Journal of Sustainable Mining xxx (2017) 1–9

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Contents lists available at ScienceDirect

Journal of Sustainable Mining

journal homepage: http://www.elsevier.com/locate/jsm

Research paper

# Decision-making on the integration of renewable energy in the mining industry: A case studies analysis, a cost analysis and a SWOT analysis

Kateryna Zharan*, Jan C. Bongaerts

*Department of International Management of Resources and Environment, Technical University Bergakademie Freiberg, Schlossplatz 1, 09596, Freiberg, Germany*

A R T I C L E I N F O

*Article history:*
Received 6 October 2017
Received in revised form
17 November 2017
Accepted 22 November 2017
Available online xxx

*Keywords:*
Renewable energy technologies
Mining industry
Decision-making rule
Greenhouse gas (GHG) emissions
Levelized cost of electricity (LCOE)

A B S T R A C T

The mining industry is showing increasing interest in using renewable energy (RE) technologies as one of the principles of sustainable mining. This is witnessed in several pilot projects in major mining countries around the world. Positive factors which favor this interest are gaining importance and negative barrier factors seem to be less relevant. For a mine operator, the switch from fossil fuel to RE technologies is the outcome of decision making processes. So far, research about such decision making on the use of RE in mining is underdeveloped. The purpose of this paper to present a practical decision rule based on a principle of indifference between RE and fossil fuel technologies and on appropriate time management. To achieve this objective, three investigations are made: (i) a case studies analysis, (ii) a comparative cost analysis, and (iii) a SWOT analysis.



## 1. Introduction

Sustainable mining principles, such as reducing its impact on the environment and enabling ethnical business practices and progress for local communities (Mining with principles, 2017), play a key role for mining companies and society in general. Sustainable mining comprises many issues, such as establishing transparent relationships with communities as a fundamental metric for investment decisions, engaging with communities in order to establish responsibility and accountability to enhance the industry's performance, reducing the environmental impact in all stages of the mining operation, striving for high levels of health and safety at work and maintain mutually beneficial relationships with government authorities. In this context, the impact of energy in mining on these issues has received much less attention, except in cases of conflict, as evidenced, by way of example, in the recent fight over a new electricity tariff between copper miners in Zambia and the state-owned Copperbelt Energy Corporation (Hill & Mitimingi, 2017). As an alternative way of energy procurement and in order to lower energy costs, mining companies have begun to focus on the use of renewable energy.

As a matter of fact, in recent years, mining companies around the globe have started to pay more attention to using RE technologies in their operations. There are several reasons for this. Firstly, the overall costs of RE technologies diminished significantly from 2005 (Kost et al., 2013) and the costs of RE equipment (photovoltaic (PV) modules and wind turbines, etc.) and maintenance are continually decreasing. Secondly, hybrid energy systems (HESs) have been suggested as an effective instrument to increase RE penetration (Chen & Rabiti, 2017) and represent a solution that avoids RE volatility (Kim, Chen, & Garcia, 2016). Thirdly, off-grid mines in remote areas depend on diesel as their main source of energy and, hence, adopting RE into such off-grid mining operations may improve economic perspectives (Golubova, 2016).

According to the Paris Agreement (UNFCCC., 2015), in order to limit the growth of the global average surface temperature to 1.5–2 °C, developed countries around the globe must focus on the decarbonization of their economies. In 2015, the average concentration of carbon dioxide was about 40% higher than in the mid-1800s (IEA., 2016). Therefore, replacing fossil energy used for mining operations with RE will contribute to the global requirements. Together with economic benefits, reducing carbon dioxide emissions with RE technologies may lead mining

* Corresponding author. Johann-Sebastian-Bach-Str. 1, 09599, Freiberg, Germany.
*E-mail address:* eszharan@gmail.com (K. Zharan).

https://doi.org/10.1016/j.jsm.2017.11.004
2300-3960/

Please cite this article in press as: Zharan, K., & Bongaerts, J. C., Decision-making on the integration of renewable energy in the mining industry: A case studies analysis, a cost analysis and a SWOT analysis, Journal of Sustainable Mining (2017), https://doi.org/10.1016/j.jsm.2017.11.004

companies towards "green operations".

Although RE has an environmental advantage, its dependence on weather conditions implies volatility and intermittency. This is an important obstacle to overcome for the integration of RE in mining operations, but HESs can represent a solution for this problem (Jung & Villaram, 2017). describe a hybrid renewable energy system as consisting of two or more RE sources used together. This mitigates the intermittent nature of RE resources, ensuring an overall balance to energy supply and the improvement of system efficiency. In addition (Choi & Song, 2017), described HESs as an effective solution to increase RE penetration (Zahraee, Assadi, & Saidur, 2016).

According to (Martin, 2014), RE use in the mining industry will increase from less than 0.1% to about 5%, and – tendentially - up to 8% by 2022. At present, RE technologies are sufficiently developed so as to enable complex and large implementation within the mining industry.

So far, there has been no investigation on a decision-making approach towards the integration of RE into the mining sector. To address this limitation, the purpose of this paper is to develop a practical decision rule based on a Cash Flow approach. It is derived from analysis of case studies and cost analysis. It is evaluated in a wider context in a SWOT analysis, giving a perspective on its applicability within the range of external and internal opportunities and constraints.

## 2. Material and methods

The purpose of this paper is to develop a decision-making approach to implementing RE into the mining industry. This paper consists of six sections, and two appendices. Section 1 includes the literature review, purpose of this paper, and relevance of this topic. Section 2 comprises the methodology that has been used to achieve the purpose of this study.

In section 3, analysis of case studies accomplished using a two-step approach is reported. Section 3.1 contains the evaluation of specific features of the case studies. Section 3.2 contains the analysis of the case studies of mines using RE technologies. Section 3.3 contains government regulatory mechanisms. Section Sections 3.4 to 3.6 include cost analysis of RE and fossil energy as a quick decision rule to decide on PV projects as alternatives to diesel plants. Section 3.7 contains a SWOT-analysis to analyze the benefits and barriers with respect to the integration of RE into the mining industry, i.e., the main strengths, weaknesses, opportunities, and threats in internal and external environments towards RE use in mining projects. Section 4 covers the conclusions of this study.

## 3. Results and discussions

In this paper we analyze the case studies of four major mining countries, i.e. (i) Australia, (ii) Canada, (iii) South Africa, and (iv) Chile were selected The objectives of this analysis are (i) to give a structure of the specific features of the mines and (ii) to specify the characteristics of their RE projects. The analysis takes place in two steps. Step 1 contains the characteristics of the mines and Step 2 contains the RE projects in those mines.

### 3.1. Specific features of the case studies

This part of the paper is dedicated to the first step of the analysis of the case studies. Table 1 contains the criteria used for this first step. Literature sources on these case studies are contained in Appendix A.

Table 2 lists the characteristics of the mines of the case studies. Obviously, all mines are different, as they are located in different climate conditions, geographical regions, are of different sizes, lifetimes, technologies, production levels etc. As will be shown in the second step of the analysis of the case studies, all mines have implemented RE projects. As such, it can be concluded that the characteristics listed in Table 2 have no impact on these RE project and do not impose any barriers.

**Table 1**
Criteria used for the first step of the analysis of the case studies.

| Criteria | Criteria |
|---|---|
| Type of mine | Date of construction and lifespan |
| Location | Logistic characteristics |
| Total production, t/year | Fossil energy generation facilities |
| Climatic conditions | |

### 3.2. Case studies of mines using RE technologies

This part of the paper is dedicated to the second step of the analysis of the case studies. Table 3 contains the criteria used for the second step.

Table 4 contains the outcomes of the analysis of the case studies. Literature sources on these case studies are contained in Appendix B.

According to Table 4, there are five solar-diesel and three wind-diesel projects, hence, HESs are most often used. The generation capacity varies between 1.7 MW and 40 MW. The biggest project with a capacity of 40 MW and an integrated solar-diesel microgrid system is operated by Gold Fields in South Africa. The largest RE wind-diesel microgrid system has a capacity of 9.2 MW (Diavik Diamond in Canada). Gold Fields also reports that the integration of a HES reduces diesel consumption by up to 20% of total energy consumption and that GHG emissions are reduced by 100,000 tons a year.

Table 5 shows the project values per GWh and MW.

According to Table 5, wind technology saves the most GHG emissions per GWh of RE production in the case of the Diavik Diamond mine. The Reglan mine has been saving more diesel per MW of RE production by implementing solar PV technology.

### 3.3. Government regulatory mechanisms

Table 4 also reveals two government regulatory mechanisms for the integration of RE into mining: (i) a Power Purchase Agreement – PPA and (ii) an Independent Power Producers – IPPs mechanism. A PPA is a contract between a provider (an electricity generator) and a buyer (power purchase) for a long-term period, e.g. from 5 to 20 years. In a PPA agreement, the provider may or may not use a grid connection to serve their customer.

An IPP mechanism is a facility for a private utility (the IPP) to generate and sell electricity to a grid operator, often a government agency. Such an IPP can only operate with access to a grid (Golubova, 2016; Eberhard, Kolker, & Leigland, 2014; THEnergy ANALYSIS: Solar-diesel and Wind-diesel Microgrids for Off-grid Mines Gain Momentum – New Projects Expected, 2017). Hence, a PPA requires a contract between a generator and a well-defined user whereas an IPP mechanism does not require such a use contract, but rather a feed-in agreement. Both mechanisms can be used for the integration of RE into the mining industry under different conditions of (i) off-grid and (ii) on-grid. The requirement to employ capital-intensive technology with a high up-front high investment requiring a long amortization period is common to both. Table 4 shows that PPAs are strongly correlated with off-grid locations of the mines. However, three mines operate their own RE projects. Hence, mine operators have a choice of "make or buy" in

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