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# Sustainable re-cultivation of coal mines in Mongolia

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## Abstract

*Mining is an essential cornerstone of the Mongolian economy. 85% of all Mongolian exports are raw materials and natural resources. Mining and mining closure due have a significant impact on the Mongolian environment. The vision of Mongolia is "to become a developed nation that has created the conditions for maintaining and handing down to the future generation the environmental stability and ensuring the possibility of enjoying its long-term benefits by way of creating the economic growth that is based on Green development concept and ensures involvement of citizens".*

*A German-Mongolian advisory assistance project, agreed between the Mongolian Ministry for Environment and Tourism and the German Federal Ministry for Environment and implemented 2017 till 2019, provided support for the coal-mining sector to specify and to adopt overall rehabilitation standards and recommendations for the implementation of a geo-hydrological monitoring. A "Guideline on the Rehabilitation of Open-pit Coal-mines" (GROM) addresses mine rehabilitation, targeting managers at the operational level and environmental officers from the authorities, as well as public regulators.*

*The technical guideline is framed around the operational sequence in mining operations, i.e. legal basis, planning, operations and mine closure. Particular emphasis is given to the rehabilitation of natural ecosystems and replacement and compensatory measures.*

*Landscape design for rehabilitation requires a holistic view on mining operations as a whole. Environmental staff should be able to improve and assure the quality of executed rehabilitation work and to discover and settle deficits, right from the beginning on of mining projects. The EU Mining Waste Directive (2006/21/EC) were proposed as an approved international regulation with regard to easy applicable technical and pragmatic criteria to assess the impact and remedial requirements caused by hazardous substances impacts and geo-technical issues. For the implementation, the guidance document explains international standards and gives practical recommendations on the different fields of the rehabilitation work in open-pit coal mining.*

*As an overall objective the guideline shall support the Sustainable Development Goals (especially SDG 15 "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"). Rehabilitation measures support the concept of Land Degradation Neutrality (LDN) of the UN.*

**Keywords:** *mining, coal mine, waste, geotechnical safety, soil, water, hydrogeology, rehabilitation, re-cultivation, environment*

# 1 Introduction

Mining activities have great impact on the environment but also on the social and economic situation. The Mongolian Government is aware of these impacts and regulates the mining activities on different levels. A missing link between the legal regulation and the activities on-site are technical guidelines. Technical guidelines have to convert laws into concretely applicable measures and allow the supervisory authorities to monitor the work carried out.

Coal-mining is still a growing part of the Mongolian mining industry and the by far most important energy source. Therefore, coal mining projects are crucial for their impacts on the economic, social and natural environment.

The proposed “Guideline on the Rehabilitation of Open-pit Coal-mines in Mongolia” (GROM) gives practical recommendations based on international standards and examples on the different fields of the rehabilitation work in open-pit coal mining.

Rehabilitation in any kind of mining has to deal with the impacts on water, the effects of the water onto the mine during its active phase and in the post-mining phase and the impacts on the soil.

Soil, as overburden and as future material for re-cultivation, is at the centre of this technical guideline. Furthermore, different possibilities of re-cultivation are described as well as methods to avoid erosion and dust.

A survey of upcoming mining area is a legal obligation, fixed in the Mongolian Law on Sub-soil. Two methods for soil survey of the undisturbed areas up front the opencast mines and for the dumped overburden are described in detail.

The determination of the pre and the post mining situation is an obligation fixed in different Mongolian laws (e.g. Mining law draft, Environmental Assessment Law). The technical guideline names methods of the evaluation and description.

Specific measures with the aim for replacement and compensation are meaningful if a re-cultivation on-site is not possible. Methods and approaches are addressed, templates for cost planning and examples of different acceptance certificates complete the proposed “Guideline for Rehabilitation of Open-pit Coal-mines in Mongolia”.

# 2 Observation and gaps

From an environmental point of view, the major problems of Mongolian mining are the re-cultivation of mining sites, which has been neglected in the past, and the lack of consideration of environmental protection aspects and in particular the handling of mining waste during mining operation until now. However, with regard to acceptance and implementation measures have to be in balance between economic development and the upturn in the mining sector on the one hand, and increased environmental protection to avoid later follow-up costs for the public sector on the other. To improve this lack adapted legal basis, administrative instruments, technical guidance, and qualified personnel are essential prerequisites. Moreover, re-cultivation has to combine the technical part of the process with qualitative and quantitative aspects in order to proceed the work in an environmental and sustainable manner.

In this respect, there is a concrete need in Mongolia to strengthen and improve re-cultivation as an integrative sub-process of the mining process. On the other hand, there is a need for setting standards and specifications that determine the quality of this process. In order to make these standards legally binding and administratively enforceable also to the mining companies or concessionaires, the elements, criteria and standards must be put on a legal basis.

It has been suggested that the concrete aspects of re-cultivation should be covered in a technical guideline. For this purpose, a manual was developed, which is presented below. For the implementation into the legal basis, a proposal by analogy with the European Directive and the main regulatory contents will be presented.

The administrative implementation has been proven and tested among the EU member states. Essential elements are: legal regulations on environmental aspects in mining, a cadastre of highly endangered old mining areas, a monitoring network for groundwater monitoring and a financing mechanism for orphan sites without legal successors. In particular, objective criteria for assessing environmental issues are precisely defined in technical decisions and are based on existing environmental regulations. In particular, objective criteria for assessing environmental issues are precisely defined in technical decisions and are based on existing environmental regulations.

