Survey Research on Integrating Renewable Energy into the Mining Industry

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Abstract

Mining operations are energy intensive. The share of energy costs in total share is often reported to be in the range of 30 %. Saving energy costs is therefore an economical key element of any mine operator. With the improving reliability and security of renewable energy (RE) sources, and the requirements to reduce carbon dioxide emissions, perspectives for using RE in mining operations emerge. In fact, these aspects are stimulating the mining companies to search for ways to substitute fossil energy with RE. Survey research is novel on this topic. Hereby, this paper estimates the data of a survey conducted among mining and renewable energy experts. Towards the data estimation, this study applies the following methods. Here, first, to develop the survey we summarized and reviewed the findings from the previous literature review. Secondly, using these literature review three hypotheses have been developed. Thirdly, to compare outcomes of the survey with literature review the evaluating frequencies method has been developed and applied. Consequently, the results gather the expert's knowledge and opinions on incentives for mining operators to turn to RE, barriers and challenges to be expected, environmental effects, appropriate business models and the overall impact of RE on mining operations. In addition, the outcomes of the survey allow for identifying the factors that favor and disfavor decision-making on the use of RE in mining operations.

Keywords: Carbon dioxide emissions, mining industry, photovoltaic, renewable energy, survey research, wind generation.

Introduction

The mining industry still strong depends on conventional energy sources providing for its continuous and stable operations. In addition, energy costs accounts for 30 % of all operating costs in mining operations (Slavin 2017). RE technologies do not require such fossil fuels and have become mature and reliable, in particular for wind and solar power applications. Hence, they become attractive to mining operations, especially in hybrid systems. In this way, combining these sources like solar and wind with backup units provides more reliable, economic load supply and environment-friendly compared to a single source (Talaria, et al. 2017). Usually the cost reduction potential from implementation of the hybrid-energy system in mining operations is in the range of 25%–30%, and sometimes well above (Solar projects, energy efficiency and load shifting for an optimized energy management in the mining industry 2015). They also allow for lower carbon dioxide emissions giving mine operators a possibility to contribute to national and global climate policy agreements. For instance, the Kioto Protocol (United Nations Framework Convention on Climate Change 1997), the Fifth Carbon Budget (Committee on Climate Change 2015), and the Paris Agreement (UNFCCC 2015).

Because of such policies, the installed renewable electricity generation capacity and the rate of diffusion of RE technologies has increased rapidly (Bergek and Mignon 2017). Tab. 1 contains an overview of installed RE capacity in mining operations in particular.

Tab. 1: Installed capacity of renewables powering the mining industry

RE source	Installed capacity, MW
Wind	552
Solar PV	352
Solar thermal	39
Total	943

The energy and mining global ranking report (World Congress 2016) demonstrates the installed capacity of renewables powering the mining industry, which was 943 MW in total until 2016. It breaks down to 552 MW of wind power, 39 MW of solar thermal, and 352 MW of solar photovoltaic (PV). This integration could be

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possible because storage technologies become more accessible together with micro-grid integration. Moreover, hybrid energy solutions ensure to have a reliable energy system for mining processing.

Given several pilot projects of RE in mining in the countries such as Australia, Canada, and South Africa (Zharan and Bongaerts 2016) there is no comprehensive approach towards establishing RE into the mining industry as a global priority. This has inspired the authors of this paper to conduct a 31 question survey among experts in mining and in RE technologies about the implementation of RE into the mining industry. The survey captures the experts' assessment of economic, technological, social, and environmental aspects of a replacement of fossil fuel technologies with RE technologies. Furthermore, this survey defines the key factors leading to appropriate decision-making frameworks for energy managers and policy-makers.

The research objectives of this paper are to carry out the Literature Review (LR) in order to develop three hypotheses (H1, H2, H3), to compare the survey results with these hypotheses, to draw conclusions on using RE into the mining industry. Reaching these objectives will provide energy managers, decision-makers, and policy-makers with the expert's perception about implementing RE into the mining processing. That identifies vulnerable and strong priorities towards RE penetration. Therefore, the main purpose of this paper is to recognize the motives leading the experts to use RE for mining operations. Those motives could influence on investment choices (Lillemo, et al. 2013).

