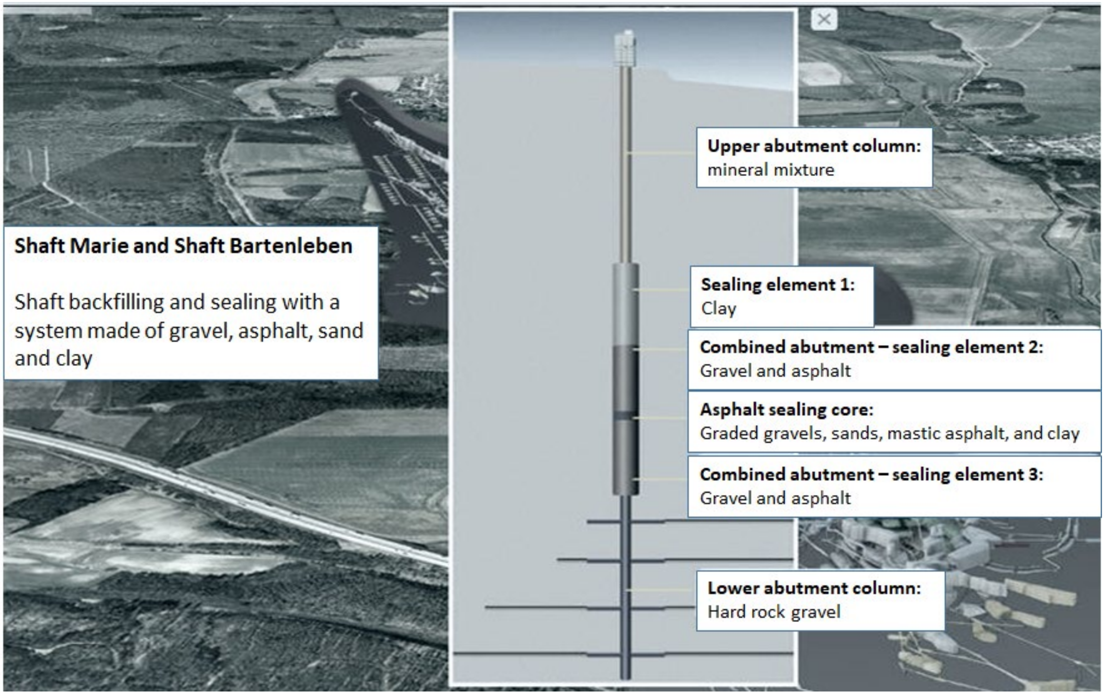


Figure 88: Underground closure of Morsleben salt mine (Bundesgesellschaft für Endlagerung, 2016)

After approval of the planned closure, the work will take 15 to 20 years more from now until the complete closure.

Fluorspar mining

The show case concerns former fluor and bar spar mine that was opened in 1972 and operated until 1985. The adit was opened as a conveyor and drainage tunnel. After approx. 1.4 km in length it reaches the fluor spar deposit in 150 m depth. The deposit was opened up via the 1st adit floor, until 1982 the 2nd and 3rd adit floors were driven up. The total production was approx. 200,000 tons, with a fluorite content of approx. 60%, was extracted. Most of the material conveyed was processed by truck. The adit system is abandoned and not used anymore. No use is planned in the future either. The mine was closed and dismantled shortly after 1985.

For safety reasons, the adit entrance was closed by a wall, in the lower area of which there is a basic drainage of the tunnel water. According to the safekeeping operating plan, selected adits were filled with extracted mineral fill material from the mine area. Over time, iron hydroxide sludge has accumulated in the adit system. This sludge represented a potential hazard with regard to the sudden mobilization. Therefore, several measures were implemented to reduce both sludge generation and uncontrolled sludge leakage into the receiving river:

- Construction of a 1.5 m high and 0.5 m thick concrete dam into the adit
- Sealing the gallery to reduce air access and thus the formation of iron hydroxides
- Closure of the adit entrance (no uncontrolled access to the adit where iron hydroxide sludge can be released)

- Creation of orderly drainage conditions with drainage of the adit mine water via a pipe system (avoidance of uncontrolled drainage conditions)
- Redirection of the adit mine water via a retention basin for any sludge potentially mobilized inside the adit.

Since the beginning of 2005, an airtight seal has been used to prevent or minimize oxidation processes in the mine. In 2006, the renovation work began, the main effect of which was the sinking and separate drainage of the pit water to the river basin. The stream between the adit entrance and a collecting basin is therefore free of mine water. In the meantime, the chemical composition of the mine water began to change gradually, i.e. a low pH, resulting increased iron loads and, high salt loads (chloride, sodium, calcium), that where meanwhile determined to be of geogenic origin.

Geotechnical stability also represents a potential hazard, as the adit are sometimes at risk of breakage and thus pose a long-term hazard to the surface. This poses a threat to public security. In the event of an adit wall breaking, there is a risk of flooding in the local area. The aim of rehabilitation is further to prevent the transfer of pollutants from the mine water into the receiving rivers. The remedial goal for people is to eliminate the currently relevant threats, in particular accessibility. From an environmental point of view and the need for mining damage, the adit system must be renovated and restored in such a way that the durability of all underground mine openings is guaranteed.

Figure 89: Current situation at the fluorspar mine site: adit with mine water outlet (left); aeration zone for mine water passive treatment of the drainage water (right)

To improve the situation on the long term, a variant assessment was prepared. The basic rehabilitation options were assessed by discussing the long-term environmental influences (environmental compatibility), the necessity, the feasibility or effectiveness (suitability), the proportionality and the assessment of the effects on further remedial measures. Further was prepared a cost-benefit-analysis.

In principle, following groups of variants were assessed:

a) maintaining the existing state, taking into account lower environmental goals,

b) treatment of the already leaked mine water,

c) adit refurbishment through refurbishment work in the gallery with closure of the hydraulic pathways,

d) Dilution of the mine water that is already discharged.

As preferred solution was concluded a two-stage process that foresees a temporary solution, in the first step this is the transfer of water from an uncontaminated water reservoir to the discharge outlet. Afterwards, an adit rehabilitation should be aimed for, with full refurbishment of the closed mine, keeping the adit open for constant water management in combination with the introduction of a SAPS (successive alcalinity producing system) inside the adit. The resulting gross costs, based on a 10-year time interval, are estimated to € 3.3 million with an uncertainty surcharge.

5. Part D: Cost Profile, Cost-Relevant Activities and Unit Cost

5.1 Data Base and Approach

The overall scope of part D is to provide support for establishing financial data on the closure process. This includes also the design process, as the engineering cost of the closure design must be covered through FG as well as updates of the design might affect FG periodic adjustment.

Cost profiles and unit cost in section 5 were obtained from about 30 closure plans and related Bills of Quantities (BoQs) from implemented mine closure activities (aggregates, ores, industrial minerals) of the last 20 years, mainly from Northern, Western and Eastern Europe. The data were complemented with information from comparable rehabilitation works, for instance landfill closure and aligned with information on unit cost provided by the MS. Furthermore, the data base was complemented with information from several unit cost data bases for landscape rehabilitation, for instance the Performance Book Brownfield Rehabilitation and Spatial Development as of 2014 (https://www.labo-deutschland.de/Leistungsbuch-Altlasten-und-Flaechenentwicklung.html).

5.2 Cost Profiles of Engineering Works

5.2.1 Cost estimation, Bills of Quantity and Procurement rules

Each mining activity needs a mining license/concession that will be issued by the competent authority based on a Feasibility Study. The FS must address the entire intended life span of the proposed activities, from construction phase to post closure monitoring and it must be supported by all types cost that characterize a mining activity: investment cost, maintenance cost, and operational cost as well as calculated income for a certain production capacity and a considered product(s) selling price(s). This requirement applies also to the mine closure phase that is the key activity financed through the deposited FG. Further, a cash flow showing expenses and incomes must be a part of the FS.

In the majority of the MS are available specialized software tools for cost estimate that have an updated price data base including the applied up to date working norms and taxation. Links to such software are:

https://shop.weka.de/bau-immobilien/baudaten-und-baukosten

http://www.wesa-software.de/html/datenbanken_sj_kosma.html#BKI

http://www.softwareparadiso.it/areef.htm

https://www.capterra.es/directory/30056/construction-estimating/software

https://www.labo-deutschland.de/Leistungsbuch-Altlasten-und-Flaechenentwicklung.html

FS is based on the mine closure plan providing all dimensions, technical and financial of the mine closure and environmental rehabilitation. Mine closure plans shall be consistent with the permits in force and have to reflect all permit conditions. The FS must provide a basic design, the requirements for consultancy and supervision, as well as environmental monitoring and reporting that are related to inspection by the competent authority. The cost concluded in the FS represents estimation and serves basically the establishment of the fund estimate. Based on the FS is prepared the Basic Design, followed by the Detailed Design, and the Final Design. Beginning from the Basic Design phase are developed Bills of Quantities, a document used in tendering in which materials, parts, and labour are itemized. It also details the terms and conditions of the construction or repair contract and itemizes all work to enable a contractor to price the work for the bidding. The closure activity is subject to procurement.

Procurement rules exist in most countries and for all financing agencies. These rules shall encourage open competition in tendering and contract award, open meetings and equitable and fair distribution of information, effective monitoring and auditing of all processes and implementation activities. After a successful procurement, the contract with the construction company will be made. World widely used conditions of Contract were published by the Fédération Internationale des Ingénieurs-Conseils (FIDIC). Relevant for tendering and contracting mine closure and environmental rehabilitation works are:

FIDIC RED BOOK

Conditions of Contract for Construction for Building and Engineering works designed by the Employer, Second Edition, 2017. The Red Book provides conditions of contract for construction works where the design is carried out by the Employer. The current Red Book bears little resemblance to its predecessors. Earlier versions of the Red Book were drafted for use on civil engineering projects. The current edition drops the words “civil engineering” from the title and this signifies a move away from the Red Book only being applicable to civil engineering works. In line with the rest of the FIDIC suite the focus is now more on type of procurement rather than the nature of the works. The Red Book is therefore applicable to any construction works were the Employer carries out the design.

FIDIC YELLOW BOOK

The Second Edition of the Conditions of Contract for Plant and Design-Build, Second Edition, 2017. The Yellow Book is therefore applicable to the provision of electrical and/or mechanical plant, and for the design and execution of building or engineering works. Under the usual arrangements for this type of contract, the Contractor designs and provides the works in accordance with the Employer’s requirements which may include any combination of civil, mechanical, electrical and/or construction works.

FIDIC EMERALD BOOK

Conditions of Contract for Underground Works (2019 Emerald book). The First Edition of the “Conditions of Contract for Underground Works” (Emerald Book) has been published by the Fédération Internationale des Ingénieurs-Conseils (FIDIC) in a joint endeavour with the International Tunnelling and Underground Space Association (ITA-AITES).

5.2.2 Site Investigation

Each mineral deposit is unique, so planning must take into account the detailed nature of the resources that are the subject of mining. Nature and sensitivity of the environment must be considered through the monitoring and data collection system in order to provide environmental constraints for mining planning.