# 3 Methodology

## 3,1 Re-cultivation within mining process

Mining operation constantly changes a landscape and its specific features. While existing features are destroyed in the excavation area, new features are then created post excavation.

Furthermore, the extraction of mineral resources does not only change the actual mining area, it often also transforms surrounding areas, soil layers and aquifers. Opencast mines are temporary, unique and massive interventions, resulting in landscapes that are detached from their historical and natural background, which can offer new directions for development.

Mine re-cultivation is therefore an instrument for counteracting the earlier incursion into nature. The process is only completed once no significant or subsequent impairments of the natural ecosystem remain, and the landscape has been restored or redesigned in a manner appropriate to that landscape.

Mongolian and international mining and environmental laws demand precisely this elimination and compensation for the interference with nature, natural functions and their networks.

The implementation of legal obligations requires consideration within the entire mining process, starting with exploration, the phase of active mining and ending with the design of a resilient post-mining landscape.

A prerequisite for the successful achievement of the objectives is knowledge of the local nature, its properties and functions within the natural environment that is to be or will be claimed by the mining project.

Mongolia as a country rich in mineral resources but with a very small population has economically limited possibilities for intensive exploration and surveillance. The methods of exploring and evaluating natural conditions should therefore be easy to perform, practical and comprehensible.

Mining is a cost-intensive process where large masses have to be loosened, extracted, transported and deposited effectively. The three main mass flows are the overburden, the water and the mineral resources.

Water and overburden are at the same time environmental media that must be protected from destruction and pollution. The aim must therefore be to integrate the protection of the two environmental media soil and water into the system for the extraction of the mineral resources.

Endangered and rare animal and plant species should be relocated, and their habitats should be part of the re-cultivation process to the possible extent.

The focus of the typical re-cultivation process is on the soil as the basis of the essential habitat functions. The soil development in the Mongolian mining regions are very slow due to the in most cases strongly continental, semi-arid to arid climate. Re-cultivation is correspondingly difficult. The preservation of the mostly very favourable soil properties of undisturbed soils is therefore of particular importance.

The establishment of a stable vegetation on the heaps and inner-dumps is a great challenge under the specific climatic conditions. The aim should be to create vegetation that offers protection against erosion and at the same time opportunities for establishing new habitats.

## 3.2 Guidance setting for re-cultivation

Successful and long-term mining requires cooperation between mining companies, the licensing authorities, local authorities and the interested public. The bases for this cooperation are clear laws and rules. Comprehensible facts are the basis for decisions. The technical guideline for the re-cultivation of coal mining dumps intends to contribute to this.

To promote ecological rehabilitation and climate-smart mining land management and to coordinate rural development after mining has ceased, spatial planning is a necessary tool for an integrated approach. The following enumeration portrays the basic aspects relevant for planning the re-use of mining heaps and dumps:

- Cross-coordination with all relevant laws, regulations, policies, technical standards, and programs, so as to determine reasonable rehabilitation goals (responsibility is with Mongolian government and authorities);
- Design of actions according to local and regional conditions and existing land use types taking account of infrastructure, farming, herding, forestry, and grassland conditions in relation to hydrology and geology, topography and soil properties (responsibility is with mining companies, authorities and provincial governments);
- Configuration of economically viable and environmentally compatible engineering measures in relation to the local landscape, its natural environment, and topography, so as to meet the re-use objectives (responsibility is with mining companies);
- Adherence to the unity of economic, ecological, and social benefits (sustainable use of land resources), so as to prioritize nature conservation where – and whenever feasible (responsibility is with authorities);
- Preservation of bio-diversity by gradually integrating ecological recovery processes in post-mining rehabilitation projects taking full account of soil, water, and other environmental resources, as well as the local/regional cultural heritage so as to control soil erosion, prevent secondary pollution, and to garner support of the local population (responsibility is with mining companies).

## 3.3 Determining the pre- and post-mining situation

Large-scale mining activities aggravate the deterioration of the vulnerable ecological environment in semi-arid regions, which are not resilient to natural disasters. It is crucial to make plans to improve the devastated ecosystems for keeping mining in check and ensuring sustainable development. The following aspects are pivotal for designing climate-smart land utilization after rehabilitation:

- the geo-technical stability of the dump sites, slopes, and berms;
- a self-sustaining water balance and good quality of groundwater and surface waters;
- the concept of a sustainable and diverse land-use;
- design of rehabilitation measures (biological and technical engineering) for disaster prevention and risk control;
- a layout of road, irrigation, and drainage systems in relation to the requirements of the chosen land-use types;
- Proper management of scrapped-off topsoil and fertile soil substrates during intermittent storage (e.g. location, cover crops like leguminous plants) for optimal re-use.

Projects evaluation in terms of cost, but also regarding their social and environmental impacts are prior.

## 3.4 Suitability of overburden and soils within biological rehabilitation

Opencast mining thoroughly disturbs the structure of rock and soil. The creation of the optimum physical, chemical, and biological conditions for promoting biological growth and soil productivity is the foundation of reshaping landscapes, promoting vegetation growth and reducing soil erosion.

Best materials for reclamation purposes are in descending order: topsoil, subsoil, and parent materials like loess. Generally, topsoil is the upper-most surface layer with the highest amounts of nutrients and organic material. The seed of plants are also concentrated in the topsoil, and 80 - 90% of the roots of cultivated plants are concentrated in this layer. If topsoil material is not removed and stored separately and finally returned to re-cultivation sites, the top layer of the dumped soil substrates has to be enriched with nutrients and organic material. One possible method is to seed adopted local grass and herb species. A slight but repeated grazing and leaving the manure speeds up the development of organic material. Mixing soil material with compost, sewage sludge, or other organic material improve infertile soil material, provided it is free of heavy metals and pathogens.

