Potential contribution of mining universities to improve the 'social licence to operate'

C. Dauber, P. Goerke-Mallet, and A. Daniels

TH Georg Agricola University, Germany

The sustainable use of geo-resources is an important prerequisite for the acceptance of mineral extraction in our society, both nationally and globally. A growing world population - 9.8 billion people are forecast for the year 2050 - requires the extraction of additional quantities of mineral resources. On the other hand, the acceptance of mineral extraction in our society has decreased significantly. Activities of the Georg Agricola University of Technology (THGA) illustrates how universities can support the public's acceptance of mining projects. Example 1 covers the post-industrial phase of coal mining in the Ruhr region. About 10 billion t of hard coal was produced there over about 150 years; now, after mining has ceased, the public is discussing the risks of rising mine water levels and methane released into the environment. The THGA University, represented by the Research Center of Post-Mining (FZN), strives to objectify the discussion through research activities, extensive monitoring and statements. Another example is the production and operation of salt caverns in the town of Gronau-Epe close to the German-Netherlands border. There, salt extraction has created large caverns in which natural gas, crude oil or helium is stored. Disputes between cavern operators and local residents are generated by ground movements, which in the long term may cause subsidence, damage to buildings and altered ground water levels. The cement industry worldwide, and of course also in Germany, is facing the enormous challenge of significantly reducing production-related CO_2 emissions. Replacing cement clinker with other pozzolanic materials such as clay can help to improve the CO_2 balance. The THGA has the expertise in raw material extraction and process engineering and supports these research activities. The final section describes the measures that universities can take to promote public acceptance of mining projects.

Keywords: Social licence to operate, mine water, cavern storage, subsidence, calcined clays, decarbonization

INTRODUCTION

The extraction of mineral resources is one of the oldest activities with which man has sought to secure his existence, his life and survival. While in the Stone Age it was mainly flints for the production of weapons and tools, the quantity and variety of raw materials extracted have increased enormously over the course of time. And this development will continue; by the year 2050, the world's population will increase by 2.2 billion to a total of 9.8 billion (United Nations 2022), so that additional quantities of raw materials will be required. It is also likely that the - hopefully - rising standard of living worldwide will generate a further increase in demand. The past two centuries were characterised by fossil raw materials, which created the preconditions for a worldwide and profound industrialisation. Now, fossil fuels are to be substituted by renewable energies in order to limit the consequences of the associated carbon dioxide emissions. As a consequence, other raw materials are needed for this energy transition, which now have to be made available in large quantities. Examples include battery metals such as lithium, cobalt, nickel and rare earths.

The importance of primary raw material production for the well-being of mankind is indisputable and, in view of the energy transition, will tend to grow in the coming decades. This is strongly opposed by the significant decline in social acceptance for all activities associated with the extraction of mineral resources. This perception applies not only to many industrialised countries, but also to emerging economies such as South America and Asia.

In earlier centuries, mining was a welcome driver of social advancement and prosperity; the impact on landscape, nature and the environment was more or less accepted. Today, almost every mining project is regarded as undesirable, polluting the environment and must be combated. Since public participation has become increasingly important in the approval process - a development that makes sense and is to be welcomed - this often leads to lengthy approval processes. As a result, the production of raw materials is delayed or even fails due to the lack of legal approval requirements. In self-criticism, it must be admitted that the poor reputation of the mining industry in public opinion is partly self-inflicted. We need only recall spectacular catastrophes, such as the explosion on the Deep Water Horizon oil platform in the Gulf of Mexico (National Commission 2011) or the Brumadinho tailings dam failure in Brazil, in which 270 people lost their lives (BBC News 2021).