- Establishment of baseline or current conditions;
- Provision of site-specific input for use in the safety assessment of the proposed designs.

5.2.3 Feasibility Study

The FS is the documentation that includes the main characteristics and technical-economic parameters of the project, through which the rational and efficient use of the capital and material expenses is ensured, in order to meet the economic and social requirements in the respective field. It contains basic information on geological setting; mineral deposit description; exploration and results; mineral resources and reserves estimates; mineral processing and metallurgical testing; mineral and land ownership; mining process; mine closure plan; infrastructure; permitting; local environment; etc.

Furthermore, usual contents for the FS written sections are:

- General data: Name of project Designer
- Contracting authority
- Location (county, locality, street, number)
- Subject, with substantiation of the necessity and opportunity considered upon approval of the pre-feasibility study
- Functional and technological description, including technical studies, on disciplines
- Technical data on the project
- Area and legal status on the lands to be taken (definitively and/or temporary) by the project
- Geo-physical characteristics of the site (seismic zone, nature of foundation land and conventional pressure; maximum level of water table)
- Main characteristics of constructions
- Estimated overall cost of project
- Total investment value, detailing on the yearly overall cost estimate.
- Main technical-economic parameters of project
- Total value (in prices - month, year), of which: constructions-assemblage, schedule (Investment/Construction + assemblage)

Project financing and its splitting according to the financing sources.

5.2.4 Technical Design

The technical design (TD), verified, endorsed and approved according to the legal provisions, is the documentation, written and drawn based on which the works are executed. Within the description of the works forming the object of the technical design references will be made on the following elements:

Textual part consisting of general and particular technical specifications providing for:

- location, topography, climate and natural phenomenon specific to the region, geology, seismicity;
- project description on volumes, brochures, chapters;
- construction site organization, brief description, demolitions, network diverting, etc.;
- temporary access ways;
- sources of water, electricity, gas, phones, etc. for the construction and operating phase;
- access ways, communications, etc.
- program for works execution, schedule of works, acceptance programs;
- mapping and measurement of works;
- contractor’s (tenderer) laboratory and tests he is responsible for;
- cleaning within construction site as well as sanitary services;
- required additional technical studies, on disciplines;
- Provisions on procurement procedures, consultancy, technical assistance, fees, taxes, levies, as well as contingencies.

Bills of quantities (BoQ)

Quality management plan (QMP)

Drawings

5.2.5 Supervision

The scope of the supervision is to ensure that the project is completed on time, on budget and complies with the relevant regulations and quality standards. Supervision comprises the following activities:

- Design supervision
- Independent third-party verification and certification
- Site supervision in accordance with technical and construction legal requirements
- Commissioning supervision on quality and schedule
- Technical and legal advice, and assessment consulting
- As-built documentation.

5.2.6 Occupational Health and Safety

Working on construction sites requires an Occupational Health and Safety Plan according to European requirements. In the ideal case, the contractor is required to implement an Occupational Health and Safety Management System according to ISO 45001.

At all stages of the rehabilitation and management process, it is essential to consider and address the risks to the health and safety of all persons who may be affected by activities at the site. People to be included in this consideration include:

- site users and occupants (if any),
- all workers on the site,

- visitors to the site (for example, couriers),
- people travelling across the site or near the site,
- site neighbours (as appropriate).

Monitoring of health and safety must be on-going through all stages of assessment, rehabilitation and management because known and unknown hazards can be encountered at any stage of site works. Generally following types of hazards are to be considered:

- Handling of heavy machinery,
- Use and handling of hazardous substances,
- Potentially dangerous site conditions,
- Handling of radioactive material - radiation protection (if applicable).

Work on contaminated sites requires the use of a range of personal protective equipment and clothing (PPE). PPE includes a wide range of clothing and safety equipment, such as boots, face masks, hard hats, ear plugs, respirators, gloves, safety harnesses, and high visibility clothing. The cost of all Occupational Health and Safety measures are needed to be included into the costing.

5.2.7 Environmental Monitoring

Scope of environmental monitoring is the verification of compliance with regulations, discharge authorizations and procedures as well as the verification of the effectiveness of engineering designs. The benchmark for the verification is the baseline data collection of the FS.

5.2.8 Environmental Reporting

Environmental reporting obligations are set via permits by the competent authority.

5.3 Cost Profile of Technical Works

Extraction-related activities are referred to in Annex II of the Public Procurement Directive (2014/24/EU) (public works contracts) at 45.11: earth moving: excavation, landfill, levelling and grading of construction sites, trench digging, rock removal, blasting; site preparation for mining; overburden removal and other development and preparation of mineral properties and sites; test drilling, test boring and core sampling for construction, geophysical, geological or similar purposes. Funds available to the competent authority in the above-mentioned case should be used as public money and the works should be carried out following a tender. If the mining operator enters into bankruptcy the designing solutions will require updating; also, the carrying out of environment works involves the prior obtaining of approvals, permits and agreements. If is the case to spend the FG, the competent authority will have to put into practice the mine closure according to the Mine Closure Plan (a version that is updated to match all permit site specific conditions).

5.3.1 Site Preparation

The preparatory work may contain the following steps (not all types of works are required at all sites):

- topographic works (compulsory works),
- deforestation of trees and shrubs,
- cleaning the land, mechanized scarification,
- uncovering the vegetal layer or the degraded land,
- demolition of some old constructions and the transport of the resulting materials, works complementary to the works of earthworks (the depletion of surface waters on the land intended for future construction).

It is necessary to create social-administrative spaces, to ensure the living conditions, storage of materials, etc., networks for utilities and installations related to their production, communication paths, as well as workshops (carpentry, blacksmiths, mechanics, etc.), prefabricated polygons, concrete stations, mortar, ballast and quarries stations, etc. In the case of mine closure and environmental rehabilitation works there would be already existing infrastructure available for the selected third-party company to be used. The contractor must check the situation and establish a site-specific budget for site preparation. If the existing infrastructure and buildings are to be removed according to the last approved version of the Mine Closure and Rehabilitation Plan, then the contractor will need to install temporary facilities.

Figure 90: Site preparation

Ground cleaning operation represents the removal from the ground of the residues of wood material from the deforesting, of the stones, of some industrial waste or even of the vegetation of bog. It is possible to work with several machines simultaneously. In order to remove the pond vegetation, water drainage and water removal measures will be taken first. The vegetation can be best removed with two-piece gravel bucket excavators. The transport is done with the dumper. Cranes and dumpers can be used to collect and dispose of large waste. The small waste will be collected by bulldozers and front loaders and will be transported by dumpers. The used loaders can have metal wheels with crampons and cups made of metal grids.

5.3.2 Earthworks

The main earthworks are excavations and fillings. Other earthworks are levelling and compaction. The volumes of these earthworks are measured as follows:

- excavations: the earth in its natural state (before excavation, unpaved)
- fillings: the ground put into work and compacted according to the project

The dimensions of the excavations are: length, width, the depth to the working height or the height to the working height. The level curves according to a situation plan represent the intersection of the natural relief with level plans (horizontal). On a situation plan, a horizontal plan is parallel to the level curves and the maximum slope line of the terrain is perpendicular to it.

The earthworks are represented in the project by location plans that outline the works to be executed, with the necessary details. The calculation of the volumes of the earth works can be done:

- in the case of long works in relation to the other dimensions: channels, dams, ditches, etc.
- in the case of works with a large surface area in relation to the depth of the excavation (height of filling): platforms and systematization of lands, etc.

The following are the main earthwork activities in mining site rehabilitation:

Reshaping

Re-profiling of the waste rock body is a fundamental requirement in achieving long-term geotechnical stability. From a re-profiling point of view can be distinguished two distinct technical approaches:

- relocation of excavated material within the waste rock heap;
- relocation of excavated material outside the site.

Re-profiling of embankments and slopes

The outline of the landfill storage facility aims to:

- facilitating the installation of a stable long-term final cover,
- directing the running water from the re-profiled areas to the surrounding areas.

The profiling of the dam aims to:

- obtaining a stable surface in the long term and resistant to erosion;
- facilitating the installation of a final erosion resistant cover and reducing infiltration (if necessary);
- landscape integration of waste storage facilities.

The long-term stability of the dam and the slopes includes static and dynamics, as well as resistance to wind and water erosion. In the case of processing wastes and for various types of loading (dynamic, static), optimizing the rehabilitation process may consider reducing the content of water in the pores of the processing tailings body and the lowering of the water level.

To ensure stable drainage conditions of TMFs, it is advisable accelerating consolidation in areas along the drainage ditches where packages of fine tailings with large thicknesses and / or characterized by different degrees of sedimentation are found (forced consolidation through solid material).

Pavements within the mine site are generally constructed in the form of flexible pavements which are layered systems with better materials on top and inferior materials at the bottom. Gravel roads are used as base material. In mine closure pavement would be made by using local suitable materials to minimize cost. Reuse of tailings for road construction is a trend lately. Rip-rap layers are often installed at the base of cover layers.

Earthwork cost is very site specific and it will depend on the volumes and nature of the material that have to be manipulated including of both initial and final locations of it. Equipment for extracting, loading, transport, and unloading, spreading, levelling, compacting and other necessary operation in order to put the design into practice will be chosen to optimize cost for a site specific situation.

5.3.3 Fencing and Drainage

Fencing

Fencing of hazardous areas, where it is possible to do so, involves installing a physical obstruction to reduce the risk of unintentional entry into dangerous areas. Fencing acts as a warning, not a barrier: as with marking, where individuals are determined to enter affected areas, fencing will not prevent them from doing so. Fencing strands may be of any suitable durable material including wire, string, synthetic cord or tape. Uprights may include trees, buildings or existing structures and posts erected as part of the warning system. Warning signs must be attached to the top strand of the fence. Wherever fencing is erected, it must be monitored and maintained to ensure its longevity. This can require significant resources. Special facilities would require installing chain-mesh/chainwire security fencing. Cost will be given by the type of fence, length and the location where the fence will be installed, and it will be site specific.

Drainage

In this category are included the works of removing of water from the site on which the earthworks are to be performed. Removal of surface water that flows on the site can be done by the following methods:

- the creation of channels (gutters) for gravitational drainage of water to neighbouring areas with lower elevation or to the outlets (rivers, lakes, sea, ocean),
- creation of a drainage system (pipes or ditches filled with granular material),
- the creation of wells from which to pump water,
- direct water pumping.

To prevent water infiltration to the site, works can be carried out upstream to collect waters and direct them to areas of no interest, to water treatment stations or even to a sewerage system.

5.3.4 Demolition / Decommissioning

When old buildings or parts of buildings are found on the site, they will have to be decommissioned and the resulting material will be transported to a storage place established and approved by the local and environmental authorities. There are two categories of constructions that may be subject to demolition:

- constructions developed vertically,
- constructions developed at ground level or buried.

The demolition technologies depend on the shape and size of the construction and are designed according to the used equipment: the bulldozer, the hydraulic excavator, the crane with metal ball hanging in the hook, the machine with telescopic boom bearing platform, the pneumatic or hydraulic hammer mounted on the excavator, drilling installations with thermal torch or hydraulic spear (monitor gun). Pneumatic hammers or other hand tools (hammers, chippers, welding machines for cutting, electric saws, etc.) can also be used. In certain situations, it is possible to resort even to the demolition with the help of excavators, explosives, etc.

Material resulting from the demolition can be loaded with excavators, front loaders, claws and cranes and will be transported by trailers, dumpers or hand machines (wheels, dumpers, etc.). An important action during the demolition of the underground works as well as later, during the execution of the works of earthworks and foundations, is the identification and protection of the networks of electricity, water, sewerage, gas, telecommunications, etc. These networks must be specified on the situation plan and in the field by picketing with stakes or other signals. Cost of demolition must be evaluated based on dimensions, location and the foreseen technology.

5.3.5 Placing Back Extractive Waste into Excavation Voids

There are three types of fill that can be performed simultaneously with the mine operation or at its completion, there is also the alternative of closing without filling: Total refilling can be done by mining mass transfer (if the operation is on-going) or by relocation of sterile material, including landscaping. Partial fill or stabilization of slopes is put usually in practice to mitigate or modify visual impact and to increase the stability of the pit slopes. Sometimes it is used as a compromise solution meant to replace total fill. Simultaneous refilling is usually used at mine sites with multiple quarries where execution plans allow direct storage of sterile rocks in one of the quarries (indoor waste rock heaps). Figure 91 illustrates forms of filling. For the mine operator, pit fill could mean shortened and potentially less costly downhill haulage routes, and a potential way to dispose of reactive (acid-generating) waste rock.

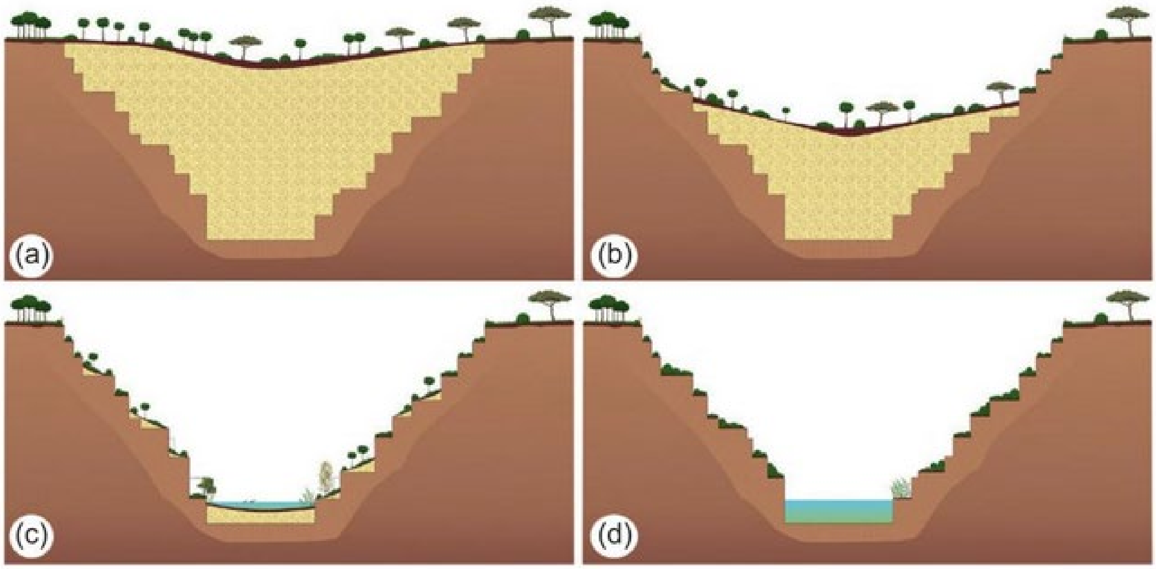


Figure 91: Scheme of an open-pit mine morphological reclamation, including landscaping possibilities. (a) Complete filling for restoration of the original agroforestry uses or the implementation of new uses, (b) partial filling for rehabilitation of pre-mine uses for implementation of new uses (e.g. recreation), (c) minimal selective filling and treatment of rock faces, tips, and embankments for replacement activities (e.g. recreation, lakes, wetlands), and (d) maintenance of morphological characteristics of the open pit with vegetation development (Favas et al. 2018)

This method is advantageous from the point of view of costs, reduces the surface area and volume of the waste rock heaps, decreasing in the same time efforts to remedy the waste rock heaps and allowing productive use of land in the post-closure phase.

Filling of drilling holes and other excavations:

Underground holes (especially near the surface), exploration drill holes and discovery areas that can contribute to surface destabilization, must stabilized by filling. If the location of an underground void is not known exactly, investigative drills and video surveys will be carried out to enable accurate understanding of the situation of these goals. For filling of underground holes, drill holes and other open areas, the same materials can be used as in the case wells and galleries.

5.3.6 Relocation

Depending on the pollution potential, the size and volume as well as the availability of an alternative location, the closure solution for mine waste heaps might be relocation. Practically, mine waste heap material can be used as consolidation material for TMFs or for filling of open cast mining sites. In such a case, the material will be hauled by dozers and transported by trucks to the alternative disposal location.

5.3.7 Groundwater Protection through Cut-off Wall

A cut-off wall is a waterproof underground wall, which on the one hand prevents groundwater from flowing into the opencast mine, on the other hand secures the natural groundwater level in the vicinity of the opencast mine and thus protects water bodies and wetlands. The use of a sealing wall is linked to certain geological conditions.

5.3.8 Shaft and Adit Closure

A shaft is defined as a vertical or inclined permanent opening that gives access and services various levels of a mine. An adit is an entrance to an underground mine which is horizontal or nearly horizontal. An Illustration of typical shafts and adits is given in figure 92.

Figure 92: Illustration of possible shaft (left) and adit (right) entrances

Shaft closure

The type and dimensions of the opening to be treated govern the choice of closure method. The size, shape, depth of shafts determines the necessary quantity of material for filling and design-sizing other safety techniques. The full filling technique requires to establish the number, size and extent of connections with other openings (shafts, tunnels) and of the main service area at the lowest level. Knowledge of voids located at a shallow depth close to the works (abandoned infrastructure or tunnel, underground worksite) is important, irrespective of the selected method of treatment. The presence of cavities or ducts must absolutely be assessed when there is a risk of escape of mine gas, which can migrate into the voids. The potential presence of pollution vectors in the abandoned works (waste, acid mine water) should be assessed to evaluate the effects of water on the closing-off works. An important aspect to consider for the evaluation of shafts long-term stability is the possible degradation of the materials (shaft lining, capping, plug).

Taking into account the excess costs generated by problems of maintenance and safety, permanent sealing-off of the openings appears preferable. If access is required, the used techniques should limit the risks and render them acceptable. Costs should include not only the safety works but also upkeep and maintenance. The filling of wells and shafts can be done using: crushed hard rock, non-cohesive rock (gravel, sand), sterile rock, waterproof, cohesive filler (concrete).

Adit closure

Choosing the appropriate closing or rehabilitation technology depends on the following factors: the location of the gallery in relation to the surface, geological and hydrogeological conditions, function of the gallery, the general state of the gallery in terms of stability and accessibility. In order to achieve a correct closing of the abandoned galleries, the following constructive solutions, compatible with best practices can be adopted:

- construction of a precast concrete or concrete dam at the mouth of the gallery
- fill a portion of at least 10 m in length immediately behind the mouth gallery with a fill (the total length of the fill area varies depending on ensuring surface stability on gallery alignment)
- complete refill of the gallery
- closing the gallery mouth by detonating the galleries sunk in view of restoring the natural environment

5.3.9 TMF Dewatering/Stabilisation and Covering

Main scope of those preliminary works of TMF stabilisation is a) to directly extract the supernatant water that is usually sent to a treatment plant, and b) to get access to the tailings material for the implementation of the vertical drains to extract the pore water for further stabilisation (figure 92).

Typically, the supernatant water is pumped or drained off to take off free pore water from the surface. Porewater from the remaining sedimentation layers are drained off through vertical drains. Holes are drilled into the processing sludge (typically 3 m deep) to introduce vertical drains. Stabilisation of the complete system is performed through a geogrid, underlain by geofabric and drain mats (Figure 92). In general, the layered system is covered with 1 to 2 m of mineral soil or waste rock material to force tailings consolidation. A standard technique for forcing sediment consolidation is the subaquatic fill of extractive waste through hopper barge.

In the upper, statically relevant fine slime areas, bonded geofabric vertical wick drains are installed accelerating both the consolidation process and the required increase in shear strength. Vertical wick drains of 0.15 m width and 0.01 m height are deployed and typically installed at 1.5 m in a triangular grid spacing. The geosynthetic elements are placed at a depth up to 8.0 m, the arrangement of the drains is adjusted to the consolidation properties and shear strength distribution of the underlying ground.

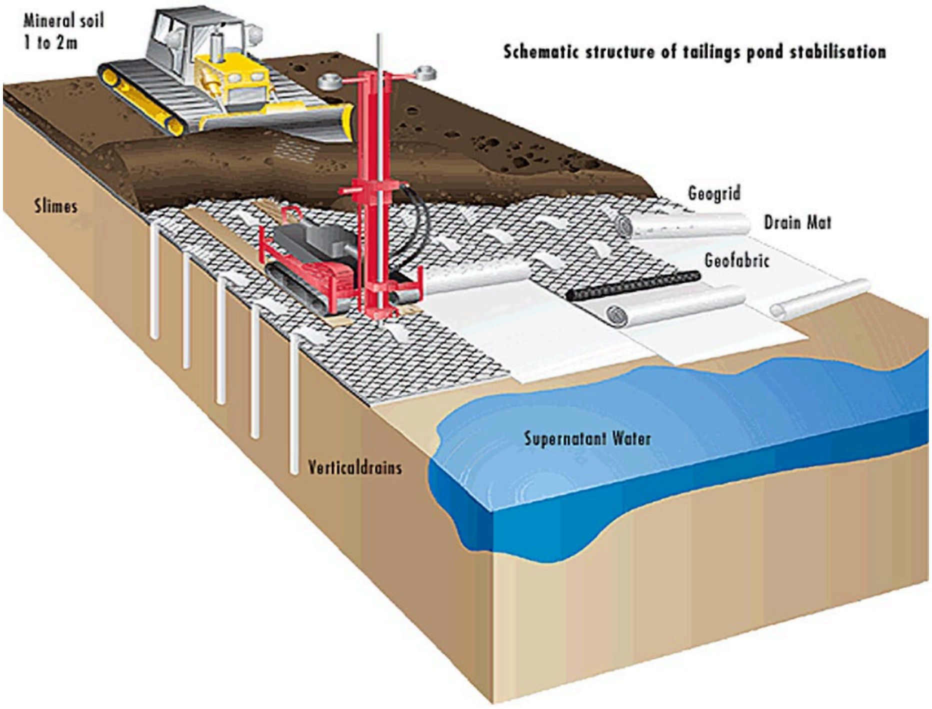


Figure 93: Stabilisation technology for tailings ponds: vertical drains in combination with a stabilisation package made of geofabric, drain mats, and geogrid. The system is covered with 1 to 2 m mineral soil or waste rock material to force consolidation (source: Wismut GmbH, 2019).