### *3.4.1 Survey of mining sites*

Mine-site surveying has two directions: first, the knowledge of the area that will be mined in future, and second, the survey of the dumped material itself. Knowledge about the upper soil layers is a prerequisite for a successful mass-management, which considers the mandatory re-cultivation measures.

Juvenile mine substrates are anthropogenic raw soils with unique properties and a set of growth-limiting factors. Generally free of recent organic matter (humus), they have a negligible biological activity. A lack of plant-available nutrients, especially nitrogen and phosphorous, is common. In the case of high acidification potential, heavy metal contamination or strong soil compaction mine sites may remain barren of vegetation, sometimes even for decades. Furthermore, raw soils and dumped waste rock partially have a high susceptibility to erosion and unfavourable mechanical properties in respect to dump and slope stability.

The following recommendations (Table 1) provide a consistent, harmonized, and reproducible methodology on mine site surveys and should (i) support ongoing rehabilitation efforts, (ii) lead to a better understanding of ecological processes, (iii) shape a quality management system, and also (iv) improve concepts and tools, for example by contemporary site-adapted land use or innovations in rehabilitation technologies.

**Table 1 Soil evaluation before excavation and after dumping (Source: TGR 2012)**

| Procedures / Technologies | Objectives |
|---|---|
| Geological survey | Exploration of overburden sediments, substrate mass calculation, projection of dumps and heaps |
| Mining, transport and dumping | Selective extraction and dumping of fertile soil substrates, creation of homogenous soil covers as possible |
| Shaping and drainage | Soil erosion control and slope stabilization |
| Mine site survey | Evaluation of mine soil properties and fertility, deduction of land-use-options, amelioration and reclamation technologies |
| Soil improvement or coverage | Creation of favourable preconditions for developing soil functions, especially regarding biomass production |
| Revegetation and cropping | Promoting the development of soil functions, reaching the sustainable site potential by “biological reclamation” |

Evaluation of basic soil properties and fertility is essential for the determination of soil (function) target values and land expectation values, which have to be reached through subsequent biological reclamation and site management. However, since mine soil dynamics are quite high in the initial stage, it is rather difficult to predict the long-term ecosystem behaviour, and thus, the final success of reclamation, based on cause-effect relationships. That is why an objective soil assessment based on function-related analytical soil parameters is essential (Figure 1).

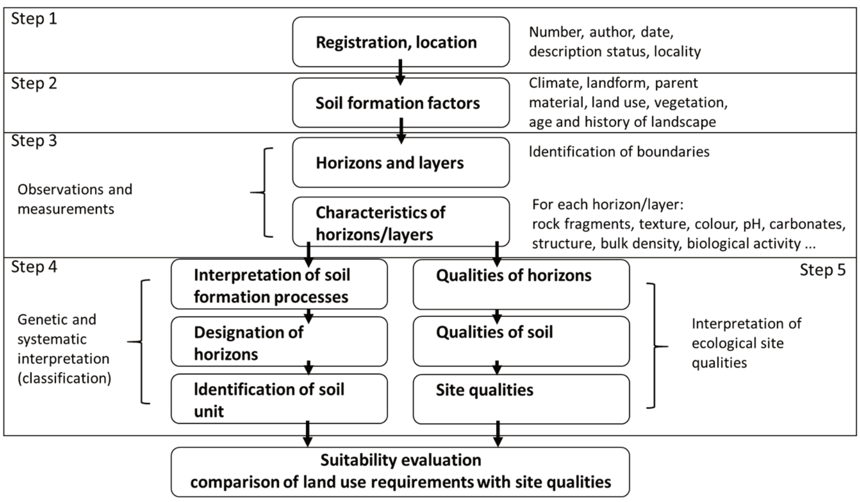


**Figure 1 Principles of soil description, classification and site quality evaluation (TGR 2012 adopted from WRB Guidelines for Soil Description 2006)**

A target-oriented mine site evaluation system should produce an overall site characterization with particular respect to plant-growth-limiting (key) soil properties and functional indicators. Moreover, it has to be a practicable in field application, compatible with national and international reference (ISO) methods but also cost-efficient (Figure 1). The intensity of soil survey, as well as investigated properties, have to be adjusted to the site-specific obstacles in reclamation. Finally, the soil evaluation leads to site-adapted recommendations for sustainable land use management, with particular respect to the turnover of nutrients and water that promotes plant growth.

The sampling design and the chosen sampling method have to produce reproducible results of the interesting soil / substrate properties. That means it is sufficient to concentrate the effort on reliable results of these properties.

## 3.5 Geological Rehabilitation with respect to after-use

The shape of a heap or dumpsite has strong influence on its geotechnical stability, define the after-use possibilities and predetermine the flow-direction of surface water and the collection of rainwater and by this the susceptibility to erosion by wind and water. It also defines the exposure to the main wind direction and the intension of solar radiation on future fields and forests.

