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New Chances from Old Shafts – Risk Management in Abandoned Mine Sites in Germany

1 Introduction

Around the world, mining has been done for thousands of years for the benefit of humankind. The winning process in mining operations ends with the depletion of the deposit or its closure if the operation becomes economically unprofitable. After that, a period of post-mining follows which may last for a very long time and which is generally regarded as a period of hazards, risk and high cost.

In the USA alone, approximately 500,000 abandoned mines do exist; worldwide, there are millions. In Germany, too, we have had to deal with abandoned mines for a considerable period of time now.

At the same time, economic and ecological requirements are constantly increasing, and the public opinion on mining has changed, e.g. its willingness to accept the consequences of mining activities. Thus it makes sense to establish suitable risk management for the post-mining era.

The mining companies in Germany are challenged to come to terms with sustainable mining: i.e. to regard the wake of the mine closure not only as a threat to economy, ecology and the affected communities, but to ensure that there will be positive effects for generations to come. Therefore, this essay will present a concept of sustainable post-mining that will help to manage risk and seize new opportunities. This concept will be of particular interest as there are more opportunities of post-mining than commonly known.

2 Mining in NRW

For our analysis, we have investigated the mining in the German state of North-Rhine Westphalia (NRW). With its 18 million inhabitants, NRW is the largest federal state in Germany. In NRW, 90% of German hard coal and 50% of its brown coal are mined; in addition, 33% of the German energy is generated here while 40% of it is consumed as well. More than one million people are employed in the energy sector, mining and affiliated industries.

Coal mining in NRW was the basis of the so-called "economic miracle" in Germany after World War II. But the production of hard coal began to decline in the 1960s, mainly due to increasing imports of cheap oil and gas.

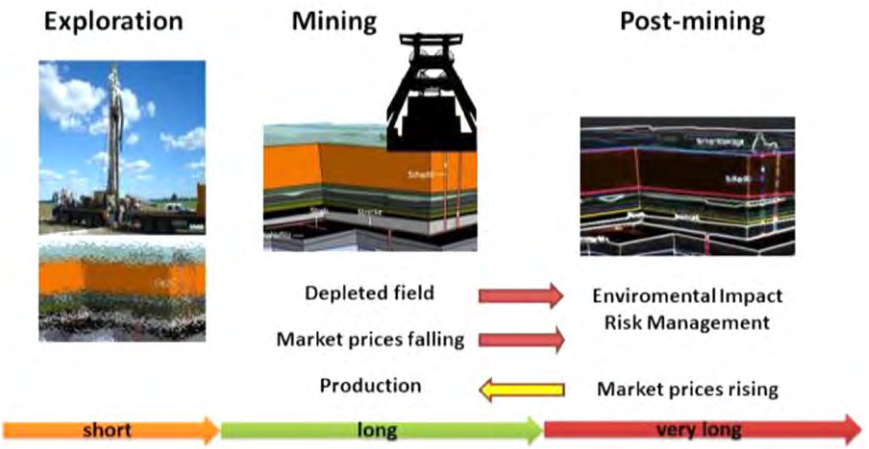

Figure 1 / The mining cycle.

Due to its non-competitive production costs, Germany's hard coal production depends on subsidies. The EU government does not allow this kind of subsidies anymore, which is the reason why the German government has decided to cease them in 2018.

This lack of funding will probably lead to the end of this more than 200 year-old industry. From hundreds of mines only four are still working in NRW. The era of post-mining has already begun.

3 The Mining Cycle

The mining cycle can be divided into three stages:

- The exploration phase, in which the deposit is investigated regarding its technical and economic profitability. The period of these undertakings is relatively short and can lead to the launch of mining operations. Even if there is an adverse decision in the beginning, this decision may be revised in case technological developments or market price will change the situation.
- What follows is the actual mining period which usually lasts for a very long time and ends latest when all deposits are fully depleted. This point of time, however, may be brought forward if the economic conditions (production cost or market price) deteriorate. Nevertheless, mining may be resumed even after a longer period of downtime if those conditions become favorable once more (examples are silver mining in Germany or rare earths mining in the USA).
- The longest stage, however, is the post-mining stage as the human interference into geology and nature usually is intensive and irreversible. It can lead to consequences which have a permanently adverse impact on people and the environment; therefore, they have be managed as best we can.

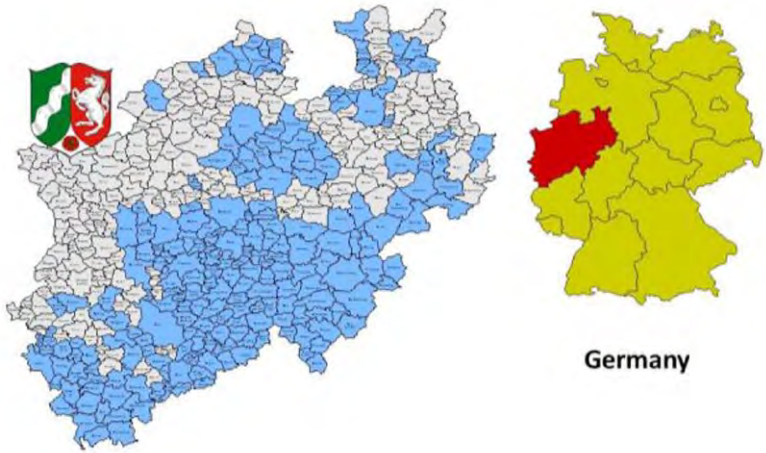

Figure 2 / Areas in NRW affected by abandoned mine sites.

More than 50% of the areas in North-Rhine Westphalia are affected by mining activities (coal, ores, and salt) – most of them are history now.

Especially the central region of NRW, the Ruhr area, has been turned into the biggest metropolitan area of Germany because of coal mining and the iron and steel industry. During its mining history, over 10 billion metric tons of hard coal has been mined in an area where today more than 5.2 million inhabitants live. Associated strata were brought to many refuse dumps. Large areas suffered from subsidence of more than 10-15 m. Roundabout 10,000 shafts and surface openings, a large part of it caused by historical mining with unknown location, were sunk to deplete the deposit. As both the impact and the time at which risks will emerge are difficult to determine, a comprehensive risk management was developed which has been established under the supervision of the mining authorities.

4 Risk Management Theory

The international risk management standard ISO 31000, codified by the International Organization for Standardization, defines the term "risk" as any "effect of uncertainty on objectives." Risk management is a special function in business management and integrated into other functions (personnel management, financial management, production management etc.) containing the identification of, protection against and mitigation of loss, damage and negative influences arising from risks.

Main objectives of risk management are:

- Coverage, early detection and assessment of risks
- Initiation of appropriate precautionary and safeguarding measures
- Creating a balance between interests of security and safety on the one hand and interests of adding or earning value on the other.

Finding and handling risks systematically provides a basis for a responsible and sustainable management of a company. There are no chances in business operations without risks. Both, chances and risks, are two sides of the same coin. Thus one can broaden the concept of risk management into one of risk and chance management which does not only tackle risks but also takes into account advantages brought up by chances.

5 Risk Management Process

There are four main steps in the risk management process:

- risk identification
- risk analysis and assessment
- risk treatment and
- risk reporting.

Risk identification is considered to be the critical step: a risk which is not identified cannot be actively managed.

Risk analysis includes estimating consequences and their likelihood. These factors are important for calculating the risk of damage or loss.

Risks are assessed in order to have a list of ranking and to point out where the level of acceptability and the priorities for treatment lie. The result of this step helps managers to deal with risks or to have suitable risk treatment.

Risk treatment is the selection and implementation of appropriate options to deal with risks like:

- avoidance (eliminate, withdraw from or not become involved)
- reduction (optimize, mitigate)
- sharing (transfer, outsource or insure)
- retention (accept and budget).

Risk reporting by communication and documentation is essential in order to implement the risk strategy in the company (top-down) and to gather risk information (bottom-up).

The risk management process can be supplemented by a systematic chance management. This will be demonstrated looking at how to manage post-mining.

6 Risks of Abandoned Mine Sites

In Germany, the mining of minerals such as hard coal, brown coal, ores, and salt, is regulated by the Federal Mining Act, the Bundesberggesetz (BBergG). Supervisory authorities are the mining authorities of the federal states.

Those are in charge of taking care that mining is operated without threats to people or the environment during all stages of the mining process, i.e. from exploration to post-mining.

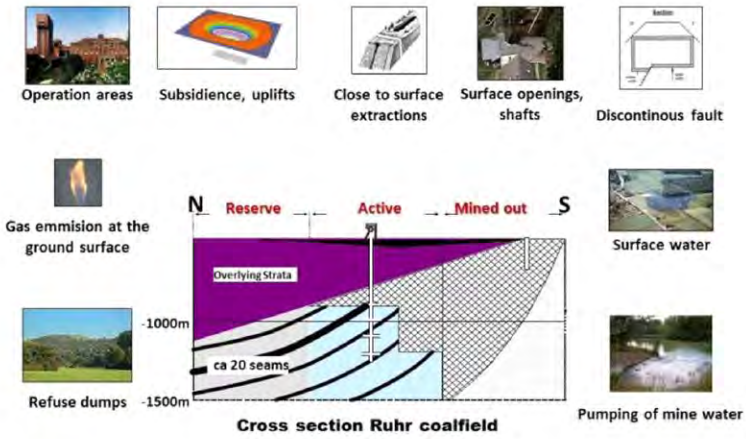

Figure 3 / Risk fields of a mining company.

As a rule, this mining charge ends after closing down production with the installation of a final operation schedule where long-lasting impact of mining is recognized and regulated as far as possible. The mining companies or their legal successors have to cover the costs.

If danger emerges from old, desolate and unknown underground work, the mining authority is responsible. If the former owner is unknown, the federal state has to bear the costs.

With particular regard to post-mining, the mining authorities – in close collaboration with the mining companies – have developed a risk management that enables to recognize all risks and define suitable measures.

The risk fields of abandoned mine sites can be divided in the categories:

- Close to surface extractions
- Surface openings, shafts
- Subsidence, uplifts
- Discontinuous faults
- Mine gas emission at the ground surface
- Surface water
- Pumping of mine water
- Refuse dumps
- Operation areas.

Negative impact of mining can be quite big and not only a long time, but also huge efforts are required to recover from. This is one of the most important issues which mining companies have to face in the communities, especially when it comes to mine closures. Without sustainability, there will presumably be no long-lasting acceptance of mining activities.

	Impact	Risk
1	Close to surface extractions	Safety, damages
2	Surface openings, shafts	Safety, damages
3	Subsidence, uplift	Waterlogging, damages
4	Discontinous fault	Damages
5	Mine gas emmision at the surface	Safety
6	Surface water	Continuous load of pumping
7	Pumping of mine water	Continuous load of pumping
8	Refuse dumps	Stability
9	Operation areas	Ground load

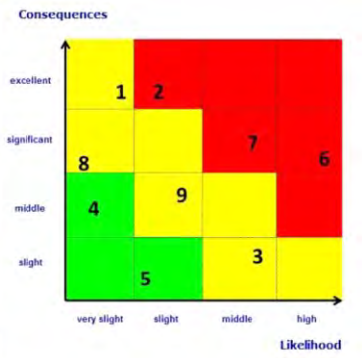

Table 1 / Analysis of risks.

In this context, sustainability means a holistic view of the mining cycle, including the opportunities that arise from abandoned mining sites.

Effective post-mining provides numerous opportunities for avoiding, mitigating or even utilizing the risks of mining for the post-mining era. However, there is no solution of "one size fits all": instead, individual solutions have to be implemented which take the geological, ecological, social and economic framework into account.

What principally matters is the successful control and management of post-mining risks and the effective use of the opportunities it provides.

7 Post-mining Management– a Chance for Sustainable Mining

Until now, post-mining management has focused on the issue of defending and preventing risks.

In the last years, however, the situation in the energy industry has undergone fundamental changes. Some keywords in this context are: the finite nature of fossil fuels, global warming, CO_2-emissions, and the risks of nuclear power.

Therefore, German politics has made it its mission to achieve a change towards renewable energies: regenerative forms of energies without CO_2-emissions such as solar energy, wind power and geothermal energy are to be the focus of public development and funding.

This move towards alternative energy sources brought about a boost of creativity and innovation which also captured post-mining areas.

Because if we take a closer look at the risk fields of historical mining, they may encompass large opportunities of generating renewable energies as well as new, future uses for former operating areas.

In the future, post-mining management has to incorporate these opportunities as the sustainable management of the mining heritage will have huge impact on the accept-

	Impact	Chance
1	Close to surface extractions	Geologic park
2	Surface openings, shafts	Methane production, Pump-storage power plant, Heat storage
3	Subsidence, uplift	Wetland habitats
4	Discontinous fault	-
5	Mine gas emmision at the surface	Methan production
6	Surface water	Wetland habitats, recreation areas
7	Pumping of mine water	Heat production, algas for CO_2 reduction
8	Refuse dumps	Windwheels, biomass
9	Operation areas	Trade and industry, photovoltaic, culture

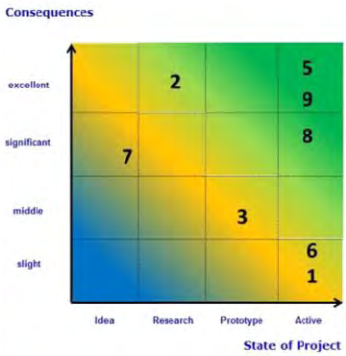

Table 2 / Analysis of chances.

ance of the mining industry as such. If we fail to seize the chances post-mining offers, there can be no long-term mining that will be truly sustainable.

8 Risk Analysis of Post-mining

Mining activities are performed in two ways: opencast mining with very obvious consequences, and underground mining where the consequences will emerge later and less directly. The general public only perceives the "tip of the iceberg" when it comes to the impact of underground mining as the entire infrastructure remains hidden for a considerable period of time. Table 1 shows an overview of the major risks, the probability at which they may occur, and their economic consequences.

9 Analyzing Chances of Post-mining

Nevertheless, these risks are balanced by considerable opportunities. A few years ago, projects were started in Germany to identify the opportunities arising from post-mining and to explore and investigate them further. Some of them have already been implemented. Table 2 shows the current state of those projects.

On the one hand, the analysis includes the stages from the initial idea to the operational use, and on the other hand it refers also to the consequences and the scope of possible projects which can only be estimated before the project actually starts.

10 Managing Risks – Seizing Chances: Working Examples

In this chapter, we will show some examples of how post-mining can work at different stages, looking at applications already in use, research projects, prototypes and some ideas and visions.

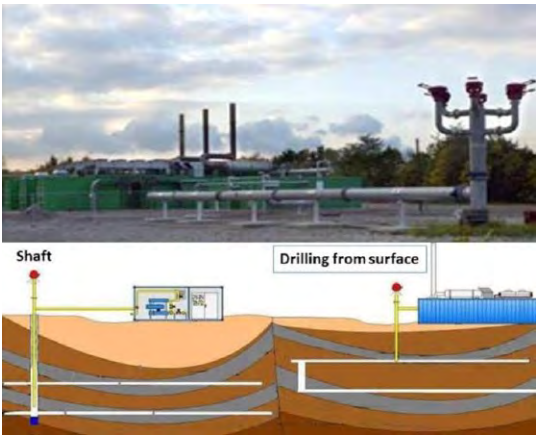

Figure 4 / Methods of utilizing methane.

Implemented Projects

Methane production

When hard coal is extracted in underground excavation, methane is released that is normally bound in the coal. Even once the extraction is finished, methane continues to flow into the open drifts, galleries and shafts. For around ten years, methane has been processed for generating energy in the Ruhr area: it is either extracted by suction directly from abandoned shafts, or holes are drilled from the surface into depleted fields to suction the gas.

By now, there are more than 100 facilities of winning methane this way with a total output of 150 MW. These small power stations help to cut 2.8m metric tons of CO_2-emissions per year.

Wind wheels on refuse dumps

The mine dumps in the Ruhr area are often 80-100m above ground surface; thus, they often feature high wind speeds which allow for an economically reasonable use of wind wheels, and three wind wheels have already been erected.

Biomass production

In addition, mine dumps often provide large, unused areas. A lighthouse project sees the planting of fastgrowing trees on these dumps: in a few years, these trees are supposed to be cut and used as biomass in ethanol production.

Research

(Wind) energy storage

As renewable energies are discontinuous in their production, they need to be stored in times of low consumption. One storage concept that can be utilized here is that of pumped-storage power plants: in these plants, water is pumped from a geometrically low-

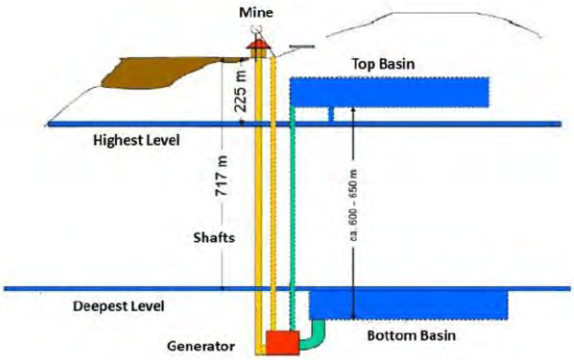

Figure 5 / Principle of pumped-storage power plant.

er level (lower reservoir) to a higher level (higher reservoir) to provide potential generation of energy. In times of peak consumption, turbines are used to generate energy from the flow of water as it is released back into the lower reservoir.

Such storage systems require a large amount of space; they are a significant interference into landscape and the permission procedure is laborious. Therefore, only a few locations have been made available for this technology. However, the extension of renewable energies requires significantly more pumped-storage water plants.

Thus it seems to be a particularly intriguing idea to use the well-known technology of pumped-storage power plants in abandoned mine sites.

Figure 5 shows the example of a mine built into very solid rock so that the lower and higher reservoirs can be cut into the ground into already existing mine structures underground. The major factors here would be the volume of the reservoirs and the penstock which both would be directly proportional to the power plant's efficiency.

Another option would be to use an already existing shaft and its entire depth as a penstock. In this case, the higher reservoir would be located overground, and the mine openings closest to the shaft would be used as the lower reservoir.

Prototypes

Photovoltaic

Apart from their height, mine dumps have another advantage: there are many free areas and hardly any shading. Therefore, they are ideal locations for photovoltaic systems; likewise, the large roofs of factory buildings can be used for these, too.

Heat from pit water

Every year, approximately 90m cubic meters of pit water are pumped in the Ruhr area. The

Figure 6 / Photovoltaic energy.

temperature of this pit water is 35-40°C (95-105°F) and can be used for supplying heating to buildings by means of heat exchangers or for accelerating the bio mass production when generating energy.

Heat from shafts

As long as a shaft is used for pit ventilation, the exhaust heat can be used to supply the premises with heating.

Ideas

Right now, mining companies and universities in Germany are developing numerous ideas on how to generate energy in abandoned mines.

Pits as heat storage

Even after a mine has been abandoned, there are still some miles of solid, stable mine structures left. There is the idea to use them for bringing in heat-storing material which would absorb the temperature of the surrounding medium of 40-50°C (104-122°F). This energy could be extracted when needed.

Heat from pit water

The heat of the pit water can be used to support the growth of algae, i.e. chlorella vulgaris, which feeds on the minerals in the water and splits CO_2 into oxygen and carbon. This would result in two positive effects: greenhouse gases would be eliminated, and biomass would be produced. Those effects would be easy to profit from as CO_2 certificates could be traded and the biomass produced could be sold as building material or filter substance.

Figure 7 / Ewald Colliery 1962.

Geothermal energy

A shaft providing sufficient depth and diameter can be used to drill clusters from the sump in order to extract geothermal energy as here, we are already many hundred meters closer to ground heat.

11 Ewald Colliery – an Example of an Integrated Post-mining Location

The largest opportunities for former mines in NRW lie in the development of locations which integrate surface and underground uses. The project of Ewald Colliery serves as an excellent example to illustrate this. Until 1999, the colliery produced an output of approximately 2.5 m metric tons per year. Its premises included around 0.44 km^2 (109 acres) of surface area, 2 shafts and more than 90 buildings.

In 2002 a team consisting of architects, urban planners, technical authorities, municipalities and individual citizens developed a concept of how to utilize the surface areas. After that, the area was redeveloped, i.e. some buildings were demolished, others restored and marketed. By now, a number of companies have found a new home there, including industries such as logistics, technology, services, crafts, commerce, leisure time and real estate, as well as catering and even a theater.

At the same time, mine gas is extracted from the old shafts and sold. At the mine dump nearby, a wind wheel is being built to generate energy; in the medium term, a hydrogen competence center is to be established at Ewald Colliery to promote the energy generation from hydrogen as a fuel.

All of these developments show that the former colliery is being revamped as a world class location which fulfills all criteria of sustainable development: new values, new jobs, and ecological recovery.

Figure 8 / Ewald Colliery 2015.

12 Risk and Chance Communication

Proper risk management and the utilization of chances are accompanied by extensive communication with the different stakeholders: this communication does not only take place at the technical level between authorities, companies and universities, but also involves municipalities and citizens. For example, university conferences, public relations campaigns and informative events are organized together with the communities.

13 Key Elements of Post-mining

The achievement of post-mining management in the German mining industry is based on an integrated riskchances system that encompasses the following key elements: ideas and visions, research and development, integration of surface and underground, excellent risk management and sustainability for the complete mining cycle.

In order to competently implement post-mining management, a sufficient number of experts and executives have to be trained in this field. For example, the TH Georg Agricola in Bochum offers a master degree course in Geoengineering and Post-mining.

Post-mining excellence requires a high motivation as well as a high level of abilities und skills. Otherwise, post-mining will be nothing but inefficient short-term thinking of muddling through, or lip service where no one practices what they preach. Figure 10. Post-mining excellence.

A high motivation needs a change of mind: postmining does no longer mean to avoid certain hazards, but has become an evolutionary process which is based on the management of risks and the utilization of chances towards a sustainable development.

This process should be encouraged by suitable governmental incentives and regulations to promote ideas, to support research and development, and to run lighthouse projects profitably.

Figure 9 / Key elements of post-mining management.

The implementation of such innovative lighthouse projects at old mine sites is often a milestone for mining communities on their long road into a brighter future.

In order to improve abilities and skills, we need to establish a network of companies, universities, government institutions, mining authorities and research centers which will promote a transfer of both knowledge and technology.

Figure 10 / Post-mining excellence.

14 Conclusion

The authors of this essay are convinced that postmining will develop into a multi-billion-dollar market worldwide. Post-mining is sustainable, it creates values and jobs, and it revives old mine sites ecologically. There are enormous opportunities for growth of which we only see the beginning!

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