After TMF geotechnical stabilisation, an appropriate surface sealing must be applied.

5.3.10 Application of Surface Sealing

Installing of a soil cover system on waste rock heaps pursues one or more of the following objectives:

- minimizing the volume of infiltration and percolating water through the waste rock body to minimize the mobilization of pollutants from the waste into groundwater
- minimizing dust generation
- minimizing the penetration of oxygen into the body of the sterile rocks in view of avoiding the formation of acidic water, respectively of spontaneous combustion
- prevention of direct contact with hazardous waste
- development of a vegetation blanket for subsequent use

From the point of view of the rehabilitation possibilities specific to the objective, typically the following types of coverage are used:

- Permeable dry covers
- evapotranspiration covers
- Impermeable and low-flux dry covers

- Oxygen-consuming dry covers
- Capillary barrier
- Multi-layer covers with or without geomembranes or other sealing elements
- Reactive covers.

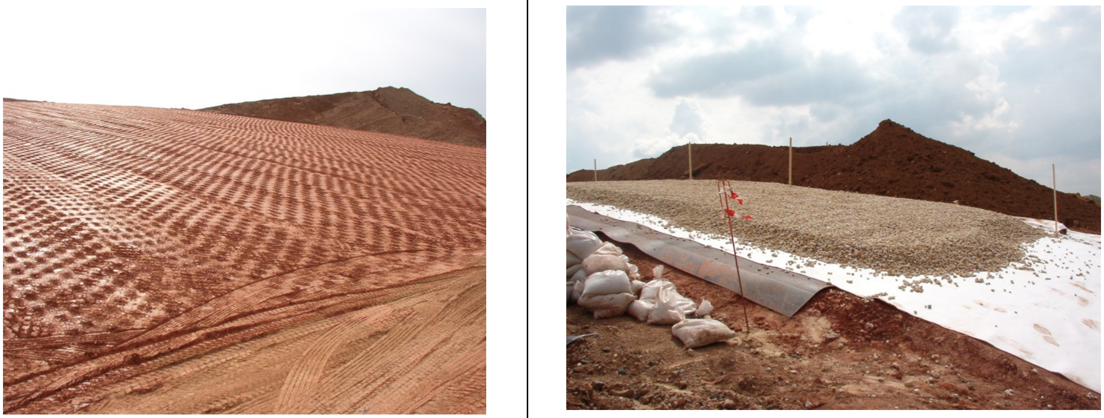


Figure 94: Installation of soil cover systems

The application of sealing systems requires a particular quality assurance that comprises the manufactured sealing element as well as the mineral soil to be used as cover. Further, the workability of a sealing component and / or a system must be demonstrated to the competent authority in a test field under construction site conditions before the sealing system is installed. In this context, the appropriate stability and sliding safety (according to the respective state of the art and in relation to the unfavourable on-site situation, e.g. steepest and longest embankment area) must be demonstrated to the competent authority.

Furthermore, quality management must be provided for every measure relating to the sealing of landfills (basic, intermediate and surface sealing). The following 3-stage quality management system is state of the art:

Prefabrication of materials / components / systems

- Self-monitoring of the manufacture by the manufacturer
- External monitoring of the production by a commissioned third party

Construction on the construction site

- Self-inspection of the executing construction company
- External inspection by a commissioned third party (commissioned by the client), which must be confirmed by the competent authority

Inspection through the Regulatory Body

- carried out by the competent authority

The external auditor must have sufficient specialist and expert personnel and, as a prerequisite for official confirmation, the corresponding accreditations according to DIN EN ISO / IEC 17020 (as external testing body) and according to DIN EN ISO / IEC

17025 (as testing laboratory). The mine operator is responsible for the costs of the external inspection.

Cover design for quarries and pits

In the case of the cover project, the same principles apply as in the case of the covers installed on the waste rock heaps. The quarry configuration includes the general angle of the slope and the height / width of the berms. Stabilization and rehabilitation of quarry's slopes may vary from keeping the original configuration of the slope, to reducing it or to filling application. Many quarries are not covered but flooded.

Construction of covers on TMFs

Arrangement of a soil cover on the surface of the TMF system related to the processing plant of mineral substances, aims to fulfil the same rehabilitation objectives as described for waste rock heaps. However, there are some specific problems that must be taken into account, namely:

- processing tailings usually contain large amounts of pore water, often at the saturation limit, at least in some parts of the tailings pond system, that inhibit consolidation
- Sedimentation / consolidation of the processing wastes can be significant in terms of subsidence. This must be taken into account to determine the optimum cover profile and installation technology
- Geochemical problems generated by the waste resulting from the processing of substances

Industrial minerals are more complex than in the case of the sterile rocks generated from mining. This fact influences both the selection of the types of cover and related technologies.

5.3.11 Reclamation / Revegetation

Vegetation blankets should be sown with grass for immediate protection against erosion, afterwards trees or shrubs can be planted for stabilization. If the predetermined conditions are met, the location of the waste rock heap may be left to the natural cycle of vegetation regeneration. To provide protection, temporary or permanent growth and normal vegetation development may be preferable the enclosure of the waste rock heap. Natural regeneration cycles (natural succession) have the advantage of presenting low costs or even zero.

The approach based on guided natural succession is based on the existence of natural analogues, such as certain biotopes, characterized by limited soil content and / or locally selective seeding / planting. This approach was designed to stimulate and speed up natural development processes. If the vegetation is to be installed on a multi-layer cover posed on the top of waste deposit that has also the role of stopping the entrance of the rain water into the waste material, than a special selection of the vegetation is to be carried out in order to avoid the damage of the insulation layer by the roots. Special maintenance measures against bioturbation must be used and this has a high cost influence.

5.3.12 Flooding

Flooding is an integral part of the mine closure and rehabilitation process. After completion of preparatory activities (refilling, stabilization, removal of contaminated machinery, recovery of recyclable metals, etc.), evacuation of mine water will be reduced and finally stopped. At this stage, the natural groundwater intake will lead to mine filling (figure 94, right).

To avoid subsidence and damage to surface constructions, as well as to diminish the impact on the environment as a result of the increase of the groundwater level, flooding the shallow horizons of the mine must be controlled by draining water by drainage or pumping and by the application of purification measures if the quality of the mine effluents is not compatible with the direct discharge in natural receivers. It will be necessary to monitor the groundwater level and quality, but in the long term, monitoring activities will be substantially reduced or they will cease. Flood strategies have, to a large extent, a preventive character. The main components of a flooding concept are:

- knowledge of the problems of geomechanically stability associated with growth of hydrostatic level and establishing a controlled flood execution plan
- early commissioning of water treatment plants
- drainage pipes
- pumping, unloading and waste management installations
- implementation of a monitoring system

Flood concepts and strategies must be tailored to the site specifics. It's necessary continuous updating of the concept underlying flood and its adaptation in depending on the results of the flooding monitoring.

Quarry/pit flooding

Flooding a quarry generally offers the opportunity to create new ecological habitats (figure 94, left). Depending on the mineralogical conditions of the rock-free surfaces, there are possibilities of generating acidic waters with high content of heavy elements at the quarry’s slopes level. Water management needs to be carefully planned so that does not endanger wildlife. If the acidic water generation on the slopes of the quarry cannot be prevented, drainage ditches will be set up to keep water from the slopes, away from the vegetated surfaces. For the sustainable management of quarry lakes, most used techniques are the following:

- installation of waterproof clay layers to prevent infiltration into underlying rock
- the application of specific methods to increase the pH (if applicable)
- sealing the boreholes to prevent seepage
- diversion of running water, around the slopes rich in sulphur, in order to not affect the lake water quality
- in-situ water treatment in the quarry proved to be a successful solution in conditions under which the minimization of generation and penetration of acidic waters can be ensured

Cost related to flooding is extremely site specific. A detailed calculation made by specialized designers is needed also for the assessment of long-term maintenance works and monitoring requirements.

Figure 95: Flooding of a quarry (left) and a lignite mining site (right)

5.3.13 Waste Disposal

In accordance with Article 5 of the Mining Waste Directive, the mining operator it is obliged to develop a waste management plan that will allow minimization the volume generated, treating, recovering and storing the mining waste, taking into account of the principle of sustainable development. From a closure point of view, the waste will be managed to reduce the degree of hazardous waste by:

- placing extraction waste back into the excavation hole after extraction of the useful mineral substance, to the extent that is technically and economically feasible and to the possible extent which corresponds to the environmental standards at community level and the requirements of the EWD, in cases of relevance;
- placing top soil to support vegetation on the former sites, after the closure or if this is not possible from the point of practical view, re-use of top soil elsewhere;

The waste will also be managed to ensure secure short-term and long-term storage of extraction waste, in particular by taking into account these aspects during the design phase or by managing the waste during the operational or post-closure period by choosing a design solution that:

- requires a minimum of control and management of the closed storage arrangement or finally allows the monitoring to be waived
- prevents or at least minimizes the long-term negative effects, for example, those that can be attributed to the migration of atmospheric pollutants or aquatics from the landfill
- ensures the long-term geotechnical stability of any structures, embankment or waste rock heap that rises above the initial topographic surface

Non-acidic waste water waste

In the case of waste that does not have a significant potential for generating acid water, the design criteria for the covering layer are the following:

- prevention of accidental access to waste
- providing vegetation support
- improving the visual appearance
- prevention of dust formation from the surface of the waste
- erosion control

Waste with potential of generating acid water

If the potential acid waste water generating waste is disposed of separately without insulation in acid-free waste, the design criteria of the cover shall be included in plus the following:

- minimization of water infiltration in the mass of waste
- minimizing oxygen intake in the mass of waste

Waste separation

Mining activities may result in sulphurous rocks which may have a potential for acid water formation. Sterile rocks will be separated by capacity for generating acid water. Separation and mixing of the sterile material according to the potential of acidity generation is part of the best available techniques category, which is advantageous from the environmental point of view and saves the efforts necessary to close the mines in from the point of view of the management of acid effluents.

5.4 Cost-relevant Activities for the FG Calculation and Periodic Adjustment

The cost items that contribute to investments include:

- investment costs for technical works
- Related investment specific costs like financing and program management costs, planning, design and supervision costs, community mobilization and hygiene promotion costs
- Operation and Maintenance costs
- Variation of costs according to different implementation methods have to be analysed and necessitate division of cost estimates into local available materials and purchased materials, unskilled labour and skilled labour

Within each component/ technology, a consistent Bill of Quantities (BoQ) has to be developed based on engineering estimates that can be verified and updated, using, where possible the lowest unit of analysis (plant, labour and materials) together with preliminary and general items.