Water is by far the most likely cause of instability in tailings or waste-rock dumpsites and for the soil underneath the dumpsite. Therefore, anything that tends to increase or decrease the amount of water or pore pressures in a dumpsite and its foundations is a potential source of weakness. Particular attention should be given to drainage around the heap in order to prevent the flow of groundwater into the heap and to prevent ponding of water at the toe. On sloping ground, drains usually constructed near the uphill side of the facility. For calculating the capacity, the following factors are considered: the catchment area uphill of the drain, the existence of springs, agricultural drains, and natural surface water flows, which will be affected by the heap. Figure 2 shows an example of an idealized tailing heap construction with coarse material.

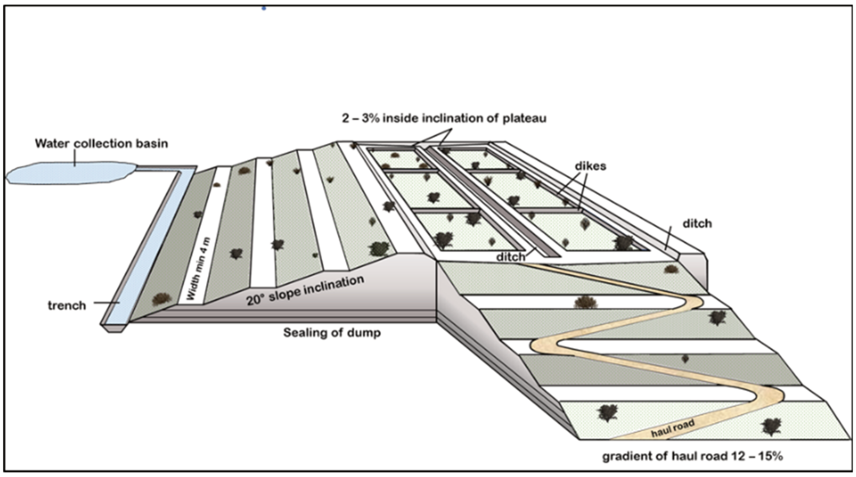


**Figure 2 Schematic drawing of tailings heap construction**

Dumping of overburden onto the heaps is principally in layers. The thickness of layers' ranges from 0.5 to 4.0 m. Compaction is achieved by way of the trucks' rolling wheels and via vibration rollers to reduce, as much as possible, penetration by oxygen or precipitation into the heap body and, thus, minimizing or even preventing the generation of AMD by pyrite oxidation.

The gradient of the haul-roads should not steeper than 12 - 15% to prevent destruction from the trucks. The management of water and wind on dumpsites are essential factors for the stability and possibility for any after-use. Rainfall is the only natural water source on dumpsites. It is a precious good, but it can be also the source for erosion. Dividing the plateau of heaps into different sectors, divided by dikes and a surrounding ditch, lets the water percolate into the fertile part of the heap and prevent water erosion. Between every slope and berm should be also a ditch to prevent water from running uncontrolled downhill.

### *3.5.1 Dump site management and stable slope geometry*

Expert calculating of the geotechnical stability of heaps, dumps and slopes in accordance to official regulations, is an indispensable prerequisite for dump design and the dumping process. The stability of dumps depends on general factors such as the material, particle size, cohesion of the particles, water content of the dump, the weight of the dump, length of the slope, and the inclination of the slope, as well as re-cultivation factors, such as soil permeability and vegetation cover.

### *3.5.2 Surfaces and inclination in agriculture and forestry*

Freshly dumped or uncultivated substrate is exposed to wind, rain, and sunshine. Erosion by wind and by water is highly likely for any dumped, poorly structured material. Inclination angle and slope aspects directly influence the susceptibility to erosion. Levelling of agricultural re-cultivation areas with a minimum inclination of 1:200 (0.5 %) allows surface water run-off and a maximum inclination of 7 % avoid soil erosion from water. For forestry, levelling is not necessary, as long as relief differences are maximum 0.5 m high. The slope angle should not exceed 1:4 (25 %) to allow mechanized tending and harvesting.

Before covering dumpsite with plants or artificial material, the dump should be designed to hasten soil development and prevent unplanned water accumulation, as well as uncontrolled surface run-off. Small dams in a checkerboard pattern divide the slope into small patches, thus, allowing rainfall to filter quickly into the soil. Depending on the inclination, dam spacing could be 100 to 20 m horizontally and 20 m vertically. This approach reduces the velocity of surface water run-off and keeps sedimentation to a minimum. Additional water collection channels and basins next to access roads lead surplus water to the bottom of the heap. Construction of berms and roads with a counter-slope to the inclination of the heap (approx. 2%) leads the water to the ditch beside the road.

### *3.5.3 Soil management and conservation measures*

Selection of the best quality soil or parent material with favourable physical and chemical properties helps to get the best results of sustainable soil rehabilitation. Extreme compaction must be avoided by restricting the movement of heavy machinery for transport and levelling, especially when soils are near their saturation point. Substrates with high silt contents are very susceptible to compaction. In general, the movement of heavy equipment must be minimized on the planed surface and strictly confined to predefined and appropriately demarcated transport routes. Vehicles must shuttle back and forth along the same route. On compaction-prone areas, the ground must be loosened up before the next layer is added. When installing the top layer, all wheeled traffic should be banned, and therefore, only tracked vehicles and/or long-arm excavators are recommended.

## 3.6 Amelioration

### *3.6.1 Compaction*

Because of soil compaction, bulk density is high and soil porosity low. Especially the coarse pore volume is reduced, leading to poor aeration and retarded water infiltration. Plant growth is impaired due to poor water and nutrient supply as well as resistance to root penetration. Bulk densities in topsoil should be less than 1.60 $g/cm^3$. Sub-soil bulk density should not exceed 1.75 $g/cm^3$. Compacted subsoil has to be loosened by technical means. Regardless of the deployed technology, the working of wet soils will do more harm than good. After deep tillage or rotation, such soils are very susceptible to re-compaction and need protection by establishing deep-rooted plants (e.g. alfalfa, sweet clover) and exclusion of any traffic during the first 3 years after the soil treatment.