In addition, interest in and appreciation of ecological issues has increased significantly in our society. Terms such as sustainability, circular economy and ecological footprint have found their place in society and are regarded, particularly by the younger generation, as main components of our way of life. With a view to our ethical responsibility towards future generations, this development is to be welcomed without reservation, and to be further promoted. In the context of this discussion, an impeding factor is that mining activities are not sustainable in the classic sense. Access to deposits and the subsequent extraction of mineral resources alters the natural environment and cannot be fully restored. And, of course, there are sufficient examples worldwide that prove the damaging influence of mining activities, with regard to landscape, flora, fauna and water bodies. On the other hand, there are numerous mining operations - ongoing and closed - that demonstrate successful, environmentally-friendly and ecologically acceptable restoration of mining areas. Concerning specific mining projects, mining companies and affected citizens, NGOs and political groups are often irreconcilably opposed to each other. The mistrust on both sides is often deep and the dispute so emotional that a fact-based dialogue seems to be impossible. For the social and sustainable shaping of our future, it is essential that the deep rift between the mining industry and the public will be at least reduce, if not close. At this point, universities and mining schools are a possible partner that can help ensure that such disputes continue in a less emotionally charged manner by providing factual information and unquestioned expertise. Universities and colleges, including those with a mining background, enjoy a rather good reputation in society. In the public perception, science has a high status; ideally, it is not subject to directives and is not guided by economic interests. Young students who are preparing for their professional life and critically reflecting on tradition, ensure that universities are perceived positively. For this reason, universities enjoy a sense of trust, in contrast to representatives of the mining industry. And trust is an indispensable prerequisite for gaining public acceptance for mining projects. Three examples from the activities of the Technische Hochschule Georg Agricola (THGA) University may demonstrate the potential contribution of universities to enhance the public acceptance with regard to mineral resources. The relevant commodities and the three case studies are:

- Hard coal: Mine water in the Ruhr area
- Natural gas: Cavern storage Gronau-Epe
- Clay: Cement production and calcined clays

The paper does not claim to cover all case studies where university engagement aided in securing a social licence. Three specific examples are presented, which have been executed in an individual manner, not as part of an overall strategy. The paper may be the starting point of a discussion at mining universities on how to enhance the public´s acceptance of mining projects in a more systematic and joint manner.

Mine water in the Ruhr area

The long lasting coal mining history in the Ruhr area left behind two major perpetual tasks which are related to two different water bodies. One of them is the mine water body in the former underground coal mines. Due to the deep underground coal mines the water level is situated mostly at a depth of more than 500 m. When pumping activities at the Zollverein colliery in a depth of nearly 1000 m is stopped by the former coal producer RAG, in the near future, the mine water level will rise. It is predicted that the rebound process will take some 15 years to reach the level of 600 m below surface. This concerns vast areas underground in the western and northern part of the Ruhr deposit.

The final concept of RAG aims to focus the pumping activities at six shaft sites (Figure 1). Each column in Figure 1 represents a shaft where submersible pumps have been or will be installed. The first number, for example at shaft LO, names the amount of mine water to be pumped at this shaft per year (35 million m^3/a). The second number indicates the level from which the mine water has to be lifted (640 m). The arrows in different colours illustrate the flow of mine water in underground galleries. The letter B indicates an active pumping site, the letter S shows shaft sites where mine water pumping is possible if the concept fails. The total amount of mine water which has to be pumped at six shafts is about 80 to 90 million m^3 per year.

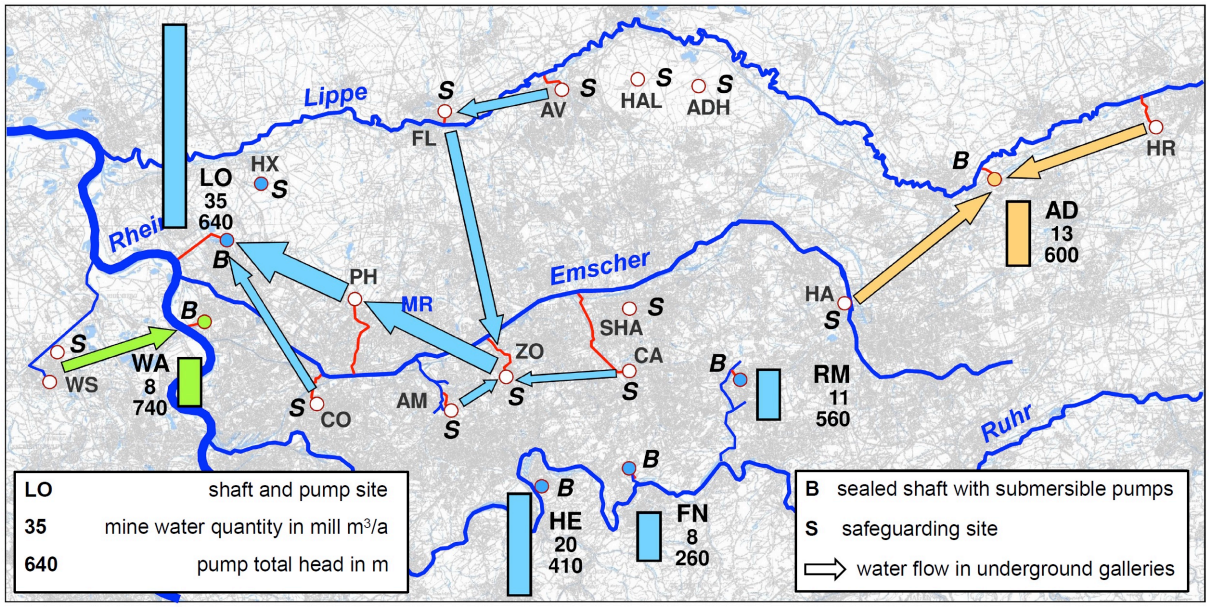

Figure 1. RAG-concept of long term mine water management in the Ruhr area (RAG 2016).

The second water body is located directly at or below the surface. Due to the subsidence evoked by the mining process, vast polder areas have been formed. Actually nearly 1000 km^2 in the Ruhr area have no direct link to creeks or rivers. Thus pumping activities are necessary to keep the polder areas dry and to protect the population and the infrastructure. In total the amount of pumped polder water is around 800 million m^3 per year (RAG 2016). The water management of these two different water bodies has been financed by the RAG Foundation since 2019. In the context of these ongoing tasks the Research Center of Post-Mining (FZN) at THGA University was founded in 2015. The aim is to provide scientific support to the cessation process of coal mining in the Ruhr, Saar and Ibbenbueren area (Melchers, Westermann & Reker 2019). Additionally, the Research Center provides comprehensive information about mine water issues to the public via its homepage (https://fzn.thga.de/). There are numerous challenges, for example the functionality of the mine openings concerning the underground flow of the mine water. The public view links mine water with the issue of 'polychlorinated biphenyls (PCB)', as traces of specific hydraulic fluids used in the mines have been detected in the mine water. The public's fears and worries about this aspect is part of the research activities to enhance the level of information and to ensure transparency. The PCB-problem is related to the velocity of the underground mine water

flow and to the density stratification in mine water bodies. This phenomena can be monitored in several flooded shafts and due to the possible contact of drinking water layers and mine water bodies, density stratification is an important aspect of the research focus.

The mine water rebound creates a heave of the surface, and may trigger mining-induced earthquakes. These aspects are naturally of particular interest to the public. In this context a proof of concept is in progress to develop comprehensive monitoring measures for the critical infrastructure of communities in the Ruhr area. An extensive research project deals with the evaluation of mine water rebound processes in Germany and other countries in Europe. In the frame of a sensitivity analysis the parameters which influence the rebound process are in focus as well as the behaviour of released methane. All of the research projects are linked to monitoring measures and the spatio-temporal interpretation of the data. The scientific objective is to enhance the understanding of the ongoing processes; the second, but just as important an objective, intends to ensure reliable and trustworthy communication. In this respect it is necessary to mention the 'Forum Mining and Water' (Forum Bergbau und Wasser 2022). This forum is a non-profit foundation and promotes science and research in the field of hydrogeology with the focus on mine water. Particular attention is paid to the opportunities and risks of a rise in mine water after the cessation of coal mining and its ecological and economic consequences. The foundation is both operational, - i.e. carries out research projects itself -, and promotional, - i.e. awards grants to third parties for specific projects. The forum operates independently and determines its own activities within the framework of the foundation's purpose. All the results of its activities are presented and published in a transparent and accessible manner. The scientific director of the FZN is also the vice-chairman of the Forum.

Ten years ago, another platform for communication between experts and the public was established. The conference is called "NACHBergbauzeit in NRW " (Post Mining Period in NRW) and takes place every two years at the THGA. While the organisers are the mining authority of North Rhine-Westphalia (NRW), referred to as the Ruhr area, and the THGA; the conference programme deals with different topics about mine water, polder water and structural changes. The conference enhances permanent communication, a continuous exchange of ideas and problems and the creation of transparency. As the access is not restricted the audience covers experts, politicians, representatives of the communities and citizens' initiatives. In addition, another small detail of the communication regime should be mentioned. At the local adult education centre in Bochum a seminar called Post-Mining has been organised and the speaker is a professor of the THGA.

Cavern storage Gronau-Epe

In Germany, a total of 272 storage caverns with a natural gas volume of about 20 billion m^3 are currently in operation at numerous locations. This form of storage has considerable safety advantages and requires a low surface area. One of these storage facilities, the Gronau-Epe cavern complex, is located in the north of the Ruhr area not far from the border with the Netherlands. In the 1960s, drilling operations in search of natural gas explored a shallow rock salt formation up to 400 metres thick at a depth of 1000 metres. Since 1972, salt in the form of brine has been extracted from this deposit; several million tons of sodium chloride annually; the caverns created by brine extraction are used as storage facilities for gaseous and liquid media.

Currently, the Gronau-Epe cavern facility comprises about 100 caverns spread over an area of 22 km^2. The storage volume is about 4 billion m^3 of natural gas and 1 million m^3 of crude oil. Helium is stored in one cavern, and the storage of hydrogen is currently being prepared for approval (SGW 2022). The salt caverns are up to 250 m high, have a diameter of about 60 m and thus a volume of more than 600 000 m^3 (Figure 2). About 60% of the cavern cavity is used as storage space; the remaining volume is filled with cushion gas under a minimum pressure of 70 bar. The caverns are operated at a maximum pressure of 200 bar; accordingly, one cavern can store about 50 million m^3 of natural gas in regular operation.

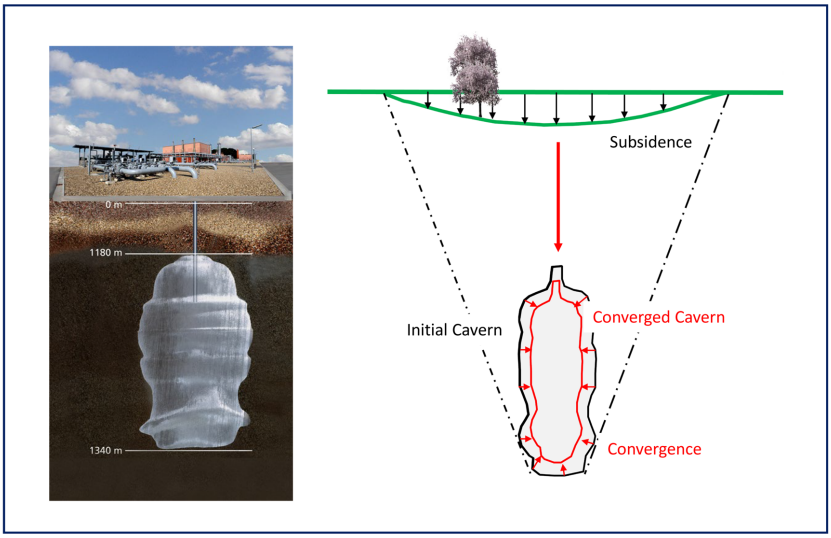

Figure 2. Salt cavern and convergence (Trianel Media Portal 2022; SGW 2022).

Both the production of the cavern reservoir by brine extraction and its further use as a storage site lead to stress changes in the reservoir as well as in the overburden. Due to the associated convergence, i.e. the movement of the salt rock into the cavity, a cavern loses on average about 1% of its volume per year. This annual volume loss of about 6000 m^3 is transmitted through the rock mass to the surface. The resulting subsidence affects an area of about 5 km^2 at a limiting angle of about 50 gon (45°). In the Gronau-Epe field, the maximum subsidence has currently reached 0.85 m (Figure 3). Prediction methods have been developed for ground movements above caverns. However, it has been demonstrated that the actual convergence behaviour of a cavern depends to a large extent on the mode of operation, i.e. the timing of storing and withdrawal of the storage medium. In the case of salt caverns, it was usual to fill them in summer until a pressure level of 200 bar was reached. In winter, the storage medium was withdrawn to a minimum pressure level of 70 bar. Due to changes in the gas market, this mode of operation was abandoned and the pressure buildup and release are now much more closely timed. As measurements indicate, this is associated with higher convergence rates in individual cases and thus greater ground movements.