Within each component/ technology, the identification of major underlying variables that have a default value but which also can be adjusted to suit regional or site-specific considerations. The regional variations like transport (e.g. average distances to regional commercial centres, proportion of gravel and tarred roads), hydro-geological conditions (e.g. drilling success rates, average depth and yield of wells and boreholes) and topographical conditions (e.g. average pumping heads for raw water, transmission and sewerage have to be considered. Within the component/ technology specific BoQs must contain further detailed design variables that can be adjusted to fine tune the cost estimates to site specific situations.

5.4.1 Site Investigation

Site investigations usually include drillings of different types, toposurvey, settlement and water balance measurements, stability measurements, sampling, as well as soil mechanical and chemical analysis. Further, there might apply geophysical measurements. Table 12 shows the unit price range for site investigations.

Table 12: Unit price range for site investigations

Description			
Topographical survey	**Unit**	**Low range [€]**	**High range [€]**
Costs for the first topographical survey incl. creation of site plans and cross sections (digital and analog)	ha	600	1,000
Survey during construction, pegging out, intermediate site plans and cross sections (digital and analog)	ha	180	324
Survey after the end of construction, as completed drawings (digital and analog)	ha	806	1,250
Restoration of boundary stones incl. cadastral survey	lump-sum	390	450

Technical site investigation	**Unit**	**Low range [€]**	**High range [€]**
Drilling without well installation			
Up to 5 m depth	pc	150	500
Up to 10 m depth	pc	300	800
Up to 20 m depth	pc	2,000	4,000
Up to 50 m depth	pc	10,000	30,000
Up to 80 m depth	pc	20,000	50,000
Drilling with well installation			
Up to 5 m depth	pc	250	700
Up to 10 m depth	pc	2,000	4,000
Up to 20 m depth	pc	5,000	10,000
Up to 50 m depth	pc	20,000	50,000
Up to 80 m depth	pc	30,000	80,000

Sampling from a well			
Up to 5 m depth	pc	100	200
Up to 10 m depth	pc	200	400
Up to 20 m depth	pc	350	700
Up to 50 m depth	pc	500	1,000
Up to 80 m depth	pc	750	1,500
Sampling surface water			
Up to 1 m depth	pc	50	150
Sampling surface soil			
Up to 1 m depth	pc	50	150

Analytics for site investigation	**Unit**	**Low range [€]**	**High range [€]**
Soil mechanical Investigation			
Soil mechanic lab investigation	pc	150	400
Chemical Investigation			
GC-MS Screening	pc	90	220
Radiometric Investigation			
Spectrometric analyses	pc	90	220

Investigation of water balance and sub-stances transport (depending on size)	**Unit**	**Low range [€]**	**High range [€]**
Measurements for water balance			
Installation of climate station incl. data logger	pc	3,000	7,000
Soil water measurement equipment			
Installation of soil measurement station	pc	1,500	5,000
Evaporation measurements (TMF)			
Installation of evaporation pan incl.	pc	1,500	5,000
Calculation of water balance			
Consulting and reporting	pc	3,000	15,000
Pollutants assessment			
Consulting and reporting	pc	3,000	15,000
Substances transport modelling			
Consulting and reporting	pc	25,000	60,000

The unit price range as listed for site preparation investigations apply as well for environmental monitoring investigations that usually include also sampling and different types of analytics.

5.4.2 Site preparation and quality management

The following tables under table 13 summary include the costs for:

- preparation of the site for the planned renovation works
- setting up the construction site
- topographical survey of the actual state before start of construction, surveys during construction and surveys after completion of construction
- building of construction roads
- occupational health and safety and
- quality management.

Table 13: Unit price range for site preparation and quality management

Site preparation	**Unit**	**Low range [€]**	**High range [€]**
Clearance of heavy vegetation from area incl. disposing	m²	0.25	0.55
Felling trees, trunk diameter 10 – 30 cm, incl. disposing	pc	33	58.00
Preparation of areas for construction site equipment, storage spaces and technologically required areas and removal after completion of works	m²	9.60	21.40

Description			
Site facilities	**Unit**	**Low range [€]**	**High range [€]**
Set up heatable site container (office container and container for the employees) and removal after completion of works	lump-sum	1,543	2,160
Operation of site container (office container and container for the employees)	month	542	651
When working in contaminated areas, set up a black and white plant and removal after completion of works	lump-sum	3,514	6,502
Operation of black and white plant	month	598	928
Erection and clearing of a mobile tire washing plant including costs for water connection, consumption meter, water consumption, removal and orderly disposal of the wastewater	lump-sum	2,570	6,425
Provision and operation of the tire washing system	week	319	574
Provision of the site equipment in the event of construction interruptions not caused by the contractor	week	29	77

Establishing of all needed media connections and removal after the end of construction	lump-sum	1,120	2,800
Erection, provision and removal after completion of works of container with cover (capacity over 10 to 15 m³) for separate collection of unsuitable waste for reinstallation, e.g. scrap, hazardous waste, etc..	pc	21	26
Clearing of all machineries, plants etc. from the construction site. Preparation of used areas and paths according to the original condition or the area planning	lump-sum	840	1,302

Description			
Topographical survey	**Unit**	**Low range [€]**	**High range [€]**
Costs for the first topographical survey incl. creation of site plans and cross sections (digital and analog)	ha	600	1,000
Survey during construction, pegging out, intermediate site plans and cross sections (digital and analog)	ha	180	324
Survey after the end of construction, as completed drawings (digital and analog)	ha	806	1,247
Restoration of boundary stones incl. cadastral survey	lump-sum	390	450

Description			
Manufacture of temporary roads (to all types of facilities to be rehabilitated)	**Unit**	**Low range [€]**	**High range [€]**
Construction of temporary roads (levelling, compacting, geotextile, ballast – thickness 0,5 m) incl. repair and maintenance works	m²	12.50	16.30
construction of temporary roads (levelling, compacting, geotextile, ballast – thickness 0,3 m) incl. repair and maintenance works	m²	8.00	10.45
Removal of temporary roads after the end of construction	m²	3.75	4.10
Quality management for geotechnical parameters	m²	0.08	0.12

Description			
Health and safety at work	**Unit**	**Low range [€]**	**High range [€]**
Development of the regulations for health and safety at work	pc	990	2,270
Safety engineer - Coordinating and monitoring of compliance with regulations for health and safety at work	d	380.00	650
Development of Occupational Health and Safety Plan acc. to ISO 45001	pc	563	1,080
Installation, maintenance, operation and removal of overpressure driver cabin with filter system	pc	1,826	9,956

Provision of personal protective equipment for work in contaminated areas (depending on the number of workers)	lump-sum/employee	317	432

Description			
Site facilities for quality management	**Unit**	**Low range [€]**	**High range [€]**
Set up heatable site container (office and quality control laboratory) and removal after completion of works	lump-sum	2,897	4,056
Operation of site container (office and quality control laboratory)	month	543	651

Description			
Site facilities for fibreglass	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Delivery of all necessary equipment, setting up the construction site container, setting up storage spaces, including removal after completion of works	lump-sum	38,900	81,850

Description			
Site facilities for installation of groundwater monitoring wells	**Unit**	**Low range [€]**	**High range [€]**
Delivery of all necessary equipment, setting up the construction site container, setting up storage spaces, including removal after completion of works	lump-sum	4,588	9,863
Relocation of drilling equipment	pc	41	651

5.4.3 Earthworks

The cost of earthworks depend on the type of operation for profiling and site preparation works (like excavation, loading to trucks, area profiling with soil relocation, compaction, slope profiling, transportation by vehicles, putting waste rock), type of equipment (excavators, excavators-dragline, backhoe, dozers, pneumatic trailer-rollers), the equipment's capacity and the handled material (soil class, waste rock). Dimensional elements (volume, deployment distance) and work technology (layered deposition, slope angles) have to be considered.

Further earthworks are demolition works (demolishing of reinforced concrete structures, excavation of solid reinforced concrete, breaking of reinforced concrete structures, arc welding when dismantling metallic structure, demolition of the brick walls, removal of railway tracks sleepers and ballast, removal of the asphalt paving and subgrade, construction garbage profiling, crushing of the demolition material into a transportable size, loading/unloading works during transportation), type of equipment, the equipment's capacity. Dimensional elements (volume, deployment distance) and work technology have to be considered. Also, the cost that has to be paid for deposition of construction and demolition waste if the case may be. The cost of pavement depends on the material used for pavement (crushed stone, asphalt-concrete mixes, concrete, the materials can be found and supplied from variable distances) and the purpose of the pavement. Table 14 illustrates the price range for earth works. Note: waste disposal is given in tons because in practice it is usually weighed for performance proof, while soil installation is given m³ because the performance proof is usually based on topo-survey data).

Table 14: Price range for earth works.

Description	**Unit**	**Low range [€]**	**High range [€]**
Earthworks			
Excavation of garbage from the construction site, load in provided containers	t	2.20	4.00
Containers loading on trucks and transportation of containers, up to 5 km and dumping the garbage	m³	9.45	12.75
Removal of waste rock and loading on trucks	m²	0.70	3.00
Putting the waste rock; layered compaction by dozers	m³	1.40	1.90
Excavation of top soil loading and disposing	m³	2.55	7.35
Excavation of soil, liquid to mushy soil type incl. loading	m³	10.00	18.46
Excavation of soil, light and medium heavy soil type incl. loading	m³	8.20	15.70
Excavation of heavy, soil type to light rock incl. loading	m³	14.75	25.60
Excavation of heavy rock incl. loading	m³	83.20	128.25
Supply and installation of subsoil, installation in layers, layer thickness ≤ 0.3 m, D Pr ≥ 92 %	m³	8.60	13.70
Supply and installation of topsoil, installation in one layer, layer thickness ≥ 0.1 m, without compaction	m³	12.25	18.40
Delivery of soil for slope profiling, layer by layer, layer thickness up to 30 cm	m³	15.75	30.85
Delivery and implementation of bentonite for soil improvement and stabilisation	m³	31.00	70.00
Delivery and implementation of lime for soil stabilisation	m³	11.80	39.00
Transportation by vehicles, distance 1 km	t	5.15	9.60
Transportation by vehicles, distance 2 km	t	6.80	12.75
Transportation by vehicles, distance 15 km	t	24.60	46.05
Area profiling with soil relocation to 5 m by dozers	m²	1.15	3.35
Area profiling with soil relocation to 10 m by dozers	m²	1.24	3.90
Soil compaction, layer thickness up to 30 cm	m²	0.55	1.00
Deliver soil and layer-by-layer installation with compaction as surface profiling, layer thickness up to 30 cm	m³	13.70	24.60
Description			
Quality management	**Unit**	**Low range [€]**	**High range [€]**
Geotechnical Parameters			
Delivered filling material	m³	0.75	0.85
Relocation material	m³	0.75	0.85
Chemical Parameters			
Delivered filling material	m³	0.05	0.10

Materials removed for disposal	m³	0.01	0.05
Radiometric survey			
Spectrometric analyses	pc	90.00	220.00

5.4.4 Fencing and Drainage

Cost for fencing should consider supply and placing temporary and definitive fence and access gates. Typical fence for various purposes would lead to specific material and dimensions. Foundation and earthworks should be included. The length of the fence and the ease of access would be key elements in the cost value range. Table 15 illustrates the unit price range for fencing.

Cost for drainage should consider water discharge channels installation, open channels at roadsides, construction of water discharges from longitudinal drainage channels, installation of drainage pipes, installation of precast concrete manhole, installation of single-entry water discharge reinforced concrete round culverts under dams. Table 16 shows the unit price range for drainage. For channels operation such as manual clearing of soil in ditches and construction of reinforced concrete walls and bottom of the channel will must be considered case by case. Length and typical cross section would be key elements in the cost value range. The method of supplying the concrete and the steel reinforcement elements would have to be considered when considering the cost range.

Table 15: Unit price range for fencing

Description			
Fencing	**Unit**	**Low range [€]**	**High range [€]**
Securing only for the construction period			
Deliver and install of warning and prohibitions signs incl. removal after the end of construction	piece	19.30	23.20
Delivery and installation of barrier tape on earth spikes (2 pcs / 10 m) incl. removal after the end of construction	m	0.95	1.40
Supply and placing building site fence, height 2,0 m, incl. base stands along editing site boundary incl. removal after the end of construction	m	9.60	17.30
Deliver the barrier and install it at the entrance including all necessary parts and services. Clear width 6 m, incl. concrete foundations and earthworks incl. Removal after the end of construction	pc	1,742	2,090
Keeping and maintenance of security systems	m and month	2.20	2.90
Permanent securing			
Deliver and install of warning and prohibitions signs	piece	27.30	31.50
Supply and placing fence, height 1,8 m, incl. concrete foundation and earthworks,	m	20.20	29.30
Supply and placing double wing gate, total width 3 m, incl. concrete foundation and earthworks	pc	2,087	3,027

Table 16: Unit price range for drainage

Description	Unit	Low range [€]	High range [€]
Drainage			
Construction of drainage channel without fastening (only soil excavation, light and medium heavy soil type), bottom width up to 0.5 m, depth up to 0.5 m	m³	7.70	10.10
Construction of drainage channel without fastening (only soil excavation, light and medium heavy soil type), bottom width up to 1.0 m, depth up to 1.0 m	m³	8.10	11.30
Fastening of drainage channel with ballast, Layer thickness up to 0,2 m	m²	1.05	1.90
Fastening of drainage channel with pavement	m²	8.10	11.30
Fastening of drainage channel with reinforced concrete elements, bottom width 0.5 m, channel thickness up to 0.75 m, slope inclination 1:2	m	225	292
Securing inlets and outlets and embankment foot with hydraulic piles in concrete	m	111	144
Delivery and installation of a sheet pile	**m²**	**252**	**453**
Installation of drainage pipe, polyethylene, d= 300 m incl. pipe trench excavation and filling, laying depth up to 1.0 m	m	120	173
Installation of drainage pipe, polyethylene, d= 300 m incl. pipe trench excavation and filling, laying depth up to 2.0 m	m	133	193
Installation of drainage pipe, polyethylene, d= 400 m incl. pipe trench excavation and filling, laying depth up to 1.0 m	m	165	239
Installation of drainage pipe, polyethylene, d= 400 m incl. pipe trench excavation and filling, laying depth up to 2.0 m	m	175	254
Building of pipe culvert under dam, reinforced concrete pipe d = 0.5 m, incl. earth works	m	1548	2,245
Installation of precast concrete manhole, d=1.0 m and h=1.0 m incl. earth works	pc	908	1,362
Installation of precast concrete manhole, d=1.0 m and height up to 2.0 m incl. earth works	pc	1,385	2,078

5.4.5 Demolition / Decommissioning

Demolition of constructions developed at ground level or buried may include: road clothing, industrial platforms, bunkers, underground galleries, pipelines, etc. Demolition works include also scaffolding and housing of buildings to be demolished. Table 17 illustrates the unit price range for demolition / decommissioning.

Table 17: Unit price range for demolition / decommissioning

Description	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Demolition / Decommissioning			
Demolishing of reinforced concrete structures by hydraulic hammer	m^3	434	608
Construction garbage profiling,	m^3	1.90	3.00
Loading/unloading works during transportation. large parts of prefabricated reinforced concrete with mass up to 3 t: unloading	t	32.45	51.90
Breaking of reinforced concrete structures of reservoir and other concrete facilities by hydrau-lic hammer	m^3	418	628
Arc welding when dismantling metallic structure	t	635	889
Loading/unloading works during transportation. steel works with mass up to 1 t: unloading	t	69	90
Demolition of the brick walls (buildings)	m^3	26.80	41.55
Demolition of larger buildings	m^3 building volume	60.00	93.10
Removal of railway tracks, cleaning of material for reutilisation, evacuation	m	10.00	45.50
Removal of railway sleepers, transport to the foreseen storage area, unload - storage area, TD up to 15 km	pc	5.00	7.75
Removal of railway ballast, load on, transport to the storage area, unload - storage area, TD up to 15 km	m^3	17.20	23.20
Dismantling of concrete / reinforced concrete single foundations and walls incl. crushing into a transportable size, load on, transport to the stor-age area, unload - storage area, TD up to 15 km	m^3	50.10	72.65
Demolition of concrete channels, crushing of the demolition material, load on, transport to the storage area, unload - storage area, TD up to 15 km	m	10.50	16.30
Demolition of smaller disjointed reinforced areas, crushing of the demolition material, load on, transport to the storage area, unload - storage area, TD up to 15 km	m^2	19.80	30.70

Quality management	**Unit**	**Low range [€]**	**High range [€]**
Chemical parameters for disposal	m^3	0.05	0.15
Spectrometric analyses	pc	90.00	220.00

5.4.6 Filling

The cost of fill also depends on the dimension and location (the distance from the source of filling material, ways of access) of the type of mining element that requires fill (ditches, pockets of pits and holes, sinkholes, trenches and pits) the type of used equipment and its capacity also the class of filling material (soil, waste rock). The cost of operations that consume liquid concrete for filling must take into consideration the method of supplying the concrete when considering the cost range. Table 18 shows the unit price range for filling.

Table 18: Unit price range for filling

Description	**Unit**	**Low range [€]**	**High range [€]**
Filling			
Layer-by-layer installation of compactable overburden, located at the construction site, for the pit filling, installation according to project specifications, layer thickness up to 0.3 m	m³	1.90	4.05
Delivery and layer-by-layer installation of recycled material (brick and concrete breakage) for the pit filling, installation according to project specifications, layer thickness up to 0.3 m	m³	6.30	11.65
Delivery and layer-by-layer installation of compactable soil for the pit filling, installation according to project specifications, layer thickness up to 0.3 m	m³	13.70	24.60
Layer-by-layer installation of compactable overburden, located at the construction site, for the slope stability, installation according to project specifications, layer thickness up to 0.3 m	m³	3.81	9.25
Delivery and layer-by-layer installation of recycled material (brick and concrete breakage) for the slope stability, installation according to project specifications, layer thickness up to 0.3 m	m³	8.20	16.85
Delivery and layer-by-layer installation of compactable soil for the slope stability, installation according to project specifications, layer thickness up to 0.3 m	m³	15.75	30.85

Quality management	**Unit**	**Low range [€]**	**High range [€]**
Geotechnical parameters			
Delivered filling material (soil and RC-Material)	m³	0.75	0.85
Relocation material	m³	0.75	0.85
Soil mechanical Investigation			
Soil mechanic lab investigation	pc	150	400
Chemical Investigation			
GC-MS Screening	pc	90	220

Radiometric Investigation			
Spectrometric analyses	pc	90	220
Chemical Parameters			
Delivered filling material	m³	0.05	0.10
Materials removed for disposal	m³	0.05	0.15

5.4.7 Relocation

Relocation activities are part of the earthworks. The unit price range in included in table 14.

5.4.8 Hydraulic and Geochemical Water Protection Options

Diaphragm walls are walls made of concrete or reinforced concrete, which are either concreted in liquid-supported earth slots using the contractor method or manufactured by hanging precast concrete elements (prefabricated slot wall). Diaphragm walls can be made to great depths (100 m) and nominal thicknesses from 0.45 m to 1.50 m. Table 19 illustrates the unit price range for hydraulic and geochemical water protection options.

Table 19: Unit price range for hydraulic and geochemical water protection options

Description	**Unit**	**Low range [€]**	**High range [€]**
Diaphragm walls			
Seepage control screen construction made of geodiaphragm onto dam surface	m²	198	250
Concrete nails for geodiaphragm	pc	16.50	21

Description	**Unit**	**Low range [€]**	**High range [€]**
Permeable Reactive Barriers / Reactive walls			
Construction of reactive wall	m²	200	300
Filling of reactive wall: zero valent iron	t	286	440
Filling of reactive wall: organic material	t	20	30

Description	**Unit**	**Low range [€]**	**High range [€]**
Funnel and gate			
Construction of funnel and gate	m²	200	300
Filling of funnel and gate: zero valent iron	t	292	664

Description	Unit	Low range [€]	High range [€]
Groundwater treatment – ISCO system (≤ 10 wells, injection performance 0,5 - 5 m³/h, Fenton's reagent or permanganate)			
Construction of well gallery and injection system	pc	8,500	9,000
Operation of injection system	monthly	9,000	10,000
Demolition of well gallery and injection system	pc	6,000	7,000

Description	Unit	Low range [€]	High range [€]
Anoxic Limestone Drains / Reducing and Alkalinity Producing Systems (RAPS) in shafts and adits			
Construction drainage trench	m	25	28
Delivery of alkaline material as buffer	m³	15	30

Description	Unit	Low range [€]	High range [€]
Constructed wetland			
Construction of pond structure, 100m³ pond volume, including liner (cost depending from liner type)	pc	2,500	4,000
Installation of inlet and outlet structures	m	25	75
Planting cost (depending on planting methodology and type of plants)	ha	2,000	3,500

5.4.9 Shaft and adit closure

Table 20 shows the unit price range for shaft closure, table 21 for adit closure. The cost of shaft closure depends on the dimension and location (the distance from the source of filling material, ways of access) and the proposed closing technology (in terms of filling or only capping with a reinforced concrete slab including ways to handle the concrete handling, manual preparation on site or by using a mobile concrete pump) that is depending on the bedrock surrounding the shaft. The method of supplying the concrete and the steel reinforcement elements would have to be considered when considering the cost range. The cost of added closure depends on the dimension and location (the distance from the source of filling material, ways of access) and the proposed closing technology (in terms of filling or only capping with a reinforced concrete slab) that is depending on the bedrock surrounding the shaft. Costs are very site specific due to the particular setting of each location.

Table 20: Unit price range for shaft closure

Description	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Shaft closure			
Delivery of and filling with crushed rock, Shaft filling	m³	45	100
Delivery of and filling with debris, Shaft filling	m³	20	60
Reinforced concrete slab installation (with mobile concrete pump)	m³	178	250
Concrete bedding preparation, concrete B 7,5	m³	75	120
Install reinforced concrete slab;	m³	180	245
reinforcing 70 kg/m³			

Table 21: Unit price range for adit closure

Description	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Adit closure			
Construction of shallow ditch in adit bottom, incl. earth works	**m**	120	152
Construction concrete strip foundation	m³	140	204
Construction of brick wall (single sections)	m³	129	187
Installation of drainage pipe, polyethylene, d= 200 mm incl. earth works	m	133	150
Cuts construction into sides by air-hammers	m³	330	413
Seepage control screen construction made of geodiaphragm onto dam surface	m²	198	250
Concrete nails for geodiaphragm	pc	16	21
Protective covering with stones of the drain pipe, stone size - 200 mm	m³	33	40
Liquid concrete filling of adit (by mobile concrete pump)	m³	129	174
Beam elements installation to compensate uplift	m³	513	600
Contouring works at adit portal	m³	104	130

5.4.10 TMF Dewatering and Closure

Cost of TMF Dewatering and Closure depend on size and settlement status of the TMF. The TMF sediments that are more settled while lead to a shorter dewatering time span and shorten the closure time. TMFs that are needed to be closed through vertical drains and fostered rock stabilisation need additional closure activities. Note: prices quoted in table 22 include all necessary earthworks. Drainage layer material must consist of quality proven material that must also meet particular chemical requirements, depending on water to be drained. Quality certificates are required here (in-house and third-party testing) and, if necessary, an extraction location far away. Table 22 illustrates the unit price range for TMF dewatering and closure.

Table 22: Unit price range for TMF dewatering and closure

Description	**Unit**	**Low range [€]**	**High range [€]**
TMF Dewatering and Closure			
Delivery and installation of a gravel base	m³	25.75	41.20
Delivery and laying of excavator mats incl. transport	m²	8.35	13.50
Delivery and installation of geotextile incl. quality management	m²	3.80	5.00
Delivery and installation of geo-grids incl. quality management	m²	7.25	11.60
Delivery and installation of drain mats incl. quality management	m²	7.80	12.45
Pressing in the vertical drainage (geotextile strips)	m	3.30	6.50
Delivery and installation of a drainage layer (gravel 16/32)	m³	62.45	99.90
Delivery and installation of a precast concrete manhole as pumping shaft, d=1.0 m and hight up to 2.0 m incl. earth works	pc	1,385.35	2,078.00
Delivery and installation of a pump	pc	1,837.00	2,663.00
Delivery and installation of a pressure pipe PEHD ND 80	m	29.10	39.30
Delivery and installation of a pressure pipe PEHD ND 100	m	53.20	71.85
Delivery and installation of a mineral soil	m³	13.70	24.60
Delivery and installation of a RCL-material	m³	6.30	11.65
Installation of groundwater monitoring wells	m	74.80	462.00
Operating costs for pumps	h	5.00	15.00

Description			
Quality management	**Unit**	**Low range [€]**	**High range [€]**
Geotechnical parameters			
Bearing capacity of sludge (field torvane test)	m	15	25
Mineral soil and RCL-material	m³	0.75	0.85
Drainage gravel	m³	0.75	0.85
Radiometric survey			
Spectrometric analyses	pc	90	220

Chemical Parameters			
Mineral soil and RCL-material	m³	0.05	0.10
Drainage gravel	m³	0.05	0.10

5.4.11 Application of Surface Sealing

Table 23 shows the unit price range for the application of surface sealing. Cost of application of surface sealing depend on the surface to be sealed dimensions (surface, position) location (the distance from the source of materials to be used for sealing) ways of access and the proposed sealing technology that will give the materials characteristics (clay type, soil type, geogrids, geomembranes, geotextile, gravel-grit-crushed sand-mix with specific grain size) the equipment that should be used (dozers, sheepsfoot roller, compactors) and the volume of the sealing layers (layer thickness) if applicable.

Table 23: Unit price range for the application of surface sealing

Description	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Application of surface sealing			
Bearing and compensation layer			
Fine profiling of the surface of the filling according to the project by dozer with material relocation up to 5 m (overburden) incl. compaction	m²	1.40	4.00
Fine profiling of the surface of the filling according to the project by dozer with material relocation up to 5 m (recycled material) incl. compaction	m²	1.45	4.20
Fine profiling of the surface of the filling according to the project by dozer with material relocation up to 5 m (soil) incl. compaction	m²	1.40	4.00
Delivery and installation of a bearing and compensation layer made of suitable waste material including compression, layer thickness 0.3 m, D Pr ≥ 95 % Kf = 1 x 10 -4 m/s	m³	2.20	4.65
Delivery and installation of a bearing and compensation layer made of suitable recycled material including compression, layer thickness 0.3 m, D Pr ≥ 95 % Kf = 1 x 10 -4 m/s	m³	11.65	13.40
Delivery and installation of a bearing and compensation layer made of suitable soil including compression, layer thickness 0.3 m, D Pr ≥ 95 % Kf = 1 x 10 -4 m/s	m³	15.75	28.30
Mineral sealing layer			
Supply and installation of cohesive soil as sealing layer, installation in 2 layers with compaction, layer thickness 0.25 m, D Pr ≥ 95 % Kf < 5 · 10-9 m/s	m³	52.40	70.70
Capillary barrier			

Supply and installation of gravel as capillary block, layer thickness 0.25 m, D Pr ≥ 92 %	m²	13.30	17.90
Supply and installation of sand as capillary layer, layer thickness 0.4 m, D Pr ≥ 92 %	m²	25.90	34.90
Revegetation layers			
Supply and installation of subsoil, installation in layers, layer thickness ≤ 0.3 m, D Pr ≥ 92 %	m³	8.60	13.70
Supply and installation of topsoil, installation in one layer, layer thickness ≥ 0.1 m, without compaction	m³	12.25	18.40
Additional compaction of topsoil layer with sheepsfoot roller	m²	0.35	0.50
Geosynthetics			
Creation of an installation and applying concept for the geosynthetics	m²	0.35	0.65
Supply and installation of geogrid incl. quality management	m²	7.25	11.60
Supply and installation of drainage mats incl. quality management	m²	7.80	12.45
Supply and installation of synthetic geomembrane incl. quality management	m²	14.50	24.70
Supply and installation of geotextiles incl. quality management	m²	3.80	5.00
Tektoseal			
Design of an installation and applying concept for tektoseal	m²	0.35	0.65
Supply and installation of tektoseal incl. quality management	m²	15.20	37.30
Supply and installation of drainage mats incl. quality management	m²	7.80	12.45
Supply and installation of geotextiles incl. quality management	m²	2.80	5.00
Bentonite mat			
Design of an installation and applying concept for bentonite mat	m²	0.35	0.65
Supply and installation of bentonite mat incl. quality management	m²	6.90	12.30
Supply and installation of drainage mats incl. quality management	m²	7.80	12.45
Supply and installation of geotextiles incl. quality management	m²	3.80	5.00
Bitumen / asphalt sealing			
Design of an installation and applying concept for asphalt sealing (m²)	m²	0.25	0.50

Supply and installation of drainage mats incl. quality management (m²)	m²	7.80	12.45
Supply and installation of asphalt sealing layer incl. quality management (m²), asphalt sealing layer, 4 cm	m²	7.65	17.30
Supply and installation of asphalt sealing bearing incl. quality management (m²), asphalt bearing layer, 6cm	m²	5.90	7.70

Description	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Geotechnical Parameters			
Filling material	m³	0.05	0.15
Levelling course and bearing layer	m²	0.20	0.25
Sealing layer	m²	1.00	3.50
Subsoil	m²	0.35	0.45
topsoil	m²	0.40	0.50
Capillary Block	m²	1.00	3.50
Capillary layer	m²	1.00	3.50
Chemical Parameters			
Filling material	m³	0.01	0.05
Levelling course and bearing layer	m²	0.01	0.05
Sealing layer	m²	0.01	0.05
Subsoil	m²	0.25	0.35
topsoil	m²	0.15	0.25
Capillary Block	m²	0.01	0.05
Capillary layer	m²	0.01	0.05
Radiometric survey			
Spectrometric analyses	pc	90	220
Test field			
Test field for the surface sealing system	pc	28,690	34,500
Geotechnical quality tests	lump-sum	13,000	15,500
Chemical quality tests	lump-sum	2,800	3,350
Tests for geosynthetics	lump-sum	1,000	1,200

5.4.12 Reclamation / Revegetation

The cost of reclamation depends on the after closure foreseen usage of surface that would be subject for reclamation. Usually involves the cost related to prepare the soil cover for seeding, spread fertilizers, seeding of the selected plants and also maintenance activities such as trimming and watering. Table 24 illustrates the unit price range for reclamation / revegetation (note: pc refers to piece, e.g. per each planted shrub).

Table 24: Unit price range for reclamation / revegetation

Description	**Unit**	**Low range**	**High range**
		[€]	**[€]**
Reclamation			
Supply and installation erosion protection mats	m²	2.50	3.30
Sowing with grass seed onto surface sealing incl. first fertilization and irrigation	m²	0.35	0.50
Repair damages from erosion (lawn): Loosen the topsoil, eliminate unevenness with topsoil (to be livered) and sowing grass seed, first fertilization and irrigation	m²	0.45	0.65
Supply and planting shrubs incl. first fertilization and irrigation	pc	6.35	7.60
Supply and planting trees incl. first fertilization and irrigation	pc	151.10	181.30
Maintenance of grass seed (cutting, fertilization, irrigation)	m²	0.80	1.00
Maintenance of planted shrubs (fertilization, irrigation, pruning)	pc	0.90	1.10
Maintenance of planted trees (fertilization, irrigation, pruning)	pc	15.60	19.50

5.4.13 Flooding and Water Treatment

Usually flooding happens by stopping the extraction of water through pumping so there is no related cost. This operation is related to underground mines and for some open pits. However, flooder might require flooding water management. Table 25 illustrates the unit price range for flooding and water treatment.