### *3.6.2 Humus and nutrient deficiencies*

Most mine sites and waste rock (or parent material dumpsites) have low amounts of nitrogen and phosphorus and sometimes lack other macronutrients. A solution to this problem is to add certain amounts of mineral fertilizers that are adapted to site conditions and the prescribed after-use. Adding organic fertilizers will provide a slow release of nutrients by mineralization and contribute to humus accumulation and therefore carbon sequestration. Using organic materials like compost and bio-char will increase the contents of humus-like matter.

### *3.6.3 Cultivation of site-improving plants*

Biological measures are an important part of the rehabilitation work. Plants can indirectly create environmental and economic benefits and their establishment is an essential activity for restoring soil fertility and biological productivity as well.

The selected plants should have the following properties: strong ability to adapt to unfavourable soil and climatic conditions, ability to fix nitrogen (leguminous plants), deep and intensive root system, fast growth, and low mortality rate; and produce high amounts of organic residues for humus accumulation and, thus, carbon sequestration in the developing soils.

Especially in the early stages of land re-cultivation, the vegetation should have a strong resistance to drought and nutrient deficiencies. The plants should have high water-use efficiency and be well adapted to the regional rainfall distribution throughout the year. *Amorpha fruticosa*, *Astragalus adsurgens, Avena sativa, Caragena spec., Hippophae rhamnoides, Ligustrum lucidum, Medicago sativa, Pinus tabulaeformis, Potanina mongolica, Prunus armeniaca, Prunus humilis, Prunus pedunculata, Salsola laricifolia, Spirea aquilegifolia, Robinia pseudoacacia, Syringa oblata, Ulmus pumila*, and *Vicia faba* have all proven useful in in semi-arid areas, in terms of efficient water use, frost-hardiness, and compatibility with poor soils.

Plant cultivation should focus on herbaceous species (especially leguminous grasses). No-tillage or minimum-tillage techniques are recommended, coupled with stubble and straw mulching to reduce soil moisture loss. For small re-cultivation projects, the application of organic manure, phosphorus, and potassium fertilizer or local materials (e.g. fly ash without critical contents of contaminants) could be tested to improve soil fertility, as well as the water- and fertilizer-holding capacity of the soil.

**Table 2 Test items and methods for restored agricultural land**

| No. | Item | Unit | Method |
|---|---|---|---|
| **1** | Area of soil material cover | ha | trigonometric survey (e.g. GPS) |
| **2** | Thickness of soil material cover | m | multi-point soil auger sampling |
| **3** | Surface roughness | m | ground measurement method |
| **4** | Soil bulk density | $g/cm^3$ | ring knife, wax seal method |
| **5** | Soil organic matter | % | test of soil organic matter |
| **6** | Soil gravel content | % | sieving |
| **7** | Soil alkalinity / acidity | pH | Electrode method |
| **8** | Crop yield | kg/ha | Field Measurement |
| **9** | Grass yield | kg/ha | Measured quadrat, calculation |
| **10** | Planting density (reforestation) | plant/ha | Measured quadrat, calculation |

## 3.7 Forest and grassland re-cultivation

In Mongolia´s semi-arid mining areas, there is adequate illumination, and the temperature varies greatly between day and night, which is conducive to the accumulation of organic matter. However, obstacles persist that inhibit plant growth and development, such as water scarcity, high annual precipitation variability and uneven distribution, strong winds in spring, and risk of drought. Taken together, all these factors hasten evapo-transpiration especially during the extremely cold winters, which greatly limit the choice of plant species for land re-cultivation projects.

Under the environmentally harsh and ecologically fragile conditions of Mongolia, natural succession of plant communities is slow. To accelerate vegetation recovery, it is paramount to screen for pioneer species suitable for the establishment of resilient plant communities.

Pioneer species are generally characterized by a high tolerance to frost, desiccation by drought, wind and snow damage, waterlogging and alkalinity, and, importantly, availability of large amounts of propagation material. The following selection criteria apply: fast growth to quickly cover large areas and to reduce surface runoff, conserve water, and prevent soil and wind erosion, a strong rooting system to reduce soil erosion and to improve friability of the often-compacted topsoil layers on mining dump sites, pest and disease resistance, including to resilience against dust pollution, to decrease mortality rates, nitrogen fixation and easily decomposable litter with a narrow C/N ratio to improve soil fertility, employment of propagation material of multiple provenances to ensure high survival rates and to reduce biological (e.g. pests) and non-biological risks (e.g. desiccation) inherent with monocultures and economic value to reflect the locally pursued rural development goals.

Actually, it is hard to find one species that meets all of these conditions. The key is to match the individual requirements of the selected species with site conditions. The following considerations apply:

- Herbaceous species are low-cost solutions for quickly creating soil cover over large areas. Examples are *Allium anispodium, Allium mongolicum, Astragalus adsurgens, Agropyron* *cristatum, Bromus inermi, Dontostemon spec., Elymus dahuricus, Leymus secalinus, Leymus racemosus, Medicago sativa, Melilotus suaveolens*, and *Onobrychis vicaefolia*. Being annual plants, however, their life cycle is short and their rooting system quite low and they do not produce a layered canopy.

- Shrubs are perennial and characterized by denser crowns and rooting systems, as well as more litter production, all of which effectively contributes to soil and water protection. Examples are *Caragana korshinskii, Elaeagnus angustifolia, Hippophae rhamnoides, Rhus typhina*, and *Salix cheilophila*.
- Trees are the most effective agent in land restoration projects due to their longevity, pronounced rooting systems, and their ability to create layered canopies, which effectively provides rainwater interception. However, most species require a minimum of 400 mm rainfall per year. Obviously, under semi-arid conditions, trees can only be managed under the best of circumstances, if e.g. planted in micro-catchments on the dumpsite platform or along the lower third of dumpsite slopes, where they profit from surface run-off. Examples are *Pinus tabulaeformis, Robinia pseudoacacia*, or *Ulmus pumila*.

Shrubs and grass species lend themselves to direct seeding. Trees, on the other hand, are commonly planted by seedlings or saplings, site conditions permitting. Vegetative propagation can be used for afforestation, provided the chosen tree species have strong sprouting abilities, local site conditions permitting.

When mixed pastures of grass species are established, seed quantities of each species are slightly less than when sown alone. For instance, sowing two species together requires only 70% to 80% of the seed amount of each species when sown alone. When three species are sown, two species from the same family would require only 35 - 40% of each species and the third species 70 - 80% of the amount when sown alone.

## 3.8 Importance and recommendation for groundwater monitoring

Mining activities affect water quantity and/or quality and can pose a risk to water resources. In many cases, mining operations change the hydrological, hydrogeological, and topographical characteristics of the mining areas. Changes in surface runoff, soil moisture, groundwater dynamic, water quality, and evapotranspiration can also persist long into the post-mining phase.

Sound management practices, including interpretation of measured data, documentation and reporting are a fundamental components of mining operations for mitigating the impact on water balances and water quality for both surface and groundwater resources in a responsible manner. These practices are to be carried out throughout the life cycle of a mine, as well as post-closure, on both a local and regional scale. Water monitoring is a legal requirement and is a part of negotiations with authorities for a mining permit.

Mining operation open pits is only possible if the water table is lowered. General objectives of the water monitoring in open pit coal-mines are:

- Monitoring the safety of the mining operations with regard to water.
- Provide necessary basics for the planning, monitoring, control, and optimization of water drainage measures.
- Provide necessary basics for the planning of measures reducing the impact of mine dewatering to the environment of the mine.

International standards about water sampling and chemical analyses of the water samples are implemented in Mongolian regulations and standards. In the other hand: there is still a need to improve and to refine the recommendations about documentation, interpretation and reporting of water monitoring data. A consistent way to document hydrogeological studies, including water monitoring has proved ourselves at the handling of hydrogeological tasks coal mines in Lusatia (Germany), described in details in a recommendation document.

Within the Mongolian case study on the "Shivee Ovoo" mining site several recommendations with regard to groundwater monitoring and related issues were developed. This coal mine is planned to stay active for several decades. Besides legal requirements, the operation calls for comprehensive planning of the mentioned tasks from a technical and economic point of view, as well as from the aspect of environmental protection. Water management and monitoring aims to minimize the effects of open-pit mining (in particular, dewatering) on to lay the groundwork for planning measures in order to mitigate negative impacts.

The dewatering wells are up to 210 m deep. There are also pumps in the mine itself (sump pit). The pumping rate is currently 4 Mio. $m^3/a$. Thirty percent (1.1 Mio. $m^3/a$) of the pumped water are used for the mine operation itself (dust fixation, irrigation). The assumption is that this water then evaporates. The other part, 70 % (2,6 Mio. $m^3/a$), is run into the artificial lake Khayalga. The area of the artificial Khayalga lake is 1.5 $km^2$ and the seasonal amplitude of the water level is approximately 1 m. That means that the volume and the water level of the lake are almost stable. Approximations show that 10% of the pumped water is consumed by livestock, 40% (1 Mio. $m^3/a$) is lost to evaporation, and 50% infiltrates into the aquifer. A fraction of the infiltrated water probably flows back to the mine and the dewatering systems.

The pumping rate is controlled automatically by measurement of the groundwater (or pressure) level of the monitoring at each dewatering well. There are eight water monitoring wells in front of the mine. Groundwater samples are taken once per year. The analysis results are sent to the basin authority. More (water level) measurement results from points around the mine exist. The results show, that the drawdown of the groundwater level is more than 30 m during the time between 1999 und 2017 (Нүүрсний уурхайд 2017).

The water loss of approximately 1 Mio. $m^3/a$ by evaporation is not sustainable water management and isn't acceptable for a semi-arid region. The probable hydraulic bypass and the re-pumping of infiltrated water is an economic problem as well. However, the assumptions and estimations are to be verified and specified through the continuation of hydraulic water monitoring.

Because of the evapotranspiration from the lake, the mineralization of the lake water will increase. This also includes the increase of the chloride concentration in the water of the lake. Currently the concentration is 228 mg/L (chloride). The taste limit is given at 250 mg/l (chloride). That means, if the chloride concentration rises during next few years, the quality of the water supply for livestock will become problematic.

The chemical composition of the water samples corresponds to a natural and geogen shaped character. The concentrations comply with the limits for drinking water from the WHO and Mongolian standards in most cases (Battogtokh et al. 2012). Analyses of the water samples do not indicate fossil groundwater.