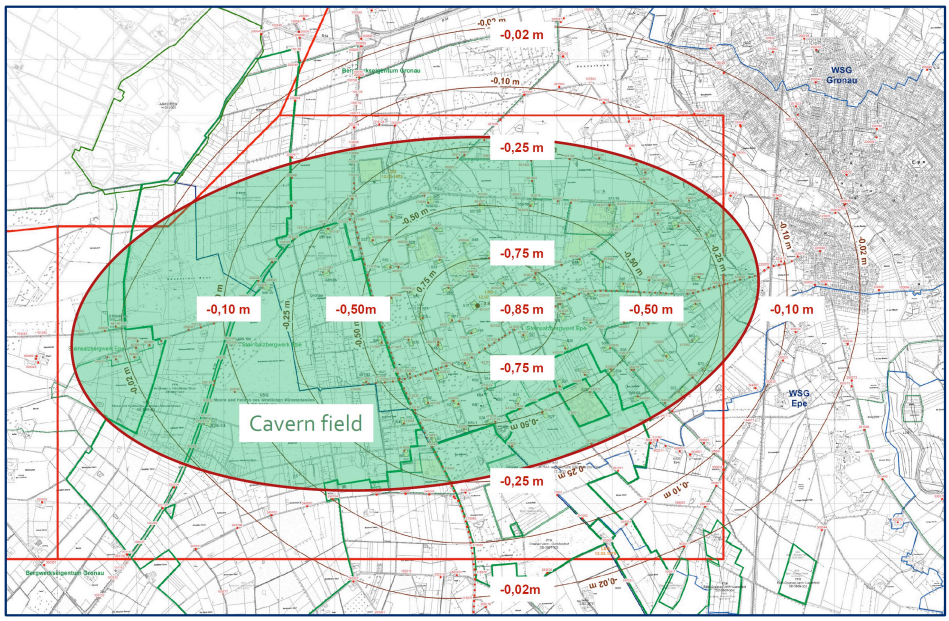

Figure 3. Subsidence in the area of the cavern storage at Gronau-Epe (SGW 2022).

The responsible authorities, the public and, in particular, the house- and landowners in the area affected by the cavern facility expect a reliable forecast of future ground movements. Additionally, there is the question of the final safekeeping of caverns; how the convergence process can be stopped or kept to a minimum when the cavern operation is terminated? Mode of operation and final safekeeping are of considerable relevance for the subsidence prognosis, which is not only associated with potential subsidence damages, but may also have an impact on flood protection at local water bodies. The special features associated with the operation of storage caverns have triggered a climate of mistrust, concern and even fear among the affected population. The resulting protest was led by a citizens' initiative formed after a spillage at an oil cavern in Gronau-Epe (Ministerium für Wirtschaft 2019). Both the citizens' initiative and the city council of Gronau showed great interest in involving a scientific institution in the communication process. Employees of the FZN were invited to meet with members of a citizens' initiative, where they had the opportunity to inform and answer numerous questions. The establishment of a research cooperation was discussed with all parties involved and agreed by contract in the summer of 2021, in the presence of the mayor of the city of Gronau. The city council, the citizens' initiative and the THGA are members of this research cooperation together with the company EFTAS from Münster. Among other things, EFTAS specialises in satellite-based remote sensing and is thus an important partner for monitoring ground movements at the surface of the cavern field. Topographic changes above the cavern site are caused by mining activities, but are also influenced by other factors, such as the nature of the soil layers, the kind of land use and extreme weather events. For the most part, subsidence movements occur slowly, but they are complex and require precise, sophisticated monitoring. Appropriate data are provided by orbiting satellite sensors (EU Copernicus Programme), as well as by aircraft and drones, and combined with terrestrial methods. Data interpretation requires a high level of expertise and is often not easy to communicate. As the first citizens' meetings in Gronau have shown, the engagement of academic representatives is met with a high level of acceptance. The technical expertise of the FZN working group is crucial in this context. For example, the members of the team have many years of practical experience in the storage industry, hydrogeology, rock mechanics, mine surveying and mining damage science, as well as communication in a tense environment.

The research cooperation creates a platform for dialogue and discussion of issues at eye level. The FZN team organises regular meetings with representatives of the research cooperation and with the steering committee, which consists of representatives of the district, the municipality, local politics and the citizens' initiative. The public homepage of the research cooperation (Monitoring Epe 2022), which offers detailed information to interested parties and is maintained by the FZN, also serves for transparency.

Cement production and calcined clays

Cement is an essential binder in the production of concrete, the world's most important building material. Around 4.4 billion t of cement are produced in the world annually and lead to the release of almost 3 billion t of carbon dioxide (United States Geological Survey 2022; IEA 2021). The production of cement accounts for around 7 % of the global release of anthropogenic carbon dioxide. With a view to climate change, the cement industry faces the enormous challenge of significantly reducing production-related CO_2 emissions. Substitutes have been used in the cement industry for a long time in order to reduce the so-called clinker content in the cement and thus also the CO_2 emissions. Common cement substitutes include hard coal fly ash and blast furnace slag, but their availability is likely to decline in the future. The use of thermally activated, i.e. calcined, clays as an additive can, in addition to economic advantages, contribute to a significant improvement in the ecological balance in cement production. Although carbon dioxide is also produced during the calcination of clays, it is produced in smaller quantities due to the significantly lower temperatures compared with clinker production. For example, the production of one ton of Portland cement generates up to 850 kg of CO_2. For the calcination of suitable clays, about 100 kg of carbon dioxide must be expected. If 30 % of the cement clinker used is replaced by calcined clays, CO_2 emissions per ton of cement can be reduced to approx. 625 kg/t. The company Hermann Nottenkämper GmbH & Co. Kommanditgesellschaft operates an opencast clay mine in the north of the Ruhr area. In addition, the volume deficits created by clay mining are used to deposit mineral waste such as excavated soil, slag and ash (landfill class 1). The company extracts around 300,000 tons of clay per year, which is primarily used to seal waste dumps and water

engineering structures. After backfilling, the site will be completely recultivated and then reforested. Figure 4 shows an overview of the Eichenallee opencast mine and the operating areas at the Gartroper Busch site.

Figure 4. Opencast clay mine Eichenallee (Company Nottenkämper 2022).

The Eichenallee opencast mine, which is currently in operation, was commenced in 2013 and is expected to be depleted by 2030. To secure the future, it is planned to apply for the exploitation of the neighbouring Buchenallee deposit section. The overall planning depends on the extent to which the raw clay is suitable for the production of calcined clay. This would offer the option to acquire new customers from the cement industry and make a contribution to reducing carbon dioxide emissions. In a master's thesis, Wellmann (2022) carried out a detailed investigation to verify the suitability of clay from the Gartroper Busch deposit as a cement substitute. The laboratory tests were executed at the THGA, the German Mining Museum and the Bauhaus University in Weimar. First, the clay from the Nottenkämper company was analysed and, among other things, the content of reactive silica was determined. This was followed by investigations of the cement and concrete properties. A common Portland cement CEM I and a Portland-limestone cement (CEM II/A-LL) served as references and were contrasted with composite cements containing 30% calcined clay, either 100% or 90% from the Eichenallee deposit. A large number of tests were necessary to check to what extent the composite cements met the requirements of the numerous DIN standards; Figure 5 gives an overview of the range of tests.

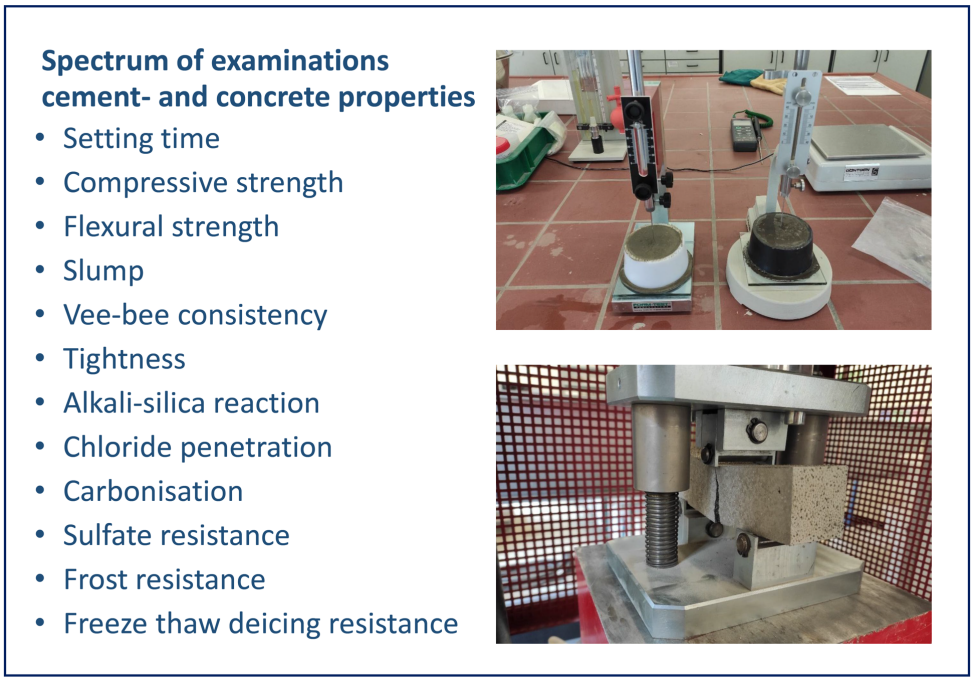

Figure 5. Test procedures for the reference and composite cement samples (own illustration).

The detailed investigations demonstrated that clays from the Gartroper Busch deposit are suitable as a cement substitute or as a concrete additive. The clay is able to replace parts of the cement clinker without significant impairment of the cement and concrete properties. Certain properties such as compressive and flexural strength, resistance to chloride penetration are even improved, and disadvantages in workability, carbonation and frost exposure can be compensated by appropriate measures. Thus, this clay may contribute to reducing the CO_2 emissions associated with cement and concrete production. Finally, the master thesis and the work of the university is a welcome support regarding the permission process, as it demonstrates the positive effect of this operation for society.

General considerations

The participation of universities in dialogue processes for mining projects is complex and often a tightrope walk between the interests of the parties involved. In general, universities with a mining focus are industry-friendly, since their graduates usually start their careers there and industry certainly awards research and service contracts to universities. On the other hand, public universities are committed to the society as a whole and must place the interests of the general public above individual interests, such as those of companies or academic institutions. How can universities contribute to improve the social acceptance of mining projects? The suggestions outlined below are not fundamentally new; they essentially relate to the core task of universities, i.e. teaching and research. This is supplemented by the topic of public relations, which should address not only university-specific but also industry-specific issues. In the past, research at mining universities has mostly focused on deposit and production related topics - e.g. drilling and blasting technology, ventilation, automation, process control etc. These focal points still have their justification, but are usually focused on tasks within the industry and are of less importance to the general public. In view of the legitimate interest of the public, the research spectrum at mining universities must be expanded to include topics that are relevant to the concerns of all citizens. This has already been implemented at many universities; three main research areas relevant to this causality are mentioned below as examples:

- Monitoring of mining operations and mining regions
- Decarbonisation of extraction and processing operations
- Transformation of society and infrastructure in mining regions.

The monitoring of environmentally relevant parameters, - e.g. water levels and water quality, emissions, vegetation, ground movements etc. - is a very complex research area that has received significant impetus from new technologies. For instance, the use of geo-data, which are constantly and often cheaply obtained by satellites, or aerial surveys with well-equipped drones. However, it is important that monitoring activities not only focus on the active operating phase, but also continue for many years after the extraction of raw materials has been completed. The university should also ensure that monitoring data and results are made accessible to the public, in joint agreement with industry, the supervisory authority and those affected. Only with transparency will it be possible to gain the trust of the affected citizens and create the conditions for an objective dialogue.

Today decarbonision is a high-priority topic due to current efforts to combat climate change. With their expertise, mining universities can contribute to sustainably reduce CO_2 emissions while extraction and processing mineral resources (Scope 1 and 2). In the meantime, numerous mining companies have organised specific actions for CO_2 reduction and are offering to partner with universities for climate projects - a topic very much in line with the traditional, technical related focus of mining universities.
The social and infrastructural changes that mining causes in the affected regions have not been the focus of mining universities so far. The topic of structural transformation is less technology-driven, but encompasses sociological, industrial policy and regional planning aspects. In particular, when mining withdraws from regions on a large scale, this has, in the past, sometimes led to massive social upheaval. The mining industry, but also the political bodies concerned, are responsible for successfully shaping the transformation process following the closure of mining operations. If this does not succeed, the general public associates the negative effects of structural change with the extraction of mineral resources.

Another area that is insufficiently dealt with by universities is public advocacy for mineral resources issues. Public relations work is mostly limited to issues of the university and research topics which are investigated at the mining institutes. Contributions describing mineral resources as necessary for the further development of society are rare. Equally rare is the information on current mining projects, in a holistic view with both positive aspects and possible impacts. Digital media such as the internet, Facebook, Twitter, Instagram, etc. offer the opportunity to reach a large group of interested parties promptly, with manageable effort and in an understandable way (see case studies 1 and 2). For example, it is easy enough to set up an info blog that regularly reports on mining activities in the region. In addition, universities should not be afraid of being available for public lectures, discussions and statements on the subject of mineral resources extraction. Disputes with mining opponents is seldom easy, often very emotional and also frustrating. Nevertheless, for their own self-image and also for their public reputation, it is important that universities do not shy away from confronting critics. At this point, you can gain the trust of many stakeholders if you take a stand authentically and with understandable information.

Teaching is another area that should be mentioned. Mining universities focus on training young engineers to optimize relevant production procedures in mining operations, according to scientific standards. The fact that these actions are often associated with social or ecological changes has not been a focus of the curriculum so far. There is no doubt that universities provide knowledge about the effects on nature, water bodies and the topography that are associated with the extraction of mineral resources. However, the evaluation of operational procedures is mostly based on technical or economic criteria, rather than on sustainability factors. A change of perspective, the struggle for a compromise that also accommodates the interests of the public, or the search for less environmentally affecting solutions are not a regular part of the curriculum. It is certainly challenging to convey this message to students in the context of a lecture, e.g., Sustainable Development of Mining Projects. Here, seminars or exercises with case studies and role reversal are certainly better suited to impart technical, but also social competence for mining-related conflicts. Universities should also illustrate clearly how important transparency and timely information are for public acceptance of mining projects. Universities should aim not only to prepare students technically for their professional life, but also enable them to include the interests of the general public in planning and operational procedures. Above all, it should convey to the students the sensitivity for such conflicting goals and the search for compromises.

SUMMARY

Using three case studies associated with major extractive industries, the paper describes opportunities for mining universities to improve the public acceptance of mining and mining related projects. In this context, research priorities should focus on the monitoring of mining activities, decarbonisation and structural transformation. The public relations work of universities should not shy away from reporting on mining-related topics and documenting the value of mineral resources extraction for society. And, of course, the university's primary goal is to educate responsible graduates who have internalised the principle of sustainability in their thinking and actions. Independent of all university activities, however, corporate responsibility is applicable at first, to ensure a sustainable consensus between privately driven mining projects and the public interest.

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Christoph Wilhelm Dauber

Professor
Technical University Georg Agricola

- Diploma degree in Mining Engineering at RWTH Aachen University
- Assistant lecturer and doctorate at RWTH Aachen University
- 25 years hard coal mining with RAG in Germany, deputy, longwall manager, head of planning department, manager underground and surface operations at Ewald and Walsum colliery, manager technical services
- Professor for Mining Engineering at TH Georg Agricola till today, 14 years
- 6 years Vice-President at TH Georg Agricola