Journal of Cleaner Production 139 (2016) 1044–1056

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Towards sustainability in underground coal mine closure contexts: A methodology proposal for environmental risk management

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ARTICLE INFO

Article history:
Received 26 February 2016
Received in revised form
5 July 2016
Accepted 29 August 2016
Available online 30 August 2016

Keywords:
Sustainability
Mine closure
Underground coal mining
Environmental risks
Risk management
Management tool

ABSTRACT

The mining industry needs community and regional governmental support to maintain its current activities and, more importantly, to develop future projects. The failure to manage environmental risks in an acceptable manner during mine operation, closing and post-closing periods is a critical factor. The mining industry must regain its reputation that has been lost over decades and centuries of environmental degradation. Several environmental management tools (e.g., life cycle assessment, multi-criteria decision analysis, etc.) are widely applied during mine development, operation and closure periods. Nevertheless, due to uncertainties associated with the post-closure phase and the end of economic activity (implying no more revenues for stakeholders in the form of workers' salaries and municipality taxes), it is crucial to adopt sound management practices during this period to achieve sustainability in the mining sector.

As operational methodologies that can be used as a reference are lacking, the management of environmental risks during and after underground coal mine closures is, in many cases, limited or is developed without specific guidance.

This statement is supported by the fact that the European Commission, through the Research Fund for Coal and Steel, encouraged research, pilot and demonstration projects and accompanying measures within the coal sector via the coal programme priority of recent years (2012–2014), namely, the "Management of environmental risks during or after mine closure".

The aim of this paper is to provide mine operators with an organized informational framework that could be applied during future underground coal mine closures independent of the major environmental problems faced and directly connected to the types and characteristics of coal and the exploitation methods used. The investigation was conducted using a literature review and interviews with experts from European universities, research institutions and coal mining companies from Poland and Spain.

1. Introduction

One of the objectives of the "Strategic Implementation Plan for the European Innovation Partnership on Raw Materials" (European Commission, 2013) is to mitigate the negative environmental impacts of the European raw materials sector. Based on inputs from stakeholders and policymakers, possible actions that should be taken have been grouped under five frameworks called Work Packages. The third one ("Regulatory framework, knowledge and infrastructure base") calls for the improvement of environmental impact assessment methodologies. Not long ago, after reviewing the literature on mining sustainability, Laurence (2011) argued that limited guidance for mine operators can be achieved to put sustainability frameworks into action.

Some environmental management tools focused on mine development, operation and closure periods are widely used:

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http://dx.doi.org/10.1016/j.jclepro.2016.08.149
0959-6526/

- Life Cycle Assessments (LCAs) can be used to determine (among alternatives) which approach has the least environmental impact and its corresponding land-use impact category (Durucan et al., 2006; Reid et al., 2009)
- Multi-criteria Decision Analysis (MCDA) allows one to couple environment, social and economy criteria (Roussat et al., 2009) to assess the value of various options
- Risk evaluations (the final step of the risk assessment process) involve comparing estimated levels of risk with risk criteria that will be defined.

Nevertheless, due to uncertainties associated with the post-closure phase and the end of economic activity, implying an end to revenues in the form of workers' salaries and municipality taxes for stakeholders, it is crucial to adopt sound management practices during this period to achieve sustainability in the mining sector. Sustainable development is a multi-dimensional problem that involves achieving balance across three main dimensions: economic, social and environmental (Bluszcz, 2015). Thus, post-closure phases should place special emphasis on the remaining dimension.

Until now, several specific tools and techniques have been developed to facilitate the management of environmental risks within a mine closure context. At the European level, an administrative French tool integrates mining and post-mining risks in land-use management, as it is the state's responsibility to evaluate residual risk and to integrate it in the management of regional planning. This tool is referred to as the "Mining Risk Prevention Plan" (MRPP), and it was designed to evaluate and map risks linked to pollution generated from historical mining activities, thus providing an assessment of the extent of soil and water contamination in surrounding mining site areas. Levels of contamination are determined through a risk assessment approach, but due to a lack of operational methodologies available, environmental hazard assessments have been limited. Only several specific cases of MRPP have generated environmental hazard maps (Didier, 2009).

In Finland, a TEKES (Finnish Funding Agency for Technology and Innovation) funded project called "Environmental Techniques for the Extractive Industries" was undertaken as a joint research project between agencies and industry and provides mine operators, regulatory authorities and industry consultants with guidelines relating to the planning and implementation of mine closure strategies (Heikkinen et al., 2008).

Among the different research projects financed by the European Union, various tools and techniques have been developed to enable the assessment of individual environmental impacts:

- MANAGER (Bondaruk et al., 2013) and WATERCHEM (Pastor et al., 2008) on mine water discharge optimization;
- PRESIDENCE (Herrero et al., 2012), which focuses on subsidence hazard prediction and monitoring;
- FLOMINET (Klinger et al., 2011), which focuses on flooding management in regional mining networks, etc.;
- ESIAS (Durucan et al., 1995), the only project that directly addresses the development of an impact assessment system while conducting environmental simulations in two European metal mines that consider groundwater, river, air, soil pollution, noise and vibration impacts.

In South Africa, the Department of Water Affairs and Forestry and the mining industry have made major strides in developing principles and approaches for the effective management of water within the mining industry. These entities have developed a series of Best Practice Guidelines (BPGs) on water management strategies, techniques and tools (Pulles, 2008b). These BPGs aim to provide a logical and clear process that can be applied by mine operators to allow for proper mine closure planning. They also allow for the mine closure transfer of water-related residual environmental and financial risk to the state and citizens, presenting an impact assessment and prediction framework and methodology based on risk assessment principles (Pulles, 2008a).

Australia uses a Strategic Framework for Mine Closure that is designed to encourage the development of comprehensive closure plans that help restore mine sites to self-sustaining ecosystems whenever possible. The Strategic Framework also holds that closure plans must be adequately financed, implemented and monitored within all jurisdictions, and it is focused mainly on reducing financial burdens associated with mine closure and rehabilitation. The Strategic Framework is structured based on a set of objectives and principles grouped under six key areas: stakeholder involvement, planning, financial provision, implementation, standards and relinquishment, but detailed guidelines are not provided (Australian Department of Industry, Tourism and Resources, 2006).

Finally, closure guidelines used in Canada and the United States employ a similar approach to mine reclamation (Cowan et al., 2010). Such legislation is found in multiple legislative acts that govern mining with a strong emphasis on financial assurance components.

2. Research methodology

This paper seeks to propose an environmental risks management methodology for an underground coal mine closure context. To achieve this goal, the authors first analysed peer-reviewed academic literature available through the Web of Knowledge ^{SM} (WOK). The authors searched for "mine closure", "mine sustainability", "mine pollution", "environmental impact assessment" and "risk management" search terms with and without using "coal" and "mine" search terms when applicable. A second web search was conducted with a focus on legislative or regulatory bodies and private companies based around the world using the same keywords.

Finally, the authors extended their search to CORDIS (Community Research and Development Information Service), the European Commission's public repository on European Union-funded research projects and results.

The employed methodology adheres to the following international standards: ISO 31000 (2012) "Risk Management, Principles and Guidelines" and IEC/ISO 31010 (2009) "Risk Management, Risk Assessment Techniques". According to these standards, the risk management process is defined as shown in Fig. 1; context establishment, risk assessment and risk treatment, and communication and consultation with stakeholders (both internal and external) must be undertaken throughout the entire process in addition to monitoring and review.

After compiling all of the data collected and structuring them according to the risk management process, the authors obtained feedback on the methodology from experts based at universities and research bodies across Europe (United Kingdom, Czech Republic, Poland, Spain, France and Germany) and from Polish and Spanish underground coal mine specialists.

3. Establishing the context

As specified in IEC/ISO 31010 (2009), establishing the context defines the basic parameters needed to manage risk while setting both the scope and criteria to be applied during the process, including external and internal parameters that are relevant and any risks that should be addressed.

As described by Didier (2009), during the Information Phase, a