The water quality is influenced by geological and hydrogeological conditions (e.g. high concentrations of Mg, Fe, and F). The very low Sulphur content and neutral pH-values in soil samples shows no risk of acid mine drainage (Battogtokh et al. 2012), except for waste coals.

Within the study of the hydraulically system, the following recommendations would be established, e.g.: (a) to intensify the monitoring program to improve the validity of the calculated water balance (Full-data documentation and durable storage of all monitoring results, monthly measurement of groundwater levels, additional monitoring wells, minimize of the impact of dewatering on the environment of the mine, measurement of evaporation from the Khayalga lake), (b) to reduce water losses due to evaporation from the lake (e.g. by reducing of the area of the lake), (c) to establish a calibrated and validated numerical groundwater flow model as a suitable tool e.g. for planning of the water management (prediction of the required pumping rate), (d) to create and expand sustainable water uses: increased and more intensive use of water to irrigate the plants in the re-cultivation areas.

The construction of a coal-fired power station at the Shivee Ovoo coal mine has been proposed since 2008. Currently (2018), it is proposed to have a power output of 5.280 GW. Even a 4.000 GW power station would require approximately 20 million tons of coal per year (13-times the current mining rate). It has also been estimated that the power station would require "water access and supply facilities of 16 million cubic meters per year" - approx. 4-times of the current pumping rate (Sourcewatch 2019). The available groundwater cannot cover the expected demand. It is not advisable to increase the production rate, as this will have a negative impact on the local water balance.

## 3.9 Criteria setting for overburden and excavated materials

Beside for re-cultivation-specific requirements related to soils and linked water issues, the setting of qualitative criteria with regard to long lasting environmental and geotechnical impacts is crucial. Criteria should address first on chemical characteristics of excavated materials, overburden and mining waste. Inert material or unpolluted soil do not need any further assessment in this regard.

A long-lasting geotechnical integrity should be guaranteed for heaps, dumps and tailing ponds as long are remaining after mine closure. However, criteria should have been pragmatic and easy to implement and be based on experiences and existing regulation for the protection of soils and water.

These parameters should not and must not replace site specific assessments, but usually they can guide the general planning and they support mining and environmental inspections. Within the project the German side proposed an implementation in analogy to Directive 2006/21/EC on the management of waste from extractive industries (for short: MWD). As seen from its official title the directive regulates not only the disposal of the waste from extractive industries but also any type of work with extractive waste including their temporary deposition, the use of extractive waste for re-cultivation or refilling in the excavation voids. The main addressed objectives also relevant for mine closure are:

- to prevent or reduce as far as possible any adverse effects on the environment, in particular water, air, soil, fauna and flora and landscape, and any resultant risks to human health,
- brought about as a result of the management of waste from the extractive industries.

Generally spoken, mining activities will lead to the exploited resources, excavated overburden without any adverse impacts and extractive residues.

Along of two conditions, these extractive residues are classified as extractive waste only:

a) The waste should be „generated by the prospecting, extraction, treatment and storage of mineral resources and the working of quarries", resulting directly from these operations.

b) 'waste' shall mean any substance or object in the categories set out in MWD, Annex I which the holder discards or intends or is required to discard.

One of the implementation-oriented tools in the MWD is the waste management plan. It is a planning instrument for the mining operator which should guarantee that the extraction has clarified all issues connected with the waste management before the implementation of the mining activities and has made a general concept.

The objectives of the waste management plan are to prevent or reduce the quantities of generated extractive waste, to decrease their harmful potential, to encourage the adoption of measures like rehabilitation, as well as to ensure safe disposal of the waste in conformity with the environmental standards.

### 3.10 Excavated material classification and value setting

Excavated materials may be considered as inert, in accordance to 2009/337/EC without specific testing if the following criteria and their short and the long-term fulfilment have been adequately confirmed:

(a) the material will not undergo any significant disintegration or dissolution or other significant change likely to cause any adverse environmental effect or harm human health;

(b) the excavated material has a maximum content of sulphide sulphur of 0,1 %, or the waste has a maximum content of sulphide sulphur of 1 % and the neutralising potential ratio, defined as the ratio between the neutralising potential and the acid potential, and determined on the basis of a static test prEN 15875 is greater than 3;

(c) the excavated material presents no risk of self-combustion and will not burn;

(d) the waste is substantially free of products used in extraction or processing that could harm the environment or human health.

Furthermore, geotechnical issues are of relevance. In this regard the assessment of consequences of a failure due to loss of structural integrity or incorrect operation are essential. Any specific evaluation of the extent of the potential impacts shall be considered in the context of the source-pathway-receptor chain.

## 4 Results

### 4.1 Ecological compensation with economic benefits

Revegetation is the foundation of land re-cultivation and is crucial to its success. Post-mining rehabilitation projects not only strive to reconstruct the original ecological environment, but also to balance environmental, economic, and ecological values that should preferably deliver better structure and higher benefits than the original land-use.

Afforestation bases on mixed stands to achieve greater ecological, economic, and social benefits. Establishment methods include direct seeding, generative propagation by seedlings or saplings, and vegetative propagation by cuttings.

Replacement and compensatory measures on third sites are the international standard in re-establishing ecological functions if the impact on the balance of nature could not be compensated on the site itself.

Existing mine sites in Mongolia often do not have a sufficient structural integrity, and a lack of knowledge of the soil properties of the dumped material exists. This hinders conformance with legally requested rehabilitation measures. According to the existing laws of Mongolia, the post-mining sites have to fulfil the following attributes: no threat to or adverse impact on the surrounding environment, especially by contaminated water fluxes and erosion by wind (dust), a possible after-use and compensation of negative impacts during mining to local communities.

