Land Classification Methodology

for open pit and underground coal mines

Contents

Table contents

1. INTRODUCTION

The World Bank encourages and supports the use of tools to assess, evaluate, and classify resources which are at risk of losing value if the threats of environmental degradation and community safety are not addressed. Moreover, this approach recognizes the interconnected nature of the issues that confront operating companies at the time of mine closure and underscores the need for mine operators to develop a comprehensive resource management plan early in mine operation and periodically through closure and repurposing. A software tool has been designed to support the Land Repurposing Methodology (LRM). The tool combines risk-based land assessment with spatial planning capabilities on a GIS platform, allowing all information on lands to be mapped and presented in their precise geospatial context. The Land Utilization Repurposing Application (LURA) has been specifically designed to support the implementation of new global standards for coal mine closure and thermal plant decommissioning. LURA is a fact-based analytical and decision-support tool that supports the recognition of land characteristics and different land categories, and their alignment with technical standards and regulatory approaches to optimize how legacy risks from surface and underground mine operations are addressed, how land value is developed, and how mine lands are spatially and economically integrated into regional planning frameworks.

For surface mine operations the risk-based approach is designed to evaluated different biological, physical, chemical, socioeconomic and financial conditions that may affect the former mine or the broader area during closure or many years following closure (post closure legacies). The aim is to characterize mine lands for legacies, but at the same time consider possible repurposing scenarios and evaluate the potential for future repurposing in order to create sustained development during mine closure operations. A dedicated cloud based, simple to use application (LURA) has been developed in order to support the mine land classification for optimized transition management.

The methodology[1] used and tested in the Western Macedonia Lignite basin via the LURA software application has been updated to include additional rating information for surface coal mines and also to include underground mined lands.

The basic structure and principals of the rating methodology was maintained for underground mines which uses five criteria (biological, physical, chemical, social-economic and financial) to characterize mining lands' repurposing potential:

- (i) location and redevelopment potential;
- (ii) geotechnical stability;
- (iii) topography and hydrography;
- (iv) environmental risks / liabilities;
- (v) development potential and financial risks.

These **criteria** are then combined with **broad scenarios for post-mining repurposing**: (i) energy production and storage / industrial production / waste processing; (ii) agricultural / horticultural / forestry; (iii) recreational / tourism; and (iv) office / research / technology parks to define the *land repurposing categories* for a given post-mining area.

A land category basically means that for a defined area, an optimized utilization scenario has been proposed based on various potential combinations of the criteria such as bio-physical and chemical characteristics; liabilities and constraints imposed naturally or due to the mining history; the geographic situation with respect to existing infrastructure, settlements and economic clusters; and the potential added value development options and the opportunity cost of sub-optimal

[1] Repurposing Land and Assets for Western Macedonia, W. Pohl and C. Steiakakis, June 2020 The World Bank

development. The methodology takes cost sensitivity into account, striving to conserve resources, e.g. avoid a costly remediation or upgrading measures for a particular purpose, if other areas are equally or better suitable and require lower investments to be fit for a specific purpose.

The overall approach for assessing and optimizing the land repurposing potential follows quite similar principles for both open cast and underground mines. However, there are some significant practical differences, thus the rating and classification system developed for open pit mining (during the initial application of the LRM and LURA), have been updated and modified. It now can also be applied to the repurposing of lands and assets associated with underground mines, which provides a wider, potentially global scope of application. The following paragraphs detail the proposal for the modification of the existing rating system together with new criteria and repurposing scenarios for lands related to underground coal mines that are being phased out, are in a closure phase or have been closed and abandoned in the past.

2. OPEN PIT COAL MINE RATING METHODOLOGY

In the following paragraphs the most important risks or legacies from the different themes for open pit mine lands are presented and criteria are provided with the accompanying five scale rating. These criteria have been incorporated in the cloud-based GIS application LURA. In this chapter the 5-rating scale is provided for the different themes and criteria, in combination with the indicators of how to select the actual rating. A brief description and explanation of technical terms included in the following chapters are provided in Appendix A of the document.

2.1 LOCATION OF OPEN PIT MINES

An important aspect for land repurposing of a former open pit coal mine is its location and connectivity. A former mine land that is very far from human settlements with low connectivity presents limited risks to people and at the same time limited opportunities for development. The proximity of the former mine land to human settlements can have positive and negative influence. The environment and the landscape are most probably below optimum in a former mine located near human settlements. At the same time this proximity can provide opportunities for future industrial development or for recreation and cultural tourism. A former coal mine most probably has significant infrastructure utilities such as power transmission grids, transportation networks such as railroads and high-capacity roads connecting the area to other developed or heavily populated areas. The location of a former mine land can significantly increase or diminish the future economic development and is considered a very important factor when rating a land. In the rating methodology for open pit mine lands, location has been addressed based on two criteria which evaluate the proximity to infrastructure and utilities and distance to human settlements.

1. **Distance to infrastructure and utilities**:
   Infrastructure, which can range from local roads, highways, dedicated railroad tracks or a public railroad system, can provide a significant driver for future repurposing of the former mined lands. Any manufacturing or logistic operation desires an area, which is well connected to transportation hubs so they can receive and deliver materials and products in a quick and efficient manner. Power repurposing opportunities such as transforming former thermal power plants (TPP) to power storage facilities with molten salt technology can greatly benefit from the installed transportation grid. Photovoltaic parks installed in former reclaimed lands also benefit tremendously from the already available power grids. Other industries can utilize drainage and sewer utilities.

The distance to infrastructure and utilities is evaluated and rated with a five-scale score with the longest distance between the area and the infrastructure receiving the lowest score and the more proximal the highest score. The distance to infrastructure rating is strongly dependent on the region and the country that the former mine land is located. For example, the distance between a former mined land and a railroad in Australia can be tens of kilometers and considered proximal whereas in a small country like Greece, that distance could be considered very long. In the LURA application, the different distances that correlate to higher or lower score can easily be modified to account for the region under evaluation.

2. **Distance to human settlements**

Open pit coal mine operations are labor intensive and require a nearby located workforce. It is very common that near or adjacent to open pit mines, pre-existing or newly formed human settlements are present. These settlements can range from small towns occupied mostly by former miners and the accompanying services such as restaurants, grocery shops, etc., as is the town of Clermont in the Isaac Region, Queensland, Australia, with a population of around 3000, or can be heavily populated cities such as Dhanbad, which is the second-most populated city in the Indian state of Jharkhand and is considered the "coal capital" of India. As is the case for the distance to infrastructure, the proximity rating (and corresponding ranges) strongly depends on the region and the country that the former mine land is located. A certain distance between the land and human settlements is assigned to the five-scale rating with the most proximal receiving a rating of five. In the rating methodology the proximity to human settlements is considered a driver for repurposing, since (a) needed skilled workers may be available nearby and (b) proximity of potential employment helps retain the local population after a coal mine is closed.

Table 1: Five scale rating for location of open pit mines in relation to infrastructure, utilities and human settlements

Theme	Criteria	1	2	3	4	5
Location of mine	Distance to infrastructure and utilities	Very far (ie >10km)	Far (ie 5-10km)	Intermediate (ie 2.5-5km)	Close (ie 0.5-2.5km)	Very close (ie 0.5-2.5km)
	Distance to human settlements	Very far (ie >10km)	Far (ie 5-10km)	Intermediate (ie 2.5-5km)	Close (ie 0.5-2.5km)	Very close (ie 0.5-2.5km)

The distance criteria are relative to the area of the mine and the region. For example, for a small European country like Greece, 10km may be considered too far for useful utilization of utilities. In Australia on the other hand 5-10km to human settlements may be considered as extremely close. The location theme needs to take into account regional and/or local conditions and the actual numerical ranges should be adjusted appropriately.

2.2 GEOTECHNICAL RISKS FROM OPEN PIT ACTIVITY

Geotechnical hazards commonly result from legacies in open pit mines due to large earthmoving operations. After open pit closure the remaining earthworks should be physically stable, not susceptible to erosion and safe, and impose no risks to public health in the long-term. However, based on geotechnical conditions and geometric constrains, the earthworks may present risks that could interfere with future repurposing. In open pit mines the geotechnical conditions that are most likely to generate risks can be categorized to a) slope instability of the final mine slopes, or the slopes of spoils or other earth made structures, b) residual ground settlement of the lands above spoils or backfilled openings c) erosion of slopes or spoils either by water or wind.

1. Slope stability of mine or spoil slopes

When a mine is excavated to extract coal, spoil is created by dumping waste material in some other location. During mining, it is typical to create depressions on the natural ground surface as material is excavated (cuts) and/or heaps or hills as waste material (fill) is deposited back on to the ground surface. The inclined sides of a cut or a heap are termed “slopes” because of their inclination to the horizontal plane. A slope can generally be stable either for the short-term or for the long-term, but there are instances when local (partial) or more widespread instabilities can occur under different circumstances and drivers. Such instabilities can cover a small or a significant part of the slope, which can eventually extend over the entire mine or spoil heap. When the instability increases in areal extend and volume and generates a catastrophic failure it is typically called a “landslide”. Various instabilities can occur in post mining slopes. They can range from very slow movement to just minimal movement due to unloading (removal of overlying material) to complete failure when displacements reach a level where it is no longer safe to operate near (above or below) the slope or even complete collapse when smaller or larger quantities of soil or waste have moved downwards completely destroying an area.

Instability of mine or spoil slopes is governed by many aspects and detailed geological, geotechnical investigation, slope stability analysis and monitoring are required to accurately evaluate the potential risk and type of a slope failure. Nevertheless, a former open pit mine together with the associated waste spoils should be evaluated in a way that can provide indicative estimates of slope conditions when considered for repurposing. The proposed methodology proposes some general criteria that can easily be assessed based, not on so detailed studies, but on available information, that can be used as a first assessment tool in relation to the quality of the land near (above or beyond) these slopes. The criteria should be considered as a screening tool for land classification on the possibility of future risks of land near slopes. These criteria typically use with a five-scale evaluation rating for the cut or fill inclinations, the height of the created slopes and their stability (safety) factor (if known). Table 2 presents the rating criteria for slope stability.

Table 2: Criteria and description for five scale rating for the geotechnical theme for open pit coal mining

Theme	Criteria	1	2	3	4	5
Geotechnical risks	Slope stability of mine or spoil slopes	Factor of safety <1.1 (if available from detailed slope stability analysis) Waste dump (fill) slope>38º Open pit (cut) slopes >26º, Slope height H>120m	Factor of safety <1.3 (if available from detailed slope stability analysis) Waste dump (fill) slope between 38º - 34º Open pit (cut) slopes between 26º - 18º, Slope height between 85m-120m	Factor of safety <1.5 (if available from detailed slope stability analysis) Waste dump (fill) slope between 34º - 30º Open pit (cut) slopes between 18º - 16º, Slope height between 50m-85m	Factor of safety <1.8 (if available from detailed slope stability analysis) Waste dump (fill) slope between 30º - 26º Open pit (cut) slopes between 16º - 14º, Slope height between 20m-50m	Factor of safety >1.8 (if available from detailed slope stability analysis) Waste dump (fill) slope<26º Open pit (cut) slopes <14º, Slope height H<20m
	Residual ground settlement	overburden H>120m, placement time <5y, Fill Area >10km^2, Stacker placed	overburden 70<H<120m, placement time 5<T<10y, Fill Area 5<A<10km^2,	overburden 30<H<70m, placement time 10<T<20y, Fill Area 1,5<A<5km^2,	overburden 15<H<30m, placement time 20<T<40y, Fill Area 0.5<A<1.5km^2,	overburden H<15m, placement time T<40y, Fill Area A<0,5km^2, Compacted

Theme	Criteria	1	2	3	4	5
			Stacker placed	Heavy dumper	Light dumper - truck	
	Impact of groundwater rebound	fills and cuts affected by GW rise ~Top	fills and cuts affected by GW rise > 2/3H	fills and cuts affected by GW rise >1/2H	fills and cuts affected by GW rise >1/3H	natural soils, low susceptibility to GW rise

2. **Residual ground settlement**

   The waste material which is found either above the coal or intercalated within the coal seam(s) in open pit mines, upon excavation is placed in stockpiles (spoil dumps) in dedicated areas either outside the mine excavation limits or inside the mine (at the back end), as pit space is made available as the excavation face is moving forward. In coal and lignite open pit operations, the excavated waste material above the coal beds can amount to huge quantities of waste material. The stripping ratio which reflects the amount of excavated overburden (waste) to extract 1 ton of coal and is typically expressed in cubic meters of overburden material per ton of coal or lignite has ranges between 2 and 5 (or higher). This means that for one ton of lignite 2 to 5 cubic meters of waste or overburden rock needs to be excavated and placed somewhere inside or outside the mine. Approximately 0.3 tons of coal is needed to light a 100-watt light bulb for a year or 1 ton of coal is needed to produce 2.5 kWh of power. It is easily understood that million of tons of coal are needed to fire up a medium sized thermal power plant for a year. As a result, millions of cubic meters of waste rock need to be excavated and placed internally (inside the mine) or externally as waste (spoil dump). These waste materials are placed in waste dumps that can range from a couple of meters to tens of meters in height and occupy large areas. After mine closure, such areas are left flattened or near flattened at the top, and can then be utilized for repurposing. These waste dumps can produce long term settlements due to internal compaction of the material and consolidation during water expulsion. These settlements can range from couple of centimeters to many meters depending on the thickness of waste spoil, material consistency (percent of fine-grained material), time since they have been placed and the water content of the waste material. Table 2 presents the expected problems due to residual ground settlement at such large scale waste dumps. The stability of the waste dump is rated using a scale of one to five based on general characteristics of height and time of placement.

3. **Geotechnical impact of groundwater rebound**

   During post closure, pumping water operations are (typically) terminated and ground water is left to rise inside the mine. The rising of the water level in the mine is a long-term process and affects the geotechnical conditions of the mine and the waste fill. The rise of groundwater table internally to the mine slopes or waste spoil slopes, increases the pore water pressure which in turn reduces the stability of the material and has a negative effect on slope erosion. Water rebound can also reduce the rate of settlement of the waste spoil dumps or even produce swelling and vertical expansion of the material in some cases. The account of water rebound in the geotechnical conditions for a repurposed land is again rated using an 1-5 scale that considers the depth of groundwater in relation to the height of the slope. This rating is more important for waste dumps, since in mine slopes a stabilizing effect can be produced between the water table inside the slope and the water table in the lake that is formed in the pit. Table 2 presents this rating.

2.3 TOPOGRAPHY AND HYDROGRAPHY FROM OPEN PIT ACTIVITY

Topography or landform is a very important issue as related to mine closure and repurposing for other land uses. In the past and without closure in mind, the only condition placed in landform design was to allocate the spoil or mine waste in locations that minimize the haulage cost. In terms of stability, the objective was develop stable slopes that could be partially or fully vegetated after closure. Additionally, during surface coal mining, a large void (pit) is created which can be partly filled with spoil and mine waste; however, after mining is completed a large hole in the ground would remain in any case, which may or may not become a lake. This practice of mining and waste or spoil disposal has produced landforms that deviate significantly from optimum and can produce liabilities in future use. Such liabilities can be instabilities or excessive erosion during rainfall which can transport significant amount of soil from higher to lower elevation. The transported soil can be either good quality top soil needed for vegetation or contaminated waste material. When such phenomena of soil transport take place, a new landform is created many times with gullies and deep erosion streams which in turn can produce hydrological risks in downstream areas. Furthermore, a depressed landform can produce temporary or permanent water-logged areas depending on the climatic conditions of the area and the possible extreme rainfall events. This issue is becoming significantly more important in recent years with higher or extreme rainfall precipitations and lower return periods.

In open pit landforms the following conditions are considered important in relation to erodibility, water logging and hydrological flooding risks: a) surface gradient and relief, b) surface drainage c) extreme precipitation events.

1. **Surface gradient and relief**

The criterion to evaluate water runoff and soil transportation is the steepness of a landform (slope inclination) and the easiness of material erosion. For example, steep slopes which can be formed during waste placement can be between 35 and 45°. Such steep slopes if not protected can produce a significant amount of water and soil transport, especially if a significant hydrological basin is located or formed above such slopes. On the other hand, flat slopes with stable or vegetated soil material can significantly withstand erosion. Table 3 presents a 1-5 scaling system with respect to water erosion and soil transport conditions.

Table 3: Five scale rating for topographic and hydrologic effects of open pit coal mines

Theme	Criteria	1	2	3	4	5
Topography and hydrography	Surface gradient and relief	Slopes steeper than 35 deg, easily erodible, without vegetation	Slopes 25-35 deg; easy to moderately erodible, partly vegetated	Slopes 15-25 deg., moderately erodible, and vegetated	Slopes 5-15 degrees, fully vegetated	Slopes flat or up to 5 degrees, fully vegetated with deep root systems and trees
	Surface drainage - describing morphology and groundwater impact	Depression with permanent waterlogging or wetland formation, high water table and low permeability	Depression with extended periods of waterlogging, high water table and high permeability	Flat with poor drainage, prone to periodic, short waterlogging, intermediate water table and low permeability	Shallow angles or flat, may be waterlogged over short time periods, e.g. snowmelt, deep water table and intermediate permeability	Waterlogging extremely unlikely, deep water table, very permeable subsurface conditions
	Hydrological risks – extreme precipitation events and flooding	susceptible to annual flooding	susceptible to 5-15-year flooding	susceptible to 15-50 year flooding	susceptible to 50-100-year flooding	susceptible only to floods >100 year magnitude

2. **Surface drainage and morphology**

The criterion to evaluate water accumulation is depressions formed in the landform. Such depressions can be either limited areas where spoil has either settled or placed in such a way to produce a trough, or they can be a larger areas such a former mine excavation pits. If such areas are present, they can become waterlogged for short periods of time or even become permanent wetlands. In order for an area to become temporary or permanently waterlogged, the most important criterion is depressed landform. Depressed trough like landforms can easily be waterlogged and depending on annual precipitation, soil permeability and water table elevation, they can become permanently or temporarily affected. Table 3 presents a 1-5 rating system related to waterlogged conditions.

3. **Hydrological risks – extreme precipitation**

To evaluate whether an area is susceptible to either water runoff and soil transportation or to become water logged, the annual precipitation and extreme rainfall events need to be assessed. In a very arid environment, where rainfall is limited or insignificant, such problems rarely exist or they occur with limited effect in the surroundings. The opposite is true for very wet or tropical areas.

2.4 ENVIRONMENTAL RISKS FROM OPEN PIT MINING

Open pit coal mines have significant environmental hazards that are easily transformed into risks. Among the most important environmental hazards from open pit mine operations is the presence of soil or groundwater contamination and its manifestation with impact to the environment. The most important environmental effects of open pit coal mines, are water quality (including a possible acid mine drainage presence), soil pollution with heavy and toxic elements, especially ones found in fly ash and air pollution with dust, toxic microparticles and air pollutants produced from thermal power plant operations.

- Acid mine drainage (AMD) is a serious environmental risk both in open pit operations and in underground mines. AMD can be produced either in the water filled mine opening or from the abandoned mine wastes, if not properly treated. When rock containing sulfides such as pyrite are exposed either in the mine slopes or the mine waste, the oxidizing action of air, together with water circulation and bacteria effects, convert inorganic sulfur into sulfate ions and sulfuric acid. In flooded open pit mines, or well covered and protected waste material the availability of oxygen is limited and a reduced rate of pyrite oxidation occurs. When oxidation occurs, it generates excess heat which can cause also internal self combustion of spoil, but also cause a chimney-like effect, sucking in oxygen to feed the ongoing oxidation process. The process is autocatalytic, in which the chemical reactions catalyze each other. These conditions significantly affect water contamination with AMD, and when such conditions occur, they are difficult or costly to mitigate effectively.
- Soil contamination from heavy elements. Such contamination is usually related to the combination of power plant emissions and fly ash disposal. Both of these operations can deposit heavy elements in the ground such as As, Cd, Cr, Ni, Hg and other trace elements. The soil contamination can be of a local scale such as in areas near or under fly ash waste deposits or it can be more broadly dispersed with air transport. Areas near or even far from an operating power plant can be contaminated especially in areas of historic power production from coal. Such contamination from heavy metals can range from negligible to high and can produce significant environmental hazards and land degradation. This is because such heavy elements

are persistent and difficult to decontaminate. With increased concentrations they can be transported through the food chain to animals and humans.

- Air pollution: Open pit mines and thermal power plant produce dust and noxious gases that are transported in the air. Elevated pollutants such as SO_2, NOxes, Benzene and H_2S have been found in the air around operating power plants and contribute significantly to the contamination of the environment.

Different methods for evaluating contamination due to heavy metals are available such as the geoaccumulation index (I_{geo}) which takes human activity into consideration (Muller, 1969), or the Nemerow pollution index P (Nemerow, 1974) or the potential ecological risk index (RI) (Maanan et al, 2015). All these methods require soil sampling and testing to produce accurate results. Since many times such data may not be available, a more qualitive assessment is used in the rating of such environmental conditions, taking into account the proximity of TPP operation, manifestation of contamination in reports or other documents and general groundwater conditions and geological settings. This approach produces a crude evaluation of possible environmental conditions that need to be addressed in more detail, based on sampling, monitoring and chemical analysis. If such data are available then this methodology can be applied with more confidence in order to classify the land. In the following table the five-scale rating is presented for the different environmental criteria of surface mining operations.

Table 4: Five scale rating for environmental hazards of open pit coal mines and thermal plants

Theme	Criteria	1	2	3	4	5
Environmental risks	Presence of soil / GW contaminations or hazardous materials	Evidence of significant soil / GW contamination / presence of hazardous materials Very low pH<4 Absence of calcitic soils (marls)	Evidence of moderate soil / GW contamination / presence of hazardous materials Low 4<pH<6 light presence of calcitic soils (marls)	Possibility of relevant soil/GW contamination / presence of hazardous materials pH above 7, abundance of calcitic soils	No evidence of contaminations or presence of hazardous materials, Natural 5.5<pH<7	Proven absence of contamination / Hazardous materials, e.g. by soil / GW sampling
	Current / manifest environmental impacts of ongoing Lignite production (dust, noise, vibrations, traffic, odors)	High	Substantial	Moderate	Low	Negligible
	Proximity to operating TPPs, including after potential repurposing, lignite bunkers, fly ash stockpiles	0-250 m	250-500 m	500-1,000 m	1,000-1,500m	< 1,500 m

3. MODIFICATIONS AND ADDITIONS TO OPEN PIT MINES

The following modifications are proposed for LURA's approach in rating different types of land-related information and using an algorithm to determine the optimally matched utilization scenarios. Encompassing additional information will allow for a more global use of the LURA tool. The additions described below apply both to post mining lands related to both open pit mines as well as underground mines.

3.1 LAND OWNERSHIP

The first version of the LURA software was based on the needs of the Western Macedonia project in which the former mine lands had a single owner which was the Public Power Corporation (Greece). A single landowner is not a representative scenario for surface and underground mines around the world. Multiple ownership of surface land is the common case and this can affect future repurposing ability or scenarios. In some venues surface ownership and mineral ownership may be severed and post closure repurposing may be challenging due to multiple owners and competing interests.

It is proposed that during data gathering and data entry into LURA an additional field (or fields) should be included that will contain the following information:

1. **Type of land ownership** which will include fields such as "Government", "Regional Government", "Public land", "Private land", "other".
2. **Condition of ownership** which will include fields such as "perpetually owned", "Leased", "Rights to explore or Develop"
3. **Surface and mineral owner information** if available.
4. **Legal representation** if available

The above information will be used to produce a colored map of ownership or type of ownership and statistical information of ownership for the rated area. Based on the color map of ownership it will be easily identified how fragmented a land is and how many types of ownerships are involved. This information is considered crucial for future repurposing, because if an area previously mined or undermined has multiple owners and multiple types of ownership it becomes more difficult to manage further development, although there is evidence that small land owners form legal partnerships to be able to enhance the chances of land redevelopment.

This type of information could be included as a rating factor in the "Development Opportunities" theme. A rating from 1 to 5 can be applied in which 1 is a multi owned land with different types of ownerships and 5 could be a single owner of the majority of the land, with rights to explore or develop.

3.2 RESTRICTED USE

A land that is being rated could be under specific use or physical conditions that may not allow change of use and thus can prohibit or impair repurposing and future development. This was encountered in the Western Macedonia project with the following restrictions:

1. **Legislative restrictions**:
   These restrictions relate to different authorities that can forbid the change of use of an area: For example, an archeological site or a cultural heritage assignment could be considered lands that cannot be repurposed in any other way.
2. **Physical restrictions**:
   Physical restrictions can be attributed to conditions that are very difficult or even impossible to modify or repurpose. For example, a lake formed in an abandoned open pit or one that will form

once the mining operations are terminated, may be considered a physical restriction. A tailings dam can also be considered as a physical restriction, since it would be very difficult or even impossible to modify. An area with a tailings dam can be either considered to be a physical restriction if it is under operation or if it cannot be reclaimed or can be an area what has very low geotechnical and environmental ratings, representing an area that has very low value. This is something that should be decided by the Rater during a rating campaign by considering the actual conditions at hand.

This information is considered important with respect to future land use since a significant amount of either legislative or physical restrictions may impair repurposing and future development. A clear idea of such conditions can be presented in a colored map of the rated area and with statistical information of the different types of land use restrictions.

3.3 DEVELOPMENT OPPORTUNITIES

The 5th theme of the rating matrix is devoted to future "development opportunities" and is rated based on the added land value due to its development potential. The rating of this criterion is based on the "Cost of potential negative impacts from sub-optimal land use" which means that if high value land which has minimum geotechnical, environmental and hydrological legacies that could be used for example for a high value office building investment, will suffer a significant loss if it is utilized for agricultural use. This criterion is abstractly rated based on a subjective assessment of the legacies from the rest of the criteria. Although it is a very useful index because it combines the general assessment and future potential of an area, at the same it can be considered a "negotiable" criterion.

It is proposed that this criterion could be modified to incorporate more objective rating sub-criteria which are the following:

1. **Permitting conditions**:
   This subcriterion could be used to assess the ease of an area to issue permits for different developments. If permitting conditions are governed for example by a single authority which can be for example [2]Special Purpose Entity (SPE) with limited bureaucratic procedures a score of 5 can be assigned. If on the other hand, multiple central and local authorities, with complicated bureaucratic procedures and time-consuming interconnections, are involved then a score of 1 can be assigned.
2. **Ownership**:
   As mentioned previously the number and type of land ownership can play a critical role in the future ease of development. A significant number of owners with different types of ownership complicate investing opportunities. On the other hand, one owner, e.g. an SPE, can significantly attract investors. In this sub-criterion a rating of 1 could be multiple and complicated ownership and a rating of 5 could correspond to single and investment oriented (SPE) ownership.
3. **Reclamation status:**
   An active or passive reclamation strategy could have been followed during the mine closure which could significantly affect future funding. This could be either a driver or a barrier for repurposing and new investments. For example, if Acid Mine Drainage is present either in the former mine land (above ground or underground) or from heaps or waste stockpiles and an active treatment system has been installed, this may prove too expensive to be maintained and operated and could be seen as a barrier. If a passive system has been installed, for example full coverage of waste with

[2] Special Purpose Entity (**SPE**) is a legal entity (usually a limited company) created to fulfill, specific or temporary objectives such as reclaiming, repurposing and redeveloping a closed or a closing mine. They could be companies or government-related organizations which disband after the need dissipates

impermeable soil and gravity drainage which does not require energy, this could be seen as a positive outcome of reclamation. A rating of 1 can be used again for a completely active reclamation system which has a high cost of operation and maintenance and a rating of 5 for a completely passive system with insignificant cost of operation.

4. **Funding availability:**
   If an area is considered eligible for transition funding, or other types of funding that can be used to reclaim and repurpose, this could be considered a significant driver. On the opposite side, an area excluded from funding can be considered a barrier for future investments.

4. UNDERGROUND MINED LANDS RATING METHODOLOGY

4.1 GENERAL

The evaluation methodology for post-mining lands of underground mines has retained the same five general themes used for open pit mines. These encompass the critical aspects for underground mined lands and ensure consistency of user experience in the LURA application. In the following paragraphs the most important risks from the different themes are presented and tentative criteria are provided with the accompanying five scale rating. At the end of this chapter a table is provided with the five themes, the criteria per theme and the rating conditions.

4.2 LOCATION

The same criteria for open pit mines can be used for rating their location.

4.3 GEOTECHNICAL RISKS

Geotechnical hazards commonly result from legacies in underground mined lands, such as residual cavities, backfilled areas, change of rock mass properties by loosening or fractioning, and by subsurface groundwater dynamics. Moreover, there usually are features with geotechnical challenges similar to open pit mining, such as waste tips. A feature that may be more often found in the context of underground mines are tailings management facilities (TMF), which present highly specific geotechnical and environmental challenges.

The major geotechnical risks from underground coal mines after closure are:

- **Continuous surface movements or trough subsidence**:
  This type of movement, also known as "subsidence", mostly occurs in areas that use caving methods in which most or all of the coal is removed in each panel and the waste rock above the coal is left to collapse and fill in the void left behind. The amplitude of subsidence is directly proportional to the extraction height in the caved area left behind. Surface subsidence starts during active mining and once a certain width to depth ratio is exceed. Maximum surface is typically a percentage of the extraction height, with a typical range of 30 to 70 percent of extraction height, with a significant areal extent that spans over all fully extracted areas. The residual settlement in subsided area depends on the properties of the overburden and it may last a few months up to a few years after mining is terminated. The magnitude and extent of the final subsidence basin depends on the properties and thickness of overburden material. The subsidence basin typically covers an area of influence defined by an angle of draw (an angle from the vertical facing away from the fully extracted area) ranging from 10 to 30^{o}. A uniform areal extend is related to shallow dipping coal horizons <10^{o} while as the dip of the extracted seam increases the surface areal extend is not uniformly distributed above each extracted panel. Due to its continuous nature, trough subsidence does not pose danger to people or livestock, but can become detrimental for infrastructure and buildings.
- **Discontinuous movements** or sinkhole subsidence
  This type of movement can appear as localized subsidence, sinkholes, or chimney development with settlement or crater creation at the surface. This type of ground movement and instability is more dangerous than trough subsidence because it can appear suddenly, many years or even hundreds of years after an underground mine has closed. It can create settlement or complete collapse (sinkholes) where the crater has an areal extent ranging from a couple of meters to even hundreds of meters. The formation of such movements is due to caving from failed support

elements ether in the form of pillars left behind, from temporary support decay of entrance adits, or from erosion or decomposition of coal or waste material left behind to fill cavities. The surface manifestation of such movements is proportional to the volume of cavities left behind and the depth of the cavities. For shallow mines with less than 50m overburden, the manifestation can take the form of sinkholes. For deeper mines the manifestation is usually in the form of local or more extended subsidence. This type of movement is usually related to shallow dipping coal horizons <30° due to its discontinuous and localized nature and sudden manifestation to the surface with shallow or deeper craters (sinkholes) can be very dangerous to people and livestock. It can also produce significant problems for buildings and infrastructure. If this occurs at a mine that was gassy and water has not filled the void, sudden release of gas can accompany the ground movement.

- **Hanging wall collapse**:
  This type of movement usually occurs in shallow mines with high coal seam dip >30° which is mined either with total or partial extraction of materials. When the supporting elements (pillars) or the gob left in place, deteriorates the hanging wall may subside or completely collapse. This type of movement can take place a long time after mine closure and can present a significant residual risk for humans, animals and infrastructure. The subsidence manifests itself mostly on the dipping side of the coal with abrupt change near the surface.
- **Shaft failure**:
  A critical area for risk and legacies is around an old shaft ether used as an entrance or exit from the underground mine or as a ventilation or utility shaft. Shafts should be completely sealed during the mine closure process except in gassy mines where an appropriate ventilation or venting system may need to be in place to control built up of explosive gasses. The following hazards can be foreseen above or around shafts: They may have been left open with only a minimum enclosure. This can produce serious risks of injuries or deaths from people falling in either from curiosity or trying to access the old mine. The shaft is not completely backfilled and has only a limited plug on top. The seal with time, may deteriorate and then have a sudden collapse leaving a deep opening in the ground surface. The shafts may be backfilled but not adequately and with time, differential settlements and depressions may form at the surface above and near the shaft. In general, unless it is a very deep shaft with significant dimensions, and poor sealing, the surface manifestation of either settlements or crates will be limited to a few meters around the circumference of the shaft.

Table 5 presents the input data and the description for score selection for the different geotechnical hazards and legacies mentioned above.

Table 5: Criteria and description for five scale rating for the geotechnical theme for underground coal mining

Theme	Criteria	1	2	3	4	5
Geotechnical risks	Continuous spatial movement (trough subsidence)	Caving method, massive coal body, flat dipping, shallow with weak overburden strength, multiple level operations	Caving method, thick coal body, flat to moderate dipping, moderate depth with weak overburden strength, multiple level operations	Caving method, thick or thin coal body, flat to moderate dipping, moderate depth with moderate overburden strength	Caving method or partial extraction method, thick or thin coal body, flat to moderate dipping, deep with moderate to high overburden strength	Partial extraction method, thin coal body, moderate to steep dipping, deep with high overburden strength

Theme	Criteria	1	2	3	4	5
	Discontinuous movements (sinkholes)	Partial extraction method, massive coal body, flat dipping, shallow with weak overburden strength, multiple level operations	Partial extraction method, thick coal body, flat to moderate dipping, moderate depth with weak overburden strength, multiple level operations	Partial extraction method thick or thin coal body, flat to moderate dipping, moderate depth with moderate overburden strength	Partial extraction method, thick or thin coal body, flat to moderate dipping, deep with moderate of high overburden strength	Partial extraction method, thin coal body, moderate to steep dipping, deep with high overburden strength
	Hanging wall collapse	Steep dipping coal seam, shallow overburden, weak hanging wall	Steep dipping coal seam, shallow overburden, moderate strength hanging wall	Moderate dipping coal seam, shallow overburden, high strength of hanging wall	Moderate dipping coal seam, moderate overburden, medium strength of hanging wall	Moderate dipping coal seam, high overburden, medium or strong strength of hanging wall
	Shaft failure	Deep, significant dimensions shaft not backfilled or sealed, with low strength overburden	Moderate depth, significant dimensions shaft, partially sealed, with low to medium strength overburden	Moderate depth, sealed, with low to medium strength overburden	Moderate depth, partially backfield and sealed, with medium strength overburden	Shallow to moderate depth, fully backfilled, and surface capping, medium to high overburden strength

The different descriptions given in Table 6 are explained in the following tables:

Table 6: Mining methods related to total or partial extraction

Extraction	Mining Method	Basic description
Caving method	Longwall	Extract all of the coal over the width of the panel face in successive slices or cuts, with the roof being allowed to cave behind the support shields. Longwall faces are usually of the order of 150 m to 300 m wide and 1,000 to 3,000 meters long. Extraction thickness can range from 1.5 m to over 5 m. Every pass of the shearer will remove a slice with a thickness ranging from 0.6 to 1.2m.
Caving method	Shortwall	Extract all of the coal over the width of the panel face in successive slices or cuts, with the roof being allowed to cave behind the supports shields. Shortwall faces are in the range of 50m to 100m.
Partial extraction method	Room and pilar	The coal is extracted, leaving parts of the material as pillars with regular or irregular pattern or dimensions to support the hanging wall. The method is well adapted to deposits with a horizontal or flat dip not exceeding about 30 degrees while the hanging wall and the deposit must be relatively competent. 30-50% of coal is recovered with this method. After closure overstressed pillars can fail, the roof may fail, or even the floor may fail and pillars can sink into the floor, and subsidence effects may show up on the surface.

Extraction	Mining Method	Basic description
Caving method	Room and pilar with pillar removal	The coal is extracted, leaving parts of the minable coal seam as pillars with regular or irregular pattern or dimensions to support the hanging wall. The method is well adapted to deposits with a horizontal or flat dip not exceeding about 30 degrees while the hanging wall and the deposit must be relatively competent. In a second phase the pillars are extracted, one row at a time, leaving the mined-out portion, or gob, free to subside.

Table 7: Coal and overburden characteristics used in Table 1

Coal deposit	Characterization		
Coal thickness	Massive	Thick	Thin
Dip	Flat (0-5°)	Moderate (5-30°)	Steep (>30°)
Depth	Shallow <30m	Moderate 30 - 100m	Deep >100m
Overburden strength	Weak <5MPa	Moderate 5-25MPa	Strong >25MPa

4.4 TOPOGRAPHY AND HYDROLOGY – HYDROGEOLOGY

Hydrology and hydrogeology are major factors contributing to closure and post closure conditions. The effect of water in underground coal mines is difficult to evaluate because both beneficial and detrimental effects can manifest themselves. The effect of flooding of an underground mine can relate to other conditions such as geotechnical and environmental, which can have a positive or negative effect.

For geotechnical conditions, positive effects are the minimization of settlement and subsidence due to reduced effective stress in the remaining coal or collapsed hanging wall. Negative effects include overburden degradation or small uplift of the ground in the order of 0.2m.

With respect to environmental conditions, hydrology and hydrogeology are major contributing factors in relation to Acid Mine Drainage (AMD), pollution transport and methane or other gas emission restriction.

The topography and hydrology – hydrogeology section of the rating methodology addresses the direct effect of water flooding for underground mines. The indirect effects such as AMD are addressed in the environmental theme. The following direct effects of the interaction of water and topography are considered for underground mined land repurposing:

- **Creation of saturated low lands**: If a flat topography prevails in the post-mining area and the original groundwater level was near the surface, then flooding the abandoned mine and reinstating the previous water table can create water-logged areas such as marshes, or even shallow lakes. The effect is more pronounced if a total extraction method has been utilized and a significant area has been undergoing subsidence, resulting in a modified ground surface that is now very close above, or even below the original groundwater table. Additionally, raising the groundwater table in combination with partial extraction methods can accelerate the creation of sinkholes and produce artificial lakes in the collapsed areas. This post-mining groundwater rebound, especially when combined with subsidence, can have highly detrimental effects on structures above and below ground level (buildings, foundations and basements), as well as roads, drainage network, and subsurface infrastructure such as sewers and drainage networks.

- **Creation of sudden flooding conditions**: In moderate to steep topography, where the underground mine has been accessed via horizontal or inclined adits[3], the mine entrance may have been sealed and the water table raised inside the mine, or left open, allowing water to seep out of the mine continuously and disrupt facilities or ecosystems below the adit entrance of the mine. When sealing is used and the water table is raised to its previous elevation, a significant risk may develop if the seal suddenly fails. This issue can be detrimental if the water table inside the mine has significant elevation in relation to the adit plug, and/or if the water is contaminated with pollutants in high concentrations. A sudden failure of the seal could produce hundreds of thousands of cubic meters of water to escape which can easily resemble a dam failure in magnitude of the released volumes. Conversely, if a mine is not sealed, it will continue draining the areas above and the original groundwater conditions may never be restored; this can affect hydrology and ecosystems above the mine, and create the challenge of dealing with large amounts of potentially contaminated mine water effluents.

Table 8 presents the input data and the description for score selection for the different topography and groundwater hazards mentioned above.

Table 8: Criteria and description for five scale rating for topography and hydrology – hydrogeology theme for underground coal mining

Theme	Criteria	1	2	3	4	5
Topography and hydrology – hydrogeology	Saturated low lands	Flat topography, original (pre-mining) groundwater table near surface, total extraction methods can create permanent waterlogging or wetland formation	Flat topography, original (pre-mining) groundwater table near surface, partial extraction methods can create depression with extended periods of waterlogging	Shallow angle topography, moderately shallow pre-mining groundwater table, can create waterlogging over short time periods in lower areas	Shallow angle topography, moderately deep pre-mining groundwater table, can create water logging over short time periods in lower areas only in combination with strong rainfall events	Flat or shallow topography, deep or absent groundwater table, waterlogging extremely unlikely
	Sudden flooding conditions	Steep terrain, shallow water table after pumping termination (pre-mining level), deep coal mine with significant extent, without backfill, and partially sealed	Steep terrain, moderate deep-water table after pumping termination, moderate depth of coal mine with significant extent, without backfill, and partially sealed	Shallow angle topography, shallow water table after pumping termination, partial backfill and sealed.	Shallow angle topography, moderate water table after pumping termination, partial backfill and sealed.	Shallow angle topography, deep or non-existent water table after pumping termination, or fully backfill and well sealed.

Table 9: Topography and ground water conditions used in table 4

Topography and groundwater	Characterization		
Topography	Flat (0-5%)	Shallow angle (5%-15%)	Steep terrain (>15°)

[3] A tunnel or gallery providing access to the mine works.

Topography and groundwater	Characterization		
Ground water	Superficial (0-3m) from ground surface	Shallow (3-15m) from ground surface	Shallow (>15m) from ground surface

4.5 ENVIRONMENTAL RISKS

Underground coal mines have significant environmental hazards that are easily transformed into risks. Among the most important environmental hazards are Acid Mine Drainage (AMD), toxic chemical pollutants in the water, coal associated methane, spontaneous combustion and underground fires that can burn for decades producing heat and toxic fumes. Centralia, the largest and best-known U.S. coal fire, has been burning since 1962 and has resulted in relocation of nearly all of the town's residents.

- **Acid Mine Drainage (AMD) - Toxic chemical pollutants**:
  Underground mines which have not been completely depleted but have been mined extensively either with total extraction or partial extraction methods and located above the groundwater level may still host significant amounts of pyrite and small quantities of alkaline materials to buffer. These can pose a serious AMD hazard. Sulfur present in pyrite combines with oxygen to produce sulfate and in the presence of water sulfuric acid is formed. Water percolating downwards and into the mine, from the hanging wall which due to its movement and partial collapse in the mine (especially in longwall mining) has increased permeability, can produce AMD which may contain manganese, aluminum, arsenic, heavy metals, and high TDS[4], depending on the geochemistry of the coal seam and surrounding broken waste rock and residual coal. The risk of AMD formation is higher in mines that are affected by a fluctuating groundwater table (e.g. due to seasonal variation). The continuous rise and fall of the water table exposes rock and coal to cycles of wetting and oxygen-contact, resulting in high rates of oxidation of the rock material, and thus an accelerated production of AMD. When water drains out of the mine from an adit opening or any other opening, AMD with its high pH and potential contamination can significantly affect areas and water systems downstream. Once AMD commences forming in a mine it is very difficult or even impossible to contain and active or passive water treatment methods are required to bring it under control. Completely flooding a mine in which the water table is significantly above the broken waste rock and coal, can slow and reliably control AMD due to the low oxidation in the "standing" underground water. For this reason, mine flooding is considered a positive outcome for locations where AMD is foreseen. AMD can also pollute adjacent aquifers that are used for drinking or irrigation purposes. When AMD enters surface water bodies, the effects include biotic impacts on stream and lake organisms through direct toxicity, habitat alteration by metal precipitates, nutrient cycle disruptions, or other mechanisms, and the water often becomes unsuitable for domestic, agricultural, and industrial uses. AMD is considered among the most serious issues of water pollution, especially from underground mines.
- **Abandoned Mine Methane (AMM) and/or coal associated gases**
  The natural burial of the organic material that accumulated in swamps along with other sediments begins the process which forms coal. As the remnants of the swamps are exposed to heat and pressure these materials are transformed into rock and coal. Heat, pressure, and water, which may contain abundant microbes interact to bring about a complex biological and geological process collectively known as coalification. During the coalification process, the remaining organic material is progressively metamorphosed from peat into coal, carbon

[4] Total dissolved solids

becomes more concentrated, and volatile organics are released. As this transformation intensifies, the metamorphic rank increases, progressing from brown coal to hard coal while migrating methane becomes sorbed onto the carbon molecules in the coal matrix. Increasing carbon content in coal increases the ability of the coal to sorb gases. The pressure exerted by water saturated overburden prevents adsorbed methane from escaping. Mining disturbs this trapping mechanism and gases are released as coal is extracted, overlying strata relax and water content is diminished.

Methane is dangerous and a hazard when encountered in an underground mine. Methane is also a powerful greenhouse gas which should be recognized by mining companies as a serious climate pollutant. Deeper underground mines from which medium to high volatile bituminous coal is extracted may liberate significant volumes of methane. Surface mining may liberate significant volumes of methane as well, but because they are open to the atmosphere the methane often goes unnoticed, but damage to the climate is still a serious problem.

When mines are closed, emissions of methane to atmosphere may not cease until the mine becomes filled with water. Closed or abandoned mines have produced sizable quantities of methane for decades as methane migrates to shallower depths and lower pressures. Methane may also be a danger to nearby communities as it may migrate along natural or mining-related fractures and pass through porous beds; it may be also be carried in solution by groundwater and be produced as water is used. Sealing may not be possible nor recommended without consideration of the potential need to vent methane in a controlled and safe manner. The potential pathways for fugitive emissions of methane should be considered during mine closure planning and measures should be taken to inhibit uncontrolled flow. As gassy mines are closed, systems should be installed to prevent uncontrolled release and facilitate the destruction of methane by employing good practices for capture, abatement and/or use.

- **Spontaneous combustion and underground fires**:
  Coal combustion caused by natural processes of human intervention can persist for many years or even decades in underground coal mines. These fires produce and emit carbon dioxide, nitrogen oxides, mercury, carbon monoxide and other toxic elements. In closed or abandoned underground mines the exposure of coal or waste rock to oxygen results in the oxidation of coal or pyrite, which is a heat generating reaction. This can generate enough heat to cause spontaneous combustion, especially as the minimum required temperature for coal combustion is lower in underground mines with high overburden. The nature and extent of coal-fire emissions has significant potential adverse impacts on people residing in proximity to fires and may be relevant on a global scale as contribution to GHG emissions.

Table 6 presents the input data and the description for score selection for the different environmental hazards mentioned above.

Table 10: Criteria and description for five scale rating for environmental hazards theme for underground coal mining

Theme	Criteria	1	2	3	4	5
Environmental Hazards	Acid Mine Drainage (AMD) and other toxic chemicals	Partial extraction method, ground water table fluctuating above and below mine absence of alkaline	Total extraction method, ground water table fluctuating above and below mine	Mine above permanent ground water table, NP:MPA ratio near 2:1, shallow to steep topography, Natural	Permanently inundated mine, NP:MPA ratio near 2:1, shallow topography, Natural 5.5<pH<7,	Permanently inundated mine, limestone or alkaline overburden, NP:MPA ratio higher than 2:1, flat topography,

Theme	Criteria	1	2	3	4	5
		overburden, shallow to steep topography, 4<pH<6 Significant AMD present, without treatment measure	[5]NP:MPA ratio less than 2:1, shallow to steep topography, 4<pH<6, AMD present, without treatment measure	pH>7, AMD present, with active treatment measure	minor AMD present, with passive treatment measure	AMD not present
	Abandoned Mine Methane (AMM)	Mine is deep and relatively dry with negligible water flooding. Little chance of mitigating fugitive emissions due to open and unknown sources which may include manmade entries and subsidence fractures that connect the mine void to the surface.	Mine is slowly filling with water but mine void volume is large with expected inundation in the distant future. Potential capture is possible, but rugged surface conditions make drainage and destruction difficult and expensive.	Mine is slowly filling with water but potential for methane drainage and capture is facilitated by modification of methane drainage system used during active coal extraction. Destruction or use of methane is possible.	Mine is rapidly filling with water but methane is being compressed in the mine void. As gas pressure rises temporary gas flows are managed using existing legacy gas drainage system to capture methane for destruction or use.	Mine flooding is complete and water levels are stable causing a natural seal prohibiting migration of methane.
	Spontaneous combustion and underground fires	Mine above permanent ground water table, Partial extraction method, not backfilled, absence of alkaline rocks,[6] history of spontaneous combustion, high overburden (can we give a range of meters?)	Mine above permanent ground water table, total extraction method, limited amount of alkaline material, many openings during operation	Partial extraction method, ground water table fluctuating above and below mine, limited alkaline overburden	Total extraction method, ground water table fluctuating above and below mine, limestone or alkaline overburden	Flat topography, permanently inundated mine, limestone or alkaline overburden,
	Proximity to operating TPPs, mine shafts,	0-250 m	250-500 m	500-1,000 m	1,000-5000m	< 5000 m

[5] maximum potential acidity (MPA), neutralization potential (NP)

[6] The exposure of coal to oxygen results in the oxidation of coal or pyrite, which is a heat generating reaction. Alkaline rocks reduce the oxidation potential of pyrite and by doing so they reduce the heat generation and self combustion

Theme	Criteria	1	2	3	4	5
	bunkers, fly ash stockpiles					

4.6 DEVELOPMENT OPPORTUNITIES

Development opportunities can be considered similarly as for open pit mines.

5. REPURPOSING POTENTIAL

5.1 ABOVE GROUND OR OPEN PIT COAL MINES

Table 11 lists and describes in detail the evaluation criteria to screen and classify locations regarding their repurposing potential for different types of post-mining use in areas of surface mining.

Table 11: Criteria and description for five scale rating for environmental hazards theme for underground coal mining

Theme	Criteria	Suitable / Favorable for…	Unsuitable / Unfavorable for…
Location	Proximity to infrastructure and utilities	Any industrial process that depends on delivery and shipping of goods or materials by road, and requires / produces significant amounts of energy and water, and solid and liquid waste	Recreational areas, research parks and other non-industrial uses may be negatively impacted by proximity to infrastructure.
	Proximity to human settlements	Recreational, business / research facilities would profit from closeness.	Industrial activities creating noise, emissions, odors and other risks / impacts should be isolated from settlements.
Geotechnical stability	Expected residual ground settlement	Almost irrelevant for agriculture and forests, recreation and tourism.	Can be extremely important for large scale structures with high loads and low tolerances esp. for differential settlement.
	Slope stability – seismic risks	Potential risk for any utilization scenario.	Can be actively hazardous for community health and safety, and infrastructure near the slopes of OD. Relevant for almost any use scenario; seismic risks need to be factored into ground stability assessments
	Impact of groundwater rebound (applies especially to interior dumps)	Almost irrelevant for agriculture and forests, recreation and tourism; can have positive biodiversity impacts due to creation of lakes, ponds and wetlands with high ecological value.	Can be very relevant and have negative impacts for large scale structures with high loads and low tolerances esp. for differential settlement. Potential agricultural and recreational issues due to water percolating through fly ash layers with elevated heavy metals content in OD
Topography and hydrography	Surface gradient and relief	Placement of PV on berms on high, stable slopes, if exposure appropriate; forests and natural reserves on slopes for stability, biodiversity, timber production or as carbon sink.	Any development requiring large, level space and stable ground; this will include almost any built structures.
	Surface drainage	Poor drainage and resulting standing water can be irrelevant, even an advantage for recreational use or biodiversity enhancement	All other uses require well drained surfaces, and tolerate neither stagnant water, nor erosion due to high flow velocities.
	Hydrological risks – extreme precipitation events and flooding	Limited tolerance for forestry, recreational use or biodiversity enhancement	Very limited or no tolerance for all other uses. Floods are particularly hazardous where they may interact with poorly consolidated dumps, which have high erosion potential.
Environmental risks	Contamination of dumped materials	Likely of low relevance for all industrial uses	Highly relevant and significant risk for agriculture; moderate risk /

Theme	Criteria	Suitable / Favorable for…	Unsuitable / Unfavorable for…
			deterrent for recreational / touristic uses.
	Current / manifest environmental impacts of ongoing Lignite production (which could continue for 30 more years): dust, emissions, noise, vibrations.	Limited relevance for industrial activities (which themselves may create noise, emissions, odors etc.), and for forestry. Moderate to significant relevance for agriculture activities – dust could e.g. create negative impacts.	High relevance / potential negative impacts for recreation and tourism, as well as "white collar" type activities such as R&D or office parks.
	Secondary impacts, such as unregulated waste disposal, processing and re-use of fly-ash from TPPs	Irrelevant for all uses except industrial processing of fly-ash.	When processing fly-ash into secondary products (e.g. concrete) need to ascertain acceptable levels of potential contaminants, especially heavy metals.
Development opportunities	cost of improving ground to suitable conditions for specific scenario	Any low cost investments such as agriculture, forestry, natural habitats.	Highly relevant and significant risk for investments requiring stable ground conditions with minimal geotechnical risks and no residual settlements.

5.2 BELOW GROUND OR UNDERGROUND COAL MINES

The table below lists and describes in detail the evaluation criteria to screen and classify locations regarding their repurposing potential for different types of post-mining use in areas of underground mining.

Theme	Criteria	Suitable / Favorable for…	Unsuitable / Unfavorable for…
Location	Proximity to infrastructure and utilities	Any industrial process depending on delivery and shipping of goods or materials by road, water and energy; producing significant amounts of solid and liquid waste.	Recreational areas, research parks and other non-industrial uses may be negatively impacted by proximity to infrastructure.
	Proximity to human settlements	Recreational, business / research facilities would profit from closeness.	Industrial activities creating noise, emissions, odors and other risks / impacts should be isolated from settlements.
Geotechnical stability	Continuous spatial movement (subsidence)	Almost irrelevant for agriculture and forests, recreation and tourism, limited influence on small buildings	Can be extremely important for large scale structures and low tolerances, irrigation and swage infrastructure especially near the edges of disturbance (e.g. wind mills).
	Discontinuous movements (sinkholes),	Forests not affected, agriculture and horticulture in limited manifestation, extreme sports recreation like cave exploration, rock climbing, etc.	Can be actively hazardous for community health and safety, and infrastructure or buildings near or above sinkholes. Due to the abrupt formulation of sinkholes, serious accidents and fatalities can occur.
	Hanging wall collapse	Forests and natural habitats partly affected. Serious effects for all other activities and developments	Can be extremely important for large- and small-scale structures, especially with low settlement tolerances, such as water supply,

Theme	Criteria	Suitable / Favorable for…	Unsuitable / Unfavorable for…
			irrigation and sewage infrastructure, tourism and recreation.
	Shaft failure	Almost irrelevant for agriculture, forests, and natural habitats due to generally limited extent of shafts. Can be a beneficial feature for recreation and tourism if shafts are maintained properly and made accessible for visiting.	Can be very relevant and have negative impacts on any structures with high loads and low settlement tolerances.
Topography and hydrography	Saturated low lands	Natural habitats, forests and lakes, biodiversity parks (wetlands), recreation and tourist attraction, agricultural crops that require significant amounts of water. Floating PV	Industrial parks, renewable energy (incl. wind and PV), large scale structures, business parks, agriculture.
	Hydrological risks – Sudden flooding conditions	Limited tolerance for forestry, recreational use or biodiversity enhancement	Very limited or no tolerance for all other uses. Floods are particularly hazardous where they may interact with downstream development.
Environmental risks	Acid Mine Drainage (AMD) and other toxic chemicals	Likely of low or limited relevance for all industrial / renewable energy uses and waste disposal units	Highly relevant and significant risk for agriculture and horticulture, fish and recreational activities, as well as natural habitats.
	Abandoned Mine Methane (AMM)	Limited relevance for forestry and natural habitat. Industrial development may use the AMM for energy production	High relevance / potential negative impacts for recreation and tourism, local communities as well as "white collar" type activities such as R&D or office parks
	Spontaneous combustion and underground fires	Limited relevance for forestry, Industrial development could operate in proximity with minor interference	High relevance / potential negative impacts for recreation and tourism, as well as "white collar" type uses such as R&D or office parks; may be a risk for RE installations.
	Proximity to operating TPPs, mine shafts, bunkers, fly ash stockpiles	Irrelevant for all uses except industrial processing of fly-ash. Recreational attraction in closed but maintained shafts	When processing fly-ash into secondary products (e.g. concrete) need to ascertain acceptable levels of potential contaminants, especially heavy metals.
Development opportunities	Added land value due to its development potential	Any low-cost investments such as agriculture, forestry, natural habitats.	Highly relevant, significant risk for investments requiring stable ground conditions with minimal geotech. risks and no residual settlements.
	Permitting conditions	Any low-cost investments such as agriculture, forestry, natural habitats.	Highly relevant for industrial development, including RE (wind or PV); significant risk for investments requiring easy permitting conditions
	Ownership	Any low-cost investments such as agriculture, forestry, natural habitats.	Highly relevant for business offices, significant risk for investments requiring large land parcels (land acquisition from different owners)
	Reclamation status	Industrial development, alternative energy production, waste disposal facilities	Highly relevant for business offices, recreation and tourism, agriculture and horticulture; can be significant opportunity for investors with environmental targets including limiting greenfield investments.
	Funding availability	Industrial development, alternative energy production, waste disposal facilities	Irrelevant for forestry and natural habitats.

APPENDIX A – GLOSSARY

Acid Mine Drainage (AMD)	Water which became acidic during its passage through pyrite bearing mined strata
Adit	A roadway, horizontal or gently inclined, which connects subsurface mine workings to the ground surface
Alkaline rocks	Rocks that contain significant amount of lime minerals
AMM	Abandon mine methane
Backfill	The broken waste rock material which occupies a restored surface or underground void
Bituminous Coal	A coal that contains 15% to 20% volatile matter. It is dark brown to black in color and burns with a smoky flame. It is intermediate between sub-bituminous and semi-bituminous coal
Bunker	The location near the thermal power plant where extracted coal is deposited to be used for coal firing the power generators
Capping	The material placed on top waste fill materials as an inert soil to protect from water infiltration
Chimney	A sudden appearance of a collapse slender crater at the surface with horizontal extension varying from a few meters to several tens of meters in diameter that reaches the underground mine
Coal	A solid, brittle, more or less distinctly stratified combustible carbonaceous rock, formed by partial to complete decomposition of vegetation; varies in color from dark brown to black; not fusible without decomposition and very insoluble
Coal associated methane	The methane that is found in coal seams. It is formed during the process of coalification, the transformation of plant material into coal
Coal panel	Subdivision of a coal block into discrete elements (panels) for orderly coal extraction
Coal seam	Block of coal into panels for orderly coal extractions
Coal seam dip	The angle that the coal seam makes with a horizontal line
Coalification	The metamorphic processes of forming coal
Collar	The rim of a mine shaft and/or the structural features used to support it
Dewatering	Remove or reduce ground water table or groundwater pressure with pumping or gravity drainage
Dip	The angle that any inclined geological stratum makes with a horizontal line
Dump waste	A pile of broken rock without economic value placed on surface
External dump	A pile of broken rock without economic value placed outside the limits of a mine void
Factor of Safety	The reserve capacity to failure of a material or construction from an applied force or stress
Fill	A pile of broken rock or ore placed on surface
Fly ash	A coal or lignite combustion product that is composed of the particulates that are produced after the coal has been burned in fired boilers together with the flue gases
Footwall	The country rock immediately underlying a dipping coal seam or fault
Gassy mine	Mines that produce significant amount of methane

GIS	Geographical Information System
Goaf or Gob	A shattered mass of rock, formed by the collapse of roof strata into a void from which coal has been removed
Groundwater rebound	The condition where the water table returns to its original depth after the termination of pumping equipment or drainage procedures
GW	Groundwater
Hanging wall	The strata (rock material) immediately overlying a dipping coal seam or fault
Heavy Dumper	Heavy trucks not allowed to travel in regular roads, used in mine haul operations
Level	Major roadway in a deep mine, or the process of developing a new bench within a surface mine
Longwall	A method of working flat-lying coal seams, in which rectangular 'panels' (usually 100 to 200 m wide by 1000 to 4000 m long) are removed by successively cutting away a strip along one of the short sides of the rectangle (the working face), allowing the roof overlying previous face positions to collapse behind forming a gob
Low lands	Lands that their surface elevation is below the natural ground water table
Mine shaft	A mine shaft is a vertical access hole that is several meters in diameter and stretches down to the location of the extracted coal. It is used to transport people or equipment and or material, air etc., deep in the underground mine
Multiple level	Extraction of underground coal in different elevations
NP:MPA	Maximum potential acidity (MPA), neutralization potential (NP)
Open pit mine	Any working (or worked) void of a surface area to extract coal or lignite
Overburden	Barren strata or waste rock or soil material without any economic value overlying the coal (economic deposit, ore)
Overburden strength	The strength of the rock above the coal seam which is usually measured with the Uniaxial Compressive Strength Test
Partial extraction	When coal remains in the mine area as support during (and after) extraction
Plug	The man-made structural element used to close underground mine openings (shafts, adits)
Power storage facilities	Industrial facilities that can store energy such as molten salt power plants
Reclaimed lands	The process of restoring land that has been mined to a natural or economically usable state
Residual cavities	Usually, underground mined cavities that have not been backfilled
Residual settlement	Ground surface settlements that occur after an underground mine operation has terminated or after fill placement has been completed
Room and pilar	A method of extraction in underground mines in which the coal is removed by means of a set of mutually perpendicular roadways (rooms), leaving pillars of intact coal to support the roof
Shaft	The principal access shaft to a deep mine
Shortwall	Same as longwall mining but with faces that are in the range of 50m το 100m
Sinkhole	A sudden appearance of a collapse slender crater at surface with horizontal extension varies from a few meters to several tens of meters
Spoils	The excavated material above the coal seam which has no economic value and is placed on fills in the vicinity of the mine area

Spontaneous combustion	The outbreak of fire without application of heat from an external source but due to internal thermal increase due to oxidation of coal material
Stacker placed	Material that are placed with a crane like equipment
Stockpiles	Excavated mined material temporarily placed in fills (could be ore, coal or waste rock)
Strip ratio (stripping ratio)	The amount of waste rock or overburden material that must be removed to release a given ore quantity
Subsidence	The surface manifestation of settlement above underground mines
Tailings facilities	Facilities that processed or mine by products are stored usually in a liquid or semiliquid phase
TDS	Total dissolved solids
Top soil	The vegetated part of the soil
Total extraction	The complete extraction of coal from an underground mine
TPP	Thermal Power Plant
Trough subsidence	The form of surface settlement above an underground mine that has a wave geometry
Underground mine	A void excavated underground for purposes of mineral (coal) extraction
Waste material	Excavated material during mining that has no economic value
Waste rock	The rock excavated above or besides a coal seam which has no economic value
Waste tips	A pile built of accumulated spoil – waste material removed during mining
Water logged areas	Areas that are temporary or permanently under water or areas in which the water table is located exactly on the ground surface