Table 25: Unit price range for flooding and water treatment

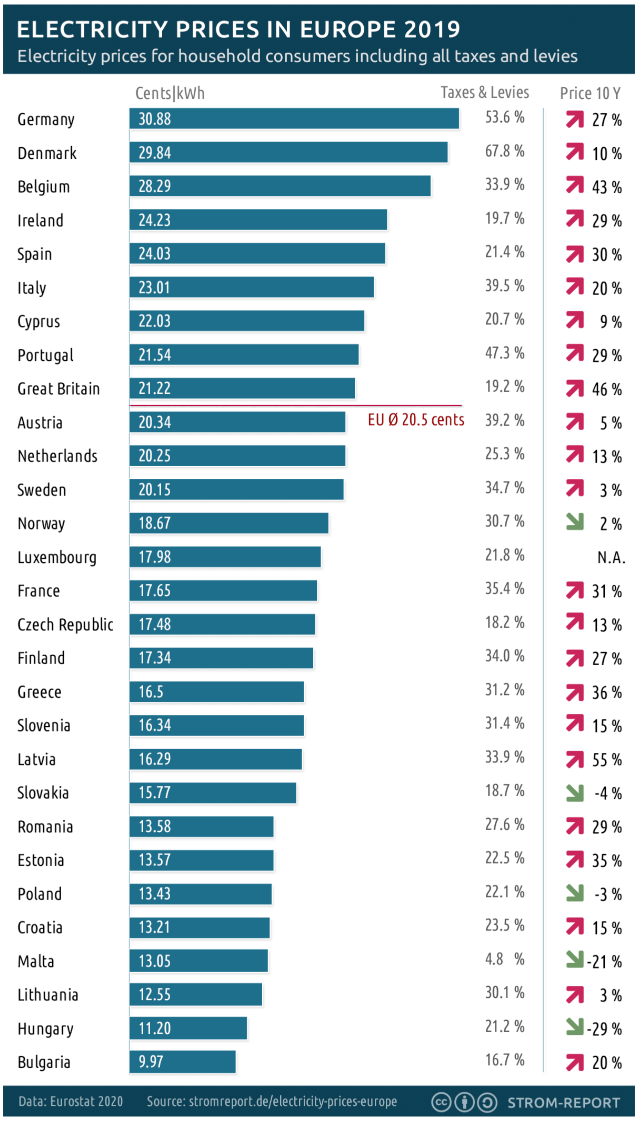
Description	**Unit**	**Low range [€]**	**High range [€]**
Flooding			
Delivery and installation of waterproof clay	m³	80	140
Filling and sealing of boreholes	m	6.00	11
Erection of embanked drainage ditches including filling with limestone gravel, cross-section area up to 1.0 m²	m	27	34
Erection of channels from concrete channel elements including filling with limestone gravel, cross-section area up to 1.0 m²	m	250	320
Erection of a water treatment plant	Lump sum	1.5 mill	7.0 mill
Construction water passive water treatment	Lump sum	300,000	1.0 mill
Deposit of immobilized products at the site	m³	5	7.50
Disposal of immobilized waste	t	50	75
Disposal of immobilized hazardous waste	t	100	850

Operation of a water treatment plant	m³	8	15
Operation of a passive water treatment setting	m³	3	10

5.4.14 Water treatment

Water treatment is typically needed at each mine site, however unit cost is not possible to be provided for that item because the setting and dimension of the treatment methodology is particularly site specific. Beside the investment cost, the operational costs of a water treatment facility accumulate on the long term. In table 26 are given the electricity prices in Europe.

Table 26: European Electricity prices (source: https://strom-report.de/electricity-prices-europe/)



ELECTRICITY PRICES IN EUROPE 2019
Electricity prices for household consumers including all taxes and levies

	Cents|kWh	Taxes & Levies	Price 10 Y
Germany	30.88	53.6 %	27 %
Denmark	29.84	67.8 %	10 %
Belgium	28.29	33.9 %	43 %
Ireland	24.23	19.7 %	29 %
Spain	24.03	21.4 %	30 %
Italy	23.01	39.5 %	20 %
Cyprus	22.03	20.7 %	9 %
Portugal	21.54	47.3 %	29 %
Great Britain	21.22	19.2 %	46 %
Austria	20.34 (EU Ø 20.5 cents)	39.2 %	5 %
Netherlands	20.25	25.3 %	13 %
Sweden	20.15	34.7 %	3 %
Norway	18.67	30.7 %	2 %
Luxembourg	17.98	21.8 %	N.A.
France	17.65	35.4 %	31 %
Czech Republic	17.48	18.2 %	13 %
Finland	17.34	34.0 %	27 %
Greece	16.5	31.2 %	36 %
Slovenia	16.34	31.4 %	15 %
Latvia	16.29	33.9 %	55 %
Slovakia	15.77	18.7 %	-4 %
Romania	13.58	27.6 %	29 %
Estonia	13.57	22.5 %	35 %
Poland	13.43	22.1 %	-3 %
Croatia	13.21	23.5 %	15 %
Malta	13.05	4.8 %	-21 %
Lithuania	12.55	30.1 %	3 %
Hungary	11.20	21.2 %	-29 %
Bulgaria	9.97	16.7 %	20 %

Data: Eurostat 2020 Source: stromreport.de/electricity-prices-europe STROM-REPORT

5.4.15 Waste disposal

Cost related to waste that is shipped outside of the mine site (construction related wastes, garbage, special waste) that is subject for closure in order to be deposited in waste management facilities that belong to third parties will be due to loading/unloading works during transportation by vehicles and the fee/ton as storage tax.

Table 27: Unit price range for waste disposal

Description	**Unit**	**Low range [€]**	**High range [€]**
Waste disposal			
Loading/unloading works during transportation by vehicles. Construction related wastes/garbage with loading by excavators	t	14.	18

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Annex 1

Correlation between the annex of the EIA Directive with the formalities of the codes of the Statistical Classification of Economic Activities in the European Community (commonly referred to as NACE).

NACE/ ISIC code	List of all industrial activities if not subject for any of EIA ANNEX I or II lists (Low risk)	EIA ANNEX II list "shall determine whether the project shall be made subject to an assessment" (Medium Risk)	EIA ANNEX I list "shall be made subject to an assessment" (High Risk)
0510	Mining of hard coal	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining (e) Surface industrial installations for the extraction of coal,	Quarries and open-cast mining where the surface of the site exceeds 25 hectares
0520	Mining of lignite	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (e) Surface industrial installations for the extraction of coal,	
0610	Extraction of crude petroleum	(2) (e) Surface industrial installations for the extraction of petroleum,	(14) Extraction of petroleum for commercial purposes where the amount extracted exceeds 500 tones/day
0620	Extraction of natural gas	(2) (e) Surface industrial installations for the extraction of natural gas,	(14) Extraction of natural gas for commercial purposes where the amount extracted exceeds 500 000 cubic meters/day
0710	Mining of iron ores	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining (e) Surface industrial installations for the extraction of ores	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares
0721	Mining of uranium and thorium ores	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining (e) Surface industrial installations for the extraction of ores	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares
0729	Mining of other non-ferrous metal ores	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining (e) Surface industrial installations for the extraction of ores	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares

0810	Quarrying of stone, sand and clay	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1)	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares
0891	Mining of chemical and fertilizer minerals	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares
0892	Extraction of peat	(2) (a) Peat extraction (projects not included in EIA list 1)	(19) peat extraction, where the surface of the site exceeds 150 hectares
0893	Extraction of salt		
0893	Extraction of salt		
0899	Other mining and quarrying n.e.c.	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining (e) Surface industrial installations for the extraction of bituminous shale	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares and (5) Installations for the extraction of asbestos
811	Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (b) Underground mining	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares
812	Operation of gravel and sand pits; mining of clays and kaolin	(2) EXTRACTIVE INDUSTRY(a) Quarries, open-cast mining (projects not included in EIA List 1) (c) Extraction of minerals by marine or fluvial dredging;	(19) Quarries and open-cast mining where the surface of the site exceeds 25 hectares
0910	Support activities for petroleum and natural gas extraction		
0990	Support activities for other mining and quarrying		
2399	Manufacture of other non-metallic mineral products n.e.c.	(5) (e) Installations for smelting mineral substances including the production of mineral fibers (11) (g) Installations for the manufacture of artificial mineral fibers	(5) Installations for the processing and transformation of asbestos and products containing asbestos for friction material, with an annual production of more than 50 tons of finished products and for other uses of asbestos, utilization of more than 200 tons per year.
5210	Warehousing and storage	(3) (c) Surface storage of natural gas;(d) Underground storage of combustible gases;(e) Surface storage of fossil fuels; (11) (e)	(21) Installations for storage of petroleum, petrochemical, or chemical products with a ca-

		Storage of scrap iron, including scrap vehicles	pacity of 200 000 tones or more.
3821	Treatment and disposal of non-hazardous waste	(b) Installations for the disposal of waste (projects not included in Annex I);(g) Dams and other installations designed to hold water or store it on a long-term basis (projects not included in Annex I);(d) Sludge-deposition sites;	10. Waste disposal installations for the incineration or chemical treatment as defined in Annex I to Directive 2008/98/EC under heading D9 of non-hazardous waste with a capacity exceeding 100 tons per day.
3822	Treatment and disposal of hazardous waste	(d) Sludge-deposition sites;	(iv) solely for the final disposal of radioactive waste; 9. Waste disposal installations for the incineration, chemical treatment as defined in Annex I to Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste (3) under heading D9, or landfill of hazardous waste, as defined in point 2 of Article 3 of that Directive.
383	Materials recovery		
39	Rehabilitation activities and other waste management services		
36	Water collection, treatment and supply	(c) Waste-water treatment plants (projects not included in Annex I);	

Annex 2

Sample of a report structure for Environmental Impact Assessment of mine closure projects

1 INTRODUCTION

1.1 Background

1.2 Regulatory basis for the Environmental Impact Assessment

1.2.1 European regulatory framework

1.2.2 National regulatory framework

1.3 Previous activities and reports

1.4 Technical scope of this project

1.5 Objectives of the EIA process

2 OVERVIEW OF PROPOSED WORKS

2.1 Identified mining legacy objects

2.2 Justification of remedial actions

2.3 Proposed rehabilitation works

2.4 Generalised of types of proposed rehabilitation works

2.5 Timeline of the proposed works

3 ENVIRONMENTAL AND SOCIAL BASELINE

4 ASSESSMENT OF POTENTIAL IMPACTS AND IDENTIFICATION OF MITIGATION MEASURES

4.1 Methodology for the assessment of environmental impacts of rehabilitation measures

4.2 Development of mitigation measures

4.3 Group A: Simple civil works, no major movements of contaminated material

4.4 Group B: Demolition of former processing facilities and burial of debris

4.5 Preferred remedial options per object and potential impacts

4.6 Summary of the results of air quality and noise impact models

5 ALTERNATIVE OPTIONS CONSIDERED

6 ASSESSMENT OF THE EXPECTED ENVIRONMENTAL SITUATION AFTER THE PROPOSED REHABILITATION WORKS

7 CONCLUSIONS

8 ENVIRONMENTAL IMPACT STATEMENT, NON-TECHNICAL SUMMARY

8.1 Introduction

8.2 Contact details of the project proponent and of the organisation implementing EIA

8.3 Justification of the proposed project

8.4 Description of the proposed project and alternative options

8.5 Analysis of the proposed work methods with regard to their compliance with best available techniques (BAT)

8.6 Description of the existing environmental situation

8.7 Assessment of the proposed project activities

8.8 Assessment of the expected environmental situation after the proposed rehabilitation works

8.9 Mitigation measures

8.10 Proposed monitoring programme

8.11 Involvement of the public

8.12 Evaluation of the acceptability of the impacts on the environment

9 REFERENCES

Publications Office
of the European Union