If the financial and technical burden prohibit the orderly preparation of the dump site for rehabilitation measures, it should be checked if the rehabilitation could be split into necessary measures on the dump site (e.g. water collection, dust reduction) and measures to fulfil the further intended goals on a third site. Splitting up the measures leads to a more-effective and sustainable use of the capital and the technological measures employed.

Ecological replacement and compensatory measures can be part of the concept of land degradation neutrality (LDN) and its implementation under goal 15 of the Sustainable Development Goals of the United Nations. Goal number 15 focuses on life on land, terrestrial ecosystems, and their sustainable management and combats desertification, soil-degradation, and biodiversity loss. These measures could be integrated into a community-driven natural resource management system.

Implemented in neighbourhood of a community or near stables and grazing grounds of the livestock the measures could add surplus benefits in comparison to a low- to-mildly successful rehabilitation of a dumpsite. Measures like protection hedges, restoration of degraded forests and restoration of degraded land and soil around communities, and grazing areas´, or the reconstruction of irrigation systems are very useful and sustainable.

The cultivation of climate adopted fruit-bearing plants, as *Lonicera caerulea,* the Tundra-Honeyberry or Haskap, could be such a plant. *Lonicera caerulea* is a worldwide occurring species of boreal coniferous forests in Asia, Europe and North America. *Lonicera caerulea* is extremely frost hardy and cold resistant. The plant has no problems with soil dryness outside the vegetation period, as it has the shallow root of cold climates and has no special soil requirements. The difference between the water requirement of the plants of approx. 600 mm/a and the annual precipitation in semi-arid areas can be compensated by irrigation with pumped water from opencast mining.

*Lonicera caerulea* might have a viable market potential. The taste of the deep blue berries is sweet-herb. The fruits and the leaves are rich in vitamins and minerals. The harvest as berries or juice is considered a so-called "superfruit" in the modern life-style movement.

The cultivation and processing of such fruits creates additional jobs, especially for the rural population living near of an opencast mine, and generates additional value. There is a productive use of the pumped water of the opencast mine.

The plants offer pollinating insects' food and birds nesting and feeding opportunities. After abandoning the economic use of the plantation after 25 to 30 years, the shrubs that die then continue to provide shelter from the wind and insemination opportunities for other grasses and shrubs.

## 4.2 Cost planning, determination of costs and documentation

Rehabilitation is an integral part of the mining process and not a separate process. Therefore, all costs assigned to the rehabilitation are one part of the overall costs of the mining and the price of the product have to cover them. Recording and calculating of all services and the necessary need of material to establish the site accordingly to the planned after-use is necessary.

Re-cultivation services are part of the rehabilitation and start after the completion of dumping, securing and rough levelling of the site. The costs include all work force, material (e.g. fertilizer, seed, plants, construction material for channels and roads, etc.), maintenance (e.g. flood control, combating drought, pest management, and fire control), and the cost per hour of technical equipment used. A rehabilitation project on a specific site ends with fulfilling of all goals and finishing of the approval. Therefore, as rehabilitation work usually lasts several years, the calculation has to sum-up all steps in between.

Rehabilitation cost planning should be part of the annual planning. For the calculation, existing national price lists should be used. If they do not exist for the specific goal, market prices or fixed internal costs should be the basis. It is necessary to name the chosen bases. The calculation should be done always with the same base (ha, $m^3$, litre, etc.)

Documentation of all relevant steps, their successful processing, and open tasks left for future execution is an integral part of modern internal quality management according to QM ISO 9001.

An internal Standard Operating Procedure (SOP) of the single mining company describes the responsibilities for the documentation process, the documentation of working steps and the schedule. The aim is to document all working results which have relevance for downstream operations (e.g. dumping for rehabilitation, water treatment for release into river), all working results with high financial contribution, as a basis for the approval processes from public authorities, and for the after-use of third parties (e.g. amelioration and fertilization of an arable land).

The documents can be reports of external experts, official bills from landscape and gardening companies, or documents elaborated from the different departments of the mining company itself. If the work was carried out by external companies an acceptance certificate is meaningful and should confirm first the completion acceptance and after an intended number of vegetation periods a final success.

# 5 Conclusion

The enhancement of the mining sector, which benefits the entire economy, requires reliable financial and economic conditions including the implementation of an environmental sound management of mining operation as well as a proper mining rehabilitation. These complex challenges require executive and legislative support. On the one hand side mining operators should not be hindered disproportionately by regulation to increase the economic prosperity. On the other hand side, it must be demanded and ensured, that mining operators carry out any obligation for an appropriate mining rehabilitation. Prices for mineral resources should be aligned on realistic mining and rehabilitation operation costs. Otherwise an economic disequilibrium will entail probability first a decrease the environmental performance of the mining sector. Environmental criteria must apply regardless the ownership of the mine and they have to be controlled and demanded equally.

Beside strengthening administrative law, technical ordinances are required for the setting binding criteria. For the practical enforcement capacity building and training among mining authorities and inspectorates is needed in order to enhance mining permits and concessions regarding the environmental issues, as well as to execute existing regulation and to ensure subsequent enforcement. Documents presented in this paper are proposing a structure and practicable advice. The recommended technical guideline shall support also the Sustainable Development Goals (SDG 15). Rehabilitation measures support the concept of Land Degradation Neutrality (LDN) of the UN.

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