To our knowledge, there is no survey completed within this topic. Therefore, this study has a novelty and scientific relevance. Additionally, there is a lack of literature so far with focus on RE penetration into the mining industry.

Methodology

2. 1. Structure of the paper

This paper consists of four sections, and one appendix. Section 1 comprises the relevance of this topic, purpose of this paper, research objectives, and literature review. Section 2 includes the chosen methods developed to reach the purpose of this paper.

In Section 3, the evaluation of the survey's results has been accomplished in two steps. The Step 1 covers the demographic information of experts. Step 2 compares of the frequencies with the LR and demonstrates the Standard errors of the survey data. Section 4 contains the conclusions of this study.

This study has been written in a following order: (i) the survey has been developed based on the literature review. (ii) We choose stratified sampling method as our sampling technique to identify the RE and mining experts who can contribute to the study. (iii) All questions and the response items completed by the experts have been coded. (iv) Three hypotheses have been developed using the Literature Review (LR) method. (v) To evaluate the survey results we used the mean, and standard deviation (Std) criteria, maximum response item, percentage, evaluating frequencies method and standard errors analysis. (vi) Comparative analysis of three hypotheses with the survey results has been established. (vii) We drew the conclusions about the key findings of this study.

2.2. Survey administration

This survey was integrated between November 2016 and January 2017 within RE and mining experts all over the world via personal interview using the conference's platform 6th Solar Integration Workshop, and 15th Wind Integration Workshop in Vienna, Austria, and via email correspondence.

2.3. Research questionnaire and method

We assume that all questions are specific related only to the mining industry. This questionnaire contains two parts. In Part 1, we asked RE and mining experts about perspectives and relevance of the topic, necessity, incentives, barriers, government's support mechanisms, effects with respect to the integration of RE into the mining industry, as well as a significance of the environmental issues for industrial processing. In Part 2, we collected the experts personal information such as gender, age, level of education, working field, and working experience in the field. Tab. 2 shows the codes and scale each of the statements of the survey using the closed ended method of collecting information.

Tab. 2: Codes and scale of the survey

Statement	Code	Scale
1	Q1	two-point scale
2	Q2	three-point scale
3	Q3	five-point scale
4.1 - 6.5; 8 - 9.5	Q4-Q18; Q25 - Q30	six-point scale
7.1 - 7.6	Q19 - Q24	five-point scale
10	Q31	two-point scale

To evaluate the survey results first, the LR method has been chosen to develop three hypotheses. These hypothesis are shown in Appendix A, Tab. A.11. Main goal of this method is to provide complete summery of literature related to the survey questions. Second, three hypotheses have been assessing using the evaluating hypotheses method developed by the authors of this paper. The results of the survey are compared with three hypotheses in order to indicate whether they are true or false.

2.4. Evaluating frequencies method

The interpretations of evaluating frequencies method are as follows:

$$\begin{cases} c \leq a + b \geq d + \mathrm{e} \\ \mathrm{a} + \mathrm{b} \geq 0.33. \end{cases} \quad \text{(eq. 1)}$$

Eq. 1: the frequency of "a and b" is at least 33% and, overall, the ratings of "very important" plus "important" are more frequent than the ratings of "neutral" and of "less important" plus "not important", respectively.

$$\begin{cases} a + b \leq c \geq d + e \\ \mathrm{c} \geq 0.33 \end{cases} \quad \text{(eq. 2)}$$

Eq. 2: the frequency of "c" is at least 33% and, overall, the ratings of "neutral" are more frequent than the ratings of "very important" plus "important" and of "less important" plus "not important", respectively.

$$\begin{cases} c \leq d + \mathrm{e} \geq a + b \\ \mathrm{d} + \mathrm{e} \geq 0.33 \end{cases} \quad \text{(eq. 3)}$$

