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Article info:
Received 17.10.2019
Accepted 02.03.2020

UDC – 620.282
DOI – 10.24874/IJQR14.02-16

RENEWABLE ENERGY FOR SUSTAINABLE MINING

Abstract: *Mining industry is known for requiring energy-intensive processes with significant impacts on the greenhouse gas emissions, which represents a major concern to both economic competitiveness of the sector and climate change. Low carbon sustainable technologies as renewable energy sources (RES) are emerging as key opportunities to sustainable mining in tandem with climate change challenges. However, the use of RES on this sector is still scarce even in countries well known for their mining potential and availability of renewable energy resources, as is the case of Brazil. This research investigates the economic viability of a proposed renewable-mining model for a mining company in the Northeast region of Brazil. The case of photovoltaic is analyzed considering the avoided electricity grid costs as potential benefits. The results showed that this renewable-mining strategy is promising for both PV and storage-PV.*

Keywords: *Renewable Energy Sources; Mining; Brazil*

1. Introduction

The demand for raw materials has been increasing worldwide over the years, despite efforts in activities such as recycling (Alves et al., 2018). This demand is still expected to increase significantly in the coming decades. Also the imeddiate effect of the extraction of raw materials on the environment has increasingly attracted the attention of researchers and practitioners. The mining industry has been playing a fundamental role on supplying raw materials for the society and several industries worldwide, although in some cases at the expense of the ecosystems (Paraszczak & Fytas, 2012).

Mining activities are known for requiring energy-intensive processes which contributes to increase the greenhouse gas emissions (Hodgkinson & Smith, 2018a). The high energy demand represents a complex issue for the sector, however, the emerging debate on climate change has been placed on the agenda putting in evidence the need to reduce energy use, and also to promote clean energy options usage.

In this context, the use of renewable energy source (RES) has been considered as a key sustainable alternative for mining industries, with some international examples already demonstrating the suitability of this low carbon energy model at industrial level, as for the case of Chile (Vyhmeister et al., 2017) and Korea (Choi & Song, 2016).

For the case of Brazil, the mining sector represents a valuable economic activity, which allied with the countries' privileged access to renewable resources such as solar and wind, turns this renewable-mining strategy particularly relevant to be considered. In fact, studies such as Alves et al. (2018) already showed the importance of sustainable mining in the country and Dranka and Ferreira (2018) clearly shows the high

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RES potential of the electricity sector. However, the mining-energy combination for sustainability is yet far from being adequately considered.

In this context, this research has two main objectives, firstly, to analyse the importance of energy for mining activities and the use of different energy sources in the processes; and secondly, to attempt for an economic evaluation of the possible use of renewable energy sources (RES) in the sector using the case of a mining company to illustrate this approach.

In order to achieve the objective of this research, a review of the relevant existing literature was conducted. Then, the case of a mining company in the Northeast region of Brazil was analyzed. A case study method was chosen in order to assess the economic viability of the proposed renewable-mining strategy under the present market conditions.

2. RES and mining industries: an overview of the literature

Over the last decades, the population growth, associated with the increasing consumption of goods, services as well as trends in urbanization, have led to an increase in the global demand for raw materials worldwide (McLellan et al., 2012). The management of economic and environmental have been an increasing concern fro business worldwide. As result, the mining industries are coming under increasing pressure with significant impacts on the energy consumption and on the greenhouse emission through its operations (Hodgkinson & Smith, 2018a). These activities are well known as an energy intensive industrial sector since extraction of ores from deeper levels requires intensive use of energy in several stages (Levesque et al., 2014).

According to the International Organizing Committee for the World Mining Congress (Reichl et al., 2017), excluding natural gas and petroleum, the countries which figure as the biggest players for mining industries in the world mineral production are China which produces 33.5% of this global production, USA 12.0 %, Australia 7.9%, Russia 7.1%, India 6.4%, South of Africa 4.7%, Indonesia 4.0%, Brazil 2.1%, and Canada 2.0%. These countries have been seen as key players on supplying raw materials for society worldwide.

Yet, the current literature related to the mining sector has been focusing on aspects such as relationships between extractive industry and development, community and its impacts and the social and environmental impacts of mining. An example of this sustainability perpective for the mining sector may be found in Alves et al., (2019). The relationship between mining and climate change has received limited attention, which configures a gap in the literature (Odell et al., 2018).

In order to deal with the global challenge of mining and energy, initiatives towards a carbon neutral through implementation of RES by mining industries may become a strong priority for industries, scientific experts and decision-makers in the coming decades. This search for low carbon mining will lead companies operating in the sector to look forward for energy efficiency measures and alternatives for fossil fuels, such as renewable energy sources.

According to Zharan and Bongaerts, (2017) the focus on the use of RES by mining companies can be seen as an alternative way of energy procurement aiming both a lower energy cost as well as a clean energy source, enabling practices and progress for a sustainable mining.

According to the Word Energy Balances, mining industries account for about 4 - 7% of the total global energy use. This indicates that energy use for mining industries is between 16 and 27 EJ annually (IEA, 2016). Excluding gas, oil, and rock excavation, the work developed by Holmberg et al. (2017) shows a similar picture with an estimation of energy by these mining industries worldwide of about 12 EJ energy per annum.

Considering that mining activities are one of the worlds' largest industrial sector and these activities are expected to expand globally, these estimations show the importance of this industrial sector on regards to energy needs and as well the need for initiatives towards clean energy sources (Hodgkinson & Smith, 2018b).

Despite of the feasible technologies used to generate electricity such as wind or solar contribute with lower greenhouse when compared with diesel which is the conventional source used in mining activities, initiatives and strategies towards implementation of these low carbon strategies are still insipient due to several aspects of mining operations.

The work developed by McLellan et al. (2012), highlights that the use of RES for mining industries depends on appropriate incentives such as regulatory schemes and policies, otherwise in the case of mining, the use of these technologies by industries will remain difficulty to be adopted. Also Zharan, (2016), claims that the implementation of RES for mining has several constraints. Technological and economic aspects emerge as the main challenges faced by the sector.

On the other hand, Vyhmesiter et al. (2017) argue that RES can play a support role on mining companies. These technologies can contribute to lower peak costs and even to bring energy to remote regions where the mines are located. This RES-mining combination can be in the long term an economically attractive alternative, moving on the sector for a reorientation of the production system to a sustainable production system (Odell et al., 2018; Choi & Song, 2017).

3. Materials and methods

This study addresses the case of medium size mining company located in the Northeast of Brazil, which works on the extraction of sheelite mineral. The process includes underground extraction activities and industrial surface related facilities. Most of the intensive electricity consumption activities are related to underground extraction, including the pumps of water exhaustion, winches for hoisting of cars, lighting, ventilation and the primary and secondary crushing. Underground extraction operates 24 hours a day from Monday to Saturday.

The information about the electricity use of the company is scarce and came mainly from monthly invoices sent by the electricity supplier and can be summarized as follows in table 1. As shown, a dual-tariff scheme is in place with about four hours of the day charged as peak period.

Table 1. Summary of electricity use for year 2016

	Peak time	Off-peak time
Electricity consumption (kWh)	39208	485918
Tariff (USD/kWh)	0.397	0.081

This study addressed the case of the possible installation of a photovoltaic (PV) system to reduce the amount of electricity purchased from the grid. Information about the expected PV power production was computed from www.renewables.ninja platform ((Pfenninger & Staffell, 2016) and (Staffell & Pfenninger, 2016)) which provides monthly and hourly data based on the geographical coordinates of the location for the PV unit. Figure 1 describes the monthly electricity consumption of the plantand the expected load factor for the PV unit.

As it can be seen, the electricity use on the plant remains fairly stable during the year, but the PV plant output will reflect the seasonality of the local conditions. For the calculations, it was assumed that the electricity use would also remain stable during peak and off-peak periods of the day.

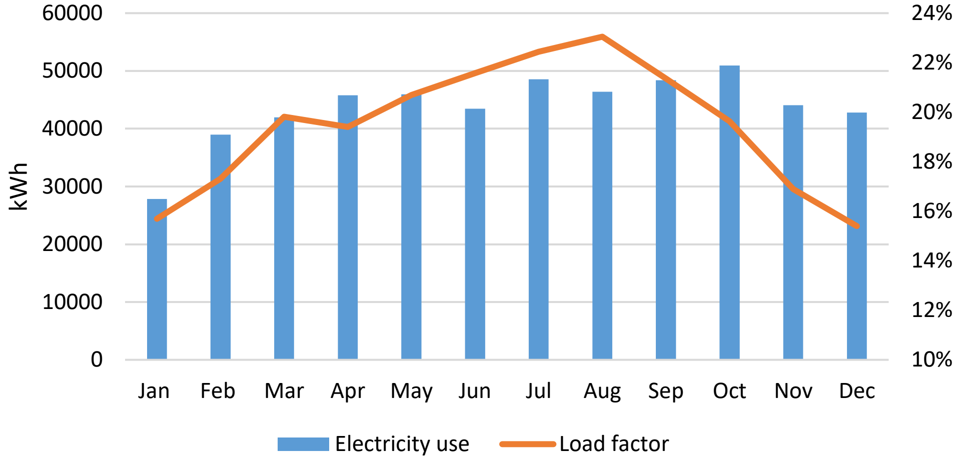

Figure 1. Electricity use on the plant and load factor for the PV unit

For the economic evaluation study, 3 scenarios were considered:

- *Scenario 1* – A PV unit of 10 kW would be installed, which would allow to produce about 3.2% of the total needs of the plant or about 6.5% of the needs to the plant during day light.
- *Scenario 2* – A PV unit of 25 kW would be installed, which would allow to produce about 8.1% of the total needs of the plant or about 16.2% of the needs to the plant during day light.
- *Scenario 3* – A PV unit of 25 kW would be installed along with a lead-acid battery storage system with a storage capacity of 30 kWh. This would allow to storage electricity produced during the day to replace consumption from the grid during peak periods at the end of the day (no day light). As in scenario 2, about 8.1% of the total needs of the plant would be met but with higher avoided costs (benefits).

As such, both scenarios 1 and 2 represent a technical approach to the problem but scenario 3 can already be seen as first strategic study to analyze the benefits of the dual tariff scheme and its relevance for the economic viability of storage systems. The economic evaluation, included the assessment of the main costs of the PV system and storage and the benefits were computed as the avoided costs, meaning the electricity which would be produced and therefore would not be bought from the grid. Table 2 summarizes the main assumptions of the scenarios.

For the sake of simplicity O&M costs were not included in the model. Information on PV investment costs was obtained from the report of Instituto IDEAL (2018) from a survey in Brazil for systems up to 5 kW. It was assumed that the value would be valid for the case of scenario 1 (10 kW) and that the investment cost could be reduced by 10% for the case of scenarios 2 and 3 (25 kW) due to some economies of scale. The information on the lead acid battery system was based on Geoffrey et al., (2018) however the uncertainty of the information must be highlighted given the relative immaturity of the stationary storage market for small electricity generation systems.

Table 2. Key parameters for the scenarios

	Scenario 1	Scenario 2	Scenario 3
Installed PV power (kW)	10	25	25
PV Investment cost (USD/kW)	1385	1247	1247
PV Life time (years)	25	25	25
Lead acid storage system (kWh)			30
Storage cost (USD/kWh)			Pessimistic – 600 Optimistic - 400
Storage life (cycles)			2000
Storage efficiency (%)			85
Discount rate (%)	5%/10%/15%	5%/10%/15%	5%/10%/15%

For each one of the scenarios, three possibilities were considered for the discount rate. The possibility of loans or access to public support scheme were not considered.

4. Results and Discussion

The results were analyzed considering a discount cash flow approach to compute the Net Present Value (NPV) and Internal Rate of Return (IRR). Table 3 presents the main results for the 3 scenarios.

From the financial perspective, the results put in evidence the importance of the discount rate as a fundamental factor for the assessment of the economic viability of the system. In fact, if a 15% discount rate is assumed all options would be economically unfeasible. The intra-bