DELIVERABLE 4.1 REPORT ON REMEDIAL ACTIONS

SUMMARY

The report provides an in-depth overview of climate change remedial measures in mining. The measures, which relate to different forms and types of mining and post-mining facilities, also take into account the important areas of the project focus - minewater, emissions, surface and structure and mine rehabilitation. The report shows that the identified measures are effective from an early stage in avoiding risks resulting from climate change. The remedial measures are also given a gradation of significance that allows them to be used in operations depending on the life stage of the mining facility.

The presented remedial measures have been described in such a way to allow the reader to refer to practice. Reference is therefore made to existing and ongoing pilot sites, risk identification and selection of solutions, etc. Last but not least, the relationship of the designed countermeasures to the modelling process carried out in WP3 is demonstrated. The results of WP3 have allowed the quantification and modelling of future impacts. The report also includes a very important element from the point of view of project implementation, namely the pilot installations that were carried out at the Janina Mine Waste Heap and the Głowacki Shaft. These installations are an example of the process of securing mining facilities in such a way that they become resistant to climate change.

METHODOLOGY

Mining is a sector that is particularly vulnerable to climate change. It is inherently dependent on the natural environment and the industry's long-term viability – and therefore, strategic decision-making – is directly tied to the location of the resource to be mined. The mining sector requires a number of suitable natural conditions including, but not limited to, a habitable climate, access to water resources and supporting infrastructure to extract resources and process them for future domestic and/or international use.

The overall approach to the identification of risks and impacts as well as mitigation and adaptation measures is presented in the figure below.

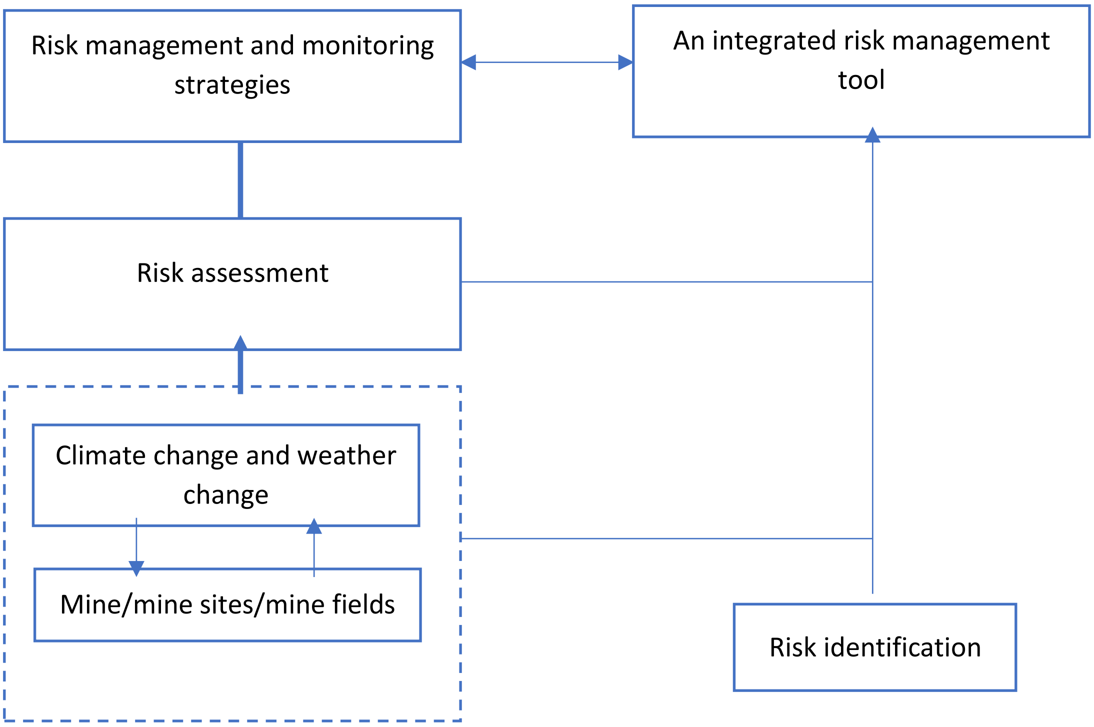

Figure 1. The overall approach to identification of risks and impacts as well as mitigation and adaptation measures

In WP4 of TEXMIN project a general methodology for conducting a risk analysis was adopted. It was determined that in order to produce a result defined as a management tool, it is necessary to first identify the hazard, next determine the probability, and then the effects of climate events. Based on the scientific data review, it was specified that it will also be important to include non-climatic factors (e.g., social factors, economic factors, etc.) in the risk analysis, as presented in the previous sections. Non-climatic factors may also affect pathways associated with climatic factor pathways and influence decision criteria. That the risk analysis be performed based on a two-parameter matrix, which consists of the probability of hazard event (P) and the consequences of that hazard (C).

The method of determining risk by combining the climate factor with climate change impacts has been adapted from other projects and approaches, including the RISKGATE and EWENT project or the EDAC (Economic and Decision Analysis Centre) and SEPO (Systems Engineering Process Office) guidelines. In TEXMIN project, the risk will be calculated also on the basis of two-parameter matrix. The probability will be quantified based on the statistics (mathematically calculated), especially for climate events or based on the opinion of experts, for the non-climate events. The calculated and categorized risk for climate and non-climate events allows to identify of preventive measures that can be applied in the mining sector. The risk assessment based on the definition of mining systems’ vulnerability to climate extreme weather events and non-climate events in different countries and on calculations of the most probable causal chains, starting from adverse weather phenomena and ending up with events that pose harmful consequences to the mining systems in different regions.

The identified climate factor and its increasing direction were combined with the climate change impact. These factors were combined using "IF" and "THEN" formula (SWIFT technique), and the result of this combination is the identified risk.

ENVIRONMENTAL IMPACTS AND REMEDIAL ACTIONS ASSOCIATED WITH MINEWATER

Water issues were evaluated by DMT and UNEXE based on their work in Task 3.1. For the efficacy verification of measures the models developed or enhanced for this Task were used by variation of input parameters relating to their particular impact. For the processes and interactions, reference is made to the findings from WP2. In terms of the BOXMODEL analysis, mitigation measures can only be proposed if it can be demonstrated that previous normal ranges of flow and concentrations will be exceeded and that existing infrastructure (pumps, treatment plants) and/or the discharge environment is not able to cope with these conditions. Therefore DMT had analysed the range of climatic causes and their impacts on mine water management and compared them with regular dimensioning of installations. With regard to minewater quality, the transition from longer periods of drought to precipitation phases were considered, as particularly intensive leaching of weathering products can take place here. From this, other mitigation measures can be proposed, estimated by cost and assured taking into account technical and sustainable options. UNEXE used the identified risks of flooding from spoil tips from their modelling to design strategies to manage the risks arising from changes of weather in the future. These included providing guidance on the requirements of the capacity of drainage channels as well as ensuring staff can be in place to manage risks on the ground.

ENVIRONMENTAL IMPACTS AND REMEDIAL ACTIONS ASSOCIATED WITH EMISSIONS

SUT has investigated mitigation and adaptation measures related to reducing noxious gas emissions from abandoned mines in relation to the most important physical impacts of atmospheric pressure and temperature – identified in tasks 2.2. and 2.3. SUT applied their own method to determine a category of gas hazard at the surface of selected post-mining areas. This methodology is based on summing up the presence of existing negative factors which may give potential gas emissions at the particular site (e.g. distance from the shaft being closed, filling level, the occurrence of the area or areas of former shallow exploitation, the time elapsed from the mine closure, state of groundwater level reconstruction, distance from the fault line, etc.). The risks will be determined in order to apply or propose effective engineering methods to mitigate specific kinds of hazards in the future.

In the second stage, SUT used the results of their model developed in Task 3.3 to develop measures to control and monitor gas emissions above abandoned or closed coal mines (especially around closed shafts and above the areas of old shallow exploitation). These measures are of relevance to the thousands of closed shafts in mining regions within the EU with respect to extreme weather events and increased frequency/rate of changes in atmospheric pressure. These measures cover the monitoring methodology, results interpretation and effective safety solutions for gas hazard reduction at the surface.

ENVIRONMENTAL IMPACT AND REMEDIAL ACTIONS ASSOCIATED WITH THE STABILITY OF SURFACE & STRUCTURES

GIG and SUB used the results of their models developed in WP3 and propose model mitigation and adaption measures related to how changes in precipitation relate to the stability of underground workings and surface structures, which could be beneficial for all mine sites (surface and underground) across the EU. Such mine sites rehabilitated under older climate regimes may require supplemental protection measures to ensure the stability of spoil tip, bench slopes and tailings covers.

SUB focused on the influence of water rebound on old slopes and dumps and on the influence of shallow workings on the stability of natural slopes. Proposed measures are modelled relating to long-term stability. There was classified in terms of being active (e.g. drainage) and inactive considering extra factors of safety in any new design. For these purposes, input data from WP2 and WP3 was applied. Detection and evaluation of damage caused by new precipitation patterns lead to simulating and verify the impact on the following aspects:

- Modelling stability of tailing dams under new conditions (failures due to changes in precipitation).
- Modelling stability of mine slopes under changeable water conditions.
- Water level variation affecting stability in underground structures, as well as sinkhole formation.

The effectiveness of these measures was evaluated by incorporating them into the numerical models developed in WP3.

Moreover GIG, SRK and TWD utilize the results of numerical simulations and with consideration of economic viability will develop methodologies to improve the technical conditions of one of the old shafts (SRK) and one spoil dump (TWD), as described in more detail in the section on the pilot installation, where small scale, pilot tests of solutions developed for the sealed shaft and spoil dump stabilisation is presented. The performed analysis will be a basis to create the construction projects of the most suitable solutions considering economical and technical analyses.

ENVIRONMENTAL IMPACTS AND REMEDIAL ACTIONS ASSOCIATED WITH MINE REHABILITATION

UNEXE and VUHU have investigate potential mitigation and adaptation measures related to effects on mine rehabilitation and biodiversity based on the identified impacts relating to changes in temperature (Task 2.2) and precipitation (Task 2.1) and the models developed in Tasks 3.1 and 3.2. The impact on biodiversity includes changes in distribution and abundance, habitat use and, as a consequence there are likely to be changed in the composition of plant and animal communities that utilise rehabilitated areas, such as spoil tips. Rehabilitation issues include revegetation, acid drainage and other pollution, flooding potential and land use. Erosion problems could occur if rainfall patterns change and more extreme events occur. The temperature may impact revegetation at the end of mining where a change means that vegetation is different to that prior to mining. These mitigation strategies were assessed and ranked in terms of their effectiveness, availability and survivability. Remedial actions that are more critical in terms of impact reduction are identified.

PILOT INSTALLATION

A part of the activities carried out in the WP4.1 was the realisation of pilot installations. For this purpose GIG, SRK and TWD have utilised the results of numerical simulations and with consideration of economic viability will develop methodologies to improve the technical conditions of one of the old shafts (SRK) and one spoil dump (TWD). Those were perform as small scale, pilot tests of solutions developed for sealed shaft and spoil dump stabilisation. Performed analysis were basis to create the construction projects of most suitable solutions considering economical and technical analyses. Two pilot installations were developed: (1) on Janina mine waste heap and (2) for the shaft Głowacki liquidation.

As for the liquidation of the Głowacki Shaft the proposed approach takes into account climate change forecasts prepared including increased water inflows associated with the occurrence of extreme precipitation events. It is also required to fulfil general safety requirements and protection of adjacent mine plants. The shaft liquidation method development use the data gathered in frame of WP 2 and utilises results of numerical simulations from WP 3. The selection of an optimum variant for the liquidation of the Głowacki Shaft and the assessment of the possibility to use the shaft as a water flow route was based on the analysis of hydrogeological-mining conditions in the area of the shaft, the existing water inflow system in the excavations towards the shaft, the system of water inflow to the area, the predicted deformations within the area of the decommissioned protective pillar resulting from the impact of the planned mining exploitation until 2042 and the identified and predicted technical condition of the shaft lining. The liquidation project of the Głowacki Shaft takes into account the variability of hydrogeological conditions in its vicinity as well as the impact of climatic changes in the years 1995 - 2018. These changes were characterized on the basis of Polish Meteorological Institute (IMiGW) data on annual precipitation. Changes in the quantity of water inflowing to the Głowacki Shaft area in the period of its exploitation, after its completion, after liquidation of the neighbouring Kościuszko Shaft up to the present time were analysed in relation to precipitation recorded at meteorological stations in Rydułtowy and Rybnik. Taking into account the existing hydrogeological and mining conditions in the area of the shaft and the further safe operation of the KWK ROW Ruch Rydułtowy, the optimum option for the liquidation of the Głowacki Shaft has been identified as the one involving the construction of a permeable backfilling column in the shaft and the use of a shaft pipe filled with permeable backfilling material as a route for water run-off from higher levels to the level of 600 m. The proposed solution will prevent accumulation of water in the excavations in the vicinity of the shaft. The analysis of hydrogeological and mining conditions indicates that the decommissioned Głowacki Shaft may long continue to function as a route for gravitational water flow through the permeable backfill.

Installation on the Janina mine waste heap illustrates how the risks associated with heap mining can be prevented. Because of the loose structure of mine waste dump slope, landslides may occur after the heavy rainfall. This requires significant labour costs in reforming the mine waste dump sites and disturbs the continuity of the depositing operations. Moreover, if the mine waste dump sites located in the built-up areas such a case in the Janina coal mine, landslides apparently can threaten lives and properties. Therefore, mine waste dump stability analysis is important for ensuring safety. The pilot installation design use the data gathered in frame of WP 2 and utilises results of numerical simulations from WP 3. Based on the rainfall data described in Deliverable 1.3, several considerations were taken into account in purpose to examine the possible impact of rainfall on the slope stability at the Janina mine waste dump. Details on case site characterization were given in Deliverable 2.1 and numerical simulation assumptions were outlined in Deliverable 3.2. As slope stability analysis above have pointed out the potential failure on the slope surface in case of the rainfall event of high-intensity and short-duration. Therefore, slope reinforcement is required to avoid slope failure in a case of extreme rainfall. After determining location of the potential landslide, slope reinforcement using nailing and steel mesh was proposed for the Janina mine waste dumps against the impact of high rainfall intensity. In the reinforced part of slope, no soil erosion event was observed, while in the unreinforced part of the slope, strong soil erosion was clearly noticed on the slope surface. By comparison of size of movements on the mine waste dump slope it can be noted that strong soil erosion was occurred in the unreinforced part of the slope, with the size of decreases up to 0.43 m (upper part)—dark blue. The soil was displaced and accumulated around the channel of water drainage and the lower unreinforced part with the size of increases in a range of 0.2 ÷ 0.4 m (orange and yellow). A slight soil erosion was observed in the reinforced part (studied site) with the size of movements less than 0.03 m. Probably, it is due to the presence of raised grasses. It can be stated that after the rainy season with an average monthly value of 100 mm rainfall, no significant movement was observed on the slope surface at the studied site, where slope reinforcement has been applied. The monitoring results confirm the numerical modelling results, i.e., slope at the studied site is considered stable after a high rainfall intensity in a short period of time, and the selected slope reinforcement is considered a proper landslide prevention method during high rainfall intensity (rainy season). Based on both modelling and monitoring results, the proposed landslide prevention method with coupling soil nailing and steel mesh is considered a proper method that can improve slope conditions and mitigate instability loss during high rainfall intensity in a short period of time at the Janina mine waste dump. Its application at the Janina mine waste dump can be a reference for other mine waste dumps and is expected to assist mine management to take proper and sufficient slope reinforcement measures to avoid slope instability. As a weather event, rainfall is unpredictable, therefore, landslide prevention measures and a continuous monitoring system (e.g., automated online) are recommended to ensure safety in long-term planning and design of a mine waste dump.

SUMMARY ON REMEDIAL MEASURES

Changing climatic conditions will have both direct (operational and performance-based) and indirect (securing of supplies and rising energy costs) impacts on the mining. These include, but are not limited to: water-related impacts (droughts, floods, cyclones and storms); heat-related impacts (bush fires and heat strokes) and sudden strong winds. A combination of these effects may endanger the sector's viability by denying the industry – and its personnel – a safe operating landscape, spatially (impacts felt across the immediate vicinity of the mining site and areas further downstream) and temporally (including, sporadic short-term and more permanent long-term changes). The impacts of climate-influenced extreme events on the mining industry remain highly complex in nature, largely due to the underlying multi-causality that takes effect across varied scales and dimensions. A whole-of-region approach is fundamental to capturing the full breadth of impacts felt directly or indirectly by the industry but also by communities and the wider ecological landscape that may both influence, and be influenced by the presence of extractive industries in the region. The analyses carried out and remedial actions identified can be structured into three groups forming a hierarchy of adaptation. Due to the layout adopted in the project and further in the report, an attempt has been made to relate these actions specifically to water, emissions, surface and structure and rehabilitation issues. Table below summaries the remedial actions which have been identified and described in the previous sections.

Table 1. Identified remedial actions

	Minewater	*Emissions*	*Stability of surface & structures*	*Mine rehabilitation*
try to avoid the impact	In the case of flooding due to rainfall runoff from spoil heaps, the following apply: • Plant spoil heap with vegetation. • Plant trees or bushes in addition to just grass. • Build or upgrade on-tip and permitter drainage ditches. • Build or upgrade storage lagoons to reduce peak demand on off-tip drains. • Consider a SuDs (Sustainable Drainage System) approach. • Consider reprofiling spoil heap (but that is expensive). Proactive pumping management	When gas hazard is expected build insulation layers under a building. Thus buildings will be protected in a passive way - insulation against the gas by application of special gas-proof materials in the ground.	Implementation of depressurisation systems Sediment traps in the drainage system Diversion of streams Installation of slurry walls Minimization of large flat surfaces in upstream works Sediment traps within the drainage system Surface water collection channels Modify the general geometry of the dam Construction of additional reinforced meshes Impervious dam cores Implementation of barriers at the slope toe Erosion resistant material layer	To improve the biodiversity of animal species on spoil heaps, the following should be avoided (but note that some of this advice is contrary to that for mitigating spoil heap runoff): • Developing spoil heaps (e.g. for housing or industry), • Reworking of spoil heaps for coal extraction, • Reprofiling spoil heaps, • Inappropriate rehabilitation of spoil heaps (i.e. without reference to promoting biodiversity), • Planting spoil heaps with woodland, • Planting spoil heaps for biofuels.
minimise the impact	In the case of flooding due to rainfall runoff from spoil heaps, many of the same actions proposed for avoiding the risk apply. However, in addition, the following is recommended: • Monitor (directly or remotely) spoil heaps to ensure correct operation	In the a building, especially in cellars and other near-to-the-ground sites – apply ventilation,	Implementation of depressurisation systems Sediment traps in the drainage system Diversion of streams Installation of slurry walls	To improve the biodiversity of animal species on spoil heaps, reduce the area of spoil heaps used for the following, thereby promoting natural succession of vegetation, and

	of drains and storage lagoons during heavy rainfall events, and to detect early signs of flood risk. Monitoring of water parameters in order to avoid the impact of contamination of surface waters and the main groundwater reservoir intended to be used as a water source Preparation and operation of treatment plants, reducing the harmful effects of minewaters	which consist of fans being turned on when gas is detected or pressure drop occurs there.	Minimisation of large flat surfaces in upstream works Sediment traps within the drainage system Surface water collection channels Construction of additional reinforced meshes Impervious dam cores Erosion resistant material layer	hence biodiversity of animals: • Forestry / woodland, • Biofuel crops. Implementation of the monitoring system and monitoring stations Reduction of seedling mortality by changing cultivation care Reduction of hydrogen gypsum occurrence by ammonium sulphate application (decrease in pH) Improvement of the water absorption capacity of the soils Application of nZVI (nano-scale zero valent iron) suspension
mitigate the consequences	In the case of flooding due to rainfall runoff from spoil heaps, these actions are not usually the responsibility of the mine operator, or those who have responsibility for abandoned mines, but of 3rd party organisations including town planners and rescue organisations. They include: • Upgrade or better maintain town/city drainage systems. • Prepare or upgrade emergency response plans.	Applying sensor-alarm system based on gas detection that cause loud alarm in a building and turning on the ventilation	Diversion of streams Minimisation of large flat surfaces in upstream works Surface water collection channels Construction of additional reinforced meshes Impervious dam cores Implementation of barriers at the slope toe Erosion resistant material layer	Change of the range of woody plants with preference for woody plants resistant to drought and heat