Eq. 3: the frequency of "d and e" is at least 33% and, overall, the ratings of "less important" plus "not important" are more frequent than the ratings of "neutral" and of "very important" plus "important", respectively.

$$\mathrm{f} \geq \mathrm{B} \; \forall \, \mathrm{f} \in [(\mathrm{a} + \mathrm{b}), \mathrm{c}, (\mathrm{d} + \mathrm{e})] \quad \text{(eq. 4)}$$

Eq. 4: the frequencies of "a and b", of "c" and of "d and e", respectively are all three larger than 33% (B).

Appendix A (Tab. A.11) demonstrates the LR. Based on the LR it assumes, that the Hypothesis 1 (H1) corresponds to the Eq. 1 and carries out for the Q3, Q4, Q5, Q7, Q8, Q9, Q11, Q12, Q15, Q16, Q18, Q19, Q22, Q24, Q25, Q26, Q27, Q28, Q29, Q30 questions. The Hypothesis 2 (H2) corresponds to the Eq. 2 and carries out for the Q6, Q14, Q20 questions. Finally, the Hypothesis 3 (H3) corresponds to the Eq. 3 and obtains for the Q10, Q13, Q17, Q21, Q23 questions.

Results

3.1 Demographic information of experts

This survey sample contained 30 observations, so called a sample size. We take this sample size as the representative sample. All the participants were male. Participants decided themselves either they are experts in the RE or mining industry, and educational institution or not. All experts had an education background starting from bachelor – a university education level. Tab. 3 shows the data of working experience and education level of the survey's participants..

Tab. 3: Working experience and educational level

Work experience in the field	Frequency	Percent	Education level	Frequency	Percent
1-5 years	7	25%	Bachelor	5	17%
5-10 years	9	32%	Master	14	47%
more than 10 years	12	43%	PhD	11	37%
Total	28	100%		30	100%

Furthermore, the surveyed sample contains engineers from either industrial companies or consulting, and researchers from educational institutions. The majority of experts 52 % are involved in the renewable energy industry.

The age of majority of experts 50 % is between 30 and 40 year. Tab. 4 shows the age and working field of the experts.

Tab. 4: Age and working field

Age	Frequency	Percent	Working field	Frequency	Percent
25 – 30 years	5	17%	mining industry	1	4%
30 – 40 years	15	50%	mining + renewable	1	4%
40 – 50 years	6	20%	renewable industry	13	48%
50 – 65 years	3	10%	renewable + education	2	7%
more than 65 years	1	3%	educational institution	10	37%
Total	30	100%		27	100%

The experts represented in this survey research are from 14 countries such as Germany – 9, Denmark – 3, Canada – 3, Finland – 3, Sweden – 2, Australia – 2, USA – 1, Austria – 1, New Zealand – 1, Mexico – 1, Ukraine – 1, France – 1, United Kingdom – 1, Chile – 1.

Tab. 5 shows the description of the survey sample..

Tab. 5: Description of the survey sample

Variables	Measurement	Mean	Std
Gender	Female/Male	1,00	0,00
Age	Six-point scale	3,33	0,96
Education level	Four-point scale	3,20	0,69
Working field	Five-point scale	2,35	0,55
Working experience in the field	Four-point scale	3,18	0,79
Sample size		30	
Response rate	Percent	96,67	

3.2 Comparing of the frequencies with the LR

In this survey research, answers of the experts were categorized in the sense that frequencies of their scale ratings were constructed. For example, if twenty percent of respondents give a rating of "very important" as answers to a specific question, that frequency is 20%.

Characterization refers to the frequency just described, e.g. characterization "a" would be 20 % as explained in Section 2.4. After, these frequencies have been compared with the hypotheses represented in Appendix A. The results of this survey conforming the frequencies for the Eq.1, Eq.2, and Eq.3 have been shown in the Tab. 6, Tab. 7, and Tab. 8 correspondingly.

Tab. 6: Survey results corresponding to Eq.1

Code	Majority of responces	Number	Frequency	Eq.1
Q3	important	11	39%	64%
Q4	very important	12	40%	70%
Q5	very important	11	37%	70%
Q7	important	11	37%	53%
Q9	very important	11	37%	60%
Q10	important	9	30%	57%
Q12	neutral	8	27%	47%
Q14	important	11	39%	54%
Q15	very important	8	29%	50%
	neutral	8	29%	
Q16	very important	8	29%	57%
	important	8	29%	
	neutral	8	29%	
Q18	important	7	25%	46%
Q19	very important	18	60%	77%
Q20	important	8	27%	43%
Q21	neutral	10	33%	43%
Q22	important	18	60%	73%
Q24	very important	8	28%	48%
Q25	important	13	50%	92%
Q26	important	15	54%	75%
Q27	important	10	36%	50%
Q28	very important	11	39%	68%
Q29	important	7	25%	46%
	neutral	7	25%	
Q30	important	10	36%	68%

According to Table 6, not all results reported by the majority of responses correspond to the Eq. 1. For instance, for the Q21 the majority of experts gave the answer "neutral", however, based on the evaluating frequency method the result of the Q21 corresponds to the Eq. 1. In this paper, we take the frequency evaluation as the main result to take a decision.

Tab. 7 shows the survey results corresponding to Eq.2.

Tab. 7: The survey results corresponding to Eq.2

Code	Majority of responces	Number	Frequency	Eq.2
Q8	neutral	12	40%	40%
Q17	neutral	11	39%	39%

Tab. 8 demonstrates the survey results corresponding to Eq.3.

Tab. 8: The survey results corresponding to Eq.3

Code	Majority of responces	Number	Frequency	Eq.3
Q6	neutral	8	27%	40%
Q11	less important	9	30%	40%
Q13	important	8	28%	45%
	less important	8	28%	
Q23	less important	10	34%	59%

According to the survey results, the hypotheses 1 (H1) is accepted for the Q3, Q4, Q5, Q7, Q9, Q12, Q14, Q15, Q16, Q18, Q19, Q22, Q24, Q25, Q26, Q27, Q28, Q29, Q30 and is rejected for the Q8, Q11 questions. To explain more precisely, government support mechanism has a "neutral" value, and connection mining to the grid has a "less important" value for experts. The H2 is rejected completely. There are not answers with the "neutral" value for experts. Eventually, the H3 is accepted for the Q13 and Q23 questions and rejected for the Q10, Q17, Q21 questions. In addition, it is confirmed that a lack of business models and development of domestic renewable energy market have "less important" value for experts.

According to the survey results, there are however, the questions which do not account the H1, H2, H3 but they have been identified by surveying. Such as, Q14, Q20, Q21 for the H1 and Q8, Q18 for the H2. For these questions, we accept that the response items are inconsistent and thereby require more detailed study integrating the second round of the survey.

Tab. 9: Comparative analysis of three hypotheses with the survey results

Hypothesis 1			Hypothesis 2			Hypothesis 3		
Important			Neutral			Less important		
LR	Results	Survey	LR	Results	Survey	LR	Results	Survey
Q3	TRUE	Q3	Q6	FALSE	Q8	Q10	FALSE	Q6
Q4	TRUE	Q4	Q14	FALSE	Q17	Q13	TRUE	Q11
Q5	TRUE	Q5	Q20	FALSE		Q17	FALSE	Q13
Q7	TRUE	Q7				Q23	TRUE	Q23
Q8	FALSE					Q21	FALSE	
Q9	TRUE	Q9						
Q11	FALSE	Q10						
Q12	TRUE	Q12						
	FALSE	Q14						
Q15	TRUE	Q15						
Q16	TRUE	Q16						
Q18	TRUE	Q18						
Q19	TRUE	Q19						
	FALSE	Q20						
	FALSE	Q21						
Q22	TRUE	Q22						
Q24	TRUE	Q24						
Q25	TRUE	Q25						
Q26	TRUE	Q26						
Q27	TRUE	Q27						

Q28	TRUE	Q28						
Q29	TRUE	Q29						
Q30	TRUE	Q30						

Identifying of standard error (SE), which refers to standard deviation of different sample statistics, establishes a data accuracy. The standard errors of each question of the survey is shown in Tab. 10. According to the survey results, the SE of the data is between 0.09 and 0.28.

Tab. 10: Standard errors of the survey data

Code	SE	Code	SE	Code	SE	Code	SE
Q1	0.09	Q9	0.25	Q17	0.26	Q25	0.14
Q2	0.13	Q10	0.22	Q18	0.28	Q26	0.20
Q3	0.17	Q11	0.24	Q19	0.23	Q27	0.23
Q4	0.22	Q12	0.25	Q20	0.25	Q28	0.23
Q5	0.24	Q13	0.24	Q21	0.20	Q29	0.26
Q6	0.23	Q14	0.22	Q22	0.12	Q30	0.22
Q7	0.22	Q15	0.25	Q23	0.24	Q31	0.08
Q8	0.20	Q16	0.22	Q24	0.25		

Conclusions

Summing up the survey research, the results are following:

- Using the LR three hypotheses have been developed.
- Demographic information of experts has been evaluated.
- *Evaluating hypotheses method* has been developed by authors to compare these hypotheses with the survey results.
- Standard errors of the survey data are between 0.09 and 0.28.

The results of this survey show that the integration of RE into the mining industry has perspectives and relevance for 24 experts (80%), with 2 experts (7%) opposing this idea and 4 experts (13%) remaining without an opinion. Decreasing costs of RE generation, off-grid location of a mine, and increasing prices of fossil energy are the main factors towards RE penetration. Volatility of RE technologies and costs of RE generation are the main barriers. Subsidies, establishing a policy, and a carbon tax might be the most efficient government support mechanisms. Reduction in fuel and electricity costs, including transportation costs, predictable energy costs; lower risk from volatile and rising diesel prices; and decreasing carbon emissions are seen as the key effects from RE implementation. All environmental issues such as low-carbon supply chain, recycling programs, using of RE, integrated waste management, and sustainable development are important for industrial companies.

In contrast, a lack of business models and the development of domestic renewable energy market are not important factors towards integrating RE into the mining industry

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Appendix A

Tab. A.11: Systematic literature review on implementing RE into the mining industry

No.	Hypothesis	Literature source
Q3	H1	(Moran, et al. 2014), (Mobile Solar- and Wind Diesel Hybrid 2016), (Hillig and Watson 2016)
Q4	H1	(Mining Sector Embracing Microgrids: Hybrid Systems Reduce Energy Costs & Environmental Impact 2017), (Bergek and Mignon 2017), (Ripasso Energy and THEnergy study 2016), (Ram, et al. 2017)
Q5	H1	(Mining Sector Embracing Microgrids: Hybrid Systems Reduce Energy Costs & Environmental Impact 2017), (ABB n.d.), (Choi and Song 2016), (Mobile Solar- and Wind Diesel Hybrid 2016), (Ripasso Energy and THEnergy study 2016), (Solar projects, energy efficiency and load shifting for an optimized energy management in the mining industry 2015)
Q6	H2	(Mobile Solar- and Wind Diesel Hybrid 2016), (Solar projects, energy efficiency and load shifting for an optimized energy management in the mining industry 2015)
Q7	H1	(Mitimingi and Hill 2017)
Q8	H1	(Mobile Solar- and Wind Diesel Hybrid 2016), (Hillig and Watson 2016)
Q9	H1	(Ripasso Energy and THEnergy study 2016), (Ram, et al. 2017)
Q10	H3	(Mobile Solar- and Wind Diesel Hybrid 2016)
Q11	H1	(Danvest and THEnergy study 2015)
Q12	H1	(Danvest and THEnergy study 2015), (Mobile Solar- and Wind Diesel Hybrid 2016)
Q13	H3	(Business models for renewable energy applications at mines n.d.)
Q14	H2	(Mobile Solar- and Wind Diesel Hybrid 2016)
Q15	H1	(Mobile Solar- and Wind Diesel Hybrid 2016)
Q16	H1	(Moran, et al. 2014)
Q17	H3	-
Q18	H1	(Mining Sector Embracing Microgrids: Hybrid Systems Reduce Energy Costs & Environmental Impact 2017), (Solomons 2017), (Huisman 2014)
Q19	H1	(Mobile Solar- and Wind Diesel Hybrid 2016), (Ripasso Energy and THEnergy study 2016), (Hillig and Watson 2016), (Danvest and THEnergy study 2015)
Q20	H2	(Boyse and Causevic 2014)
Q21	H3	-
Q22	H1	(Mining Sector Embracing Microgrids: Hybrid Systems Reduce Energy Costs & Environmental Impact 2017)
Q23	H3	(Earopean Environment Agency 2017)
Q24	H1	(Ranangen and Lindman 2017), (Mining Sector Embracing Microgrids: Hybrid Systems Reduce Energy Costs & Environmental Impact 2017), (Choi and Song 2016), (Ripasso Energy and THEnergy study 2016), (Ram, et al. 2017)
Q25	H1	(Ranangen and Lindman 2017), (Choi and Song 2016), (Ripasso Energy and THEnergy study 2016)
Q26	H1	(Moran, et al. 2014) (Dougherty 2017)

Q27	H1	(Moran, et al. 2014)
Q28	H1	(European Environment Agency 2017), (Ram, et al. 2017)
Q29	H1	(Fraser Institute 2012)
Q30	H1	(Ranangen and Lindman 2017), (Moran, et al. 2014)

Tab. A.12. Sample of the questionnaire

Code No.	Number	Question
Q1	1	Have you ever heard about implementation of renewable energy (RE) into the mining industry?
Q2	2	In your opinion, do RE have perspectives and relevance to be considered as an energy source for the mining industry?
Q3	3	How can you evaluate an integration of RE into the mining industry?
	4	The following are incentives to integrate of RE into the mining industry. Please, grade them using the scale from 1 to 5. You can use one number several times
Q4	4.1	Decreasing costs of RE generation
Q5	4.2	Off-grid location of a mine
Q6	4.3	Reliability and security of RE sources
Q7	4.4	Increasing prices of fossil energy
Q8	4.5	Government support
	5	The following are barriers in matter of RE integration into the mining industry
Q9	5.1	Volatility of RE sources
Q10	5.2	High investments in RE technologies
Q11	5.3	Connection of a mine to the grid
Q12	5.4	Costs of RE generation
Q13	5.5	Lack of business models
	6	The following are government's support mechanisms in order to integrate of RE into the mining industry
Q14	6.1	Tax breaks
Q15	6.2	Subsidies
Q16	6.3	Establishing a policy
Q17	6.4	Feed-in tariff
Q18	6.5	Carbon tax
	7	Please, evaluate the following effects from RE integration into the mining industry using the scale from 1 to 5
Q19	7.1	Reduction in fuel and electricity costs, including transportation costs
Q20	7.2	Reduction risk of power loss from supply disruptions
Q21	7.3	Predictable energy costs
Q22	7.4	Lower risk from volatile and rising diesel prices
Q23	7.5	Development of domestic renewable energy market
Q24	7.6	Decreasing of carbon emissions
Q25	8	How important is for your company (institution) making the industrial processing more environmental friendly?
	9	Evaluate, please, the following environmental issues for industrial processing using the scale from 1 to 5
Q26	9.1	Low-carbon supply chain
Q27	9.2	Recycling programs

Q28	9.3	Using of RE
Q29	9.4	Integrated waste management
Q30	9.5	Sustainable development
Q31	10	Have you ever been involved in a project for implementation of RE into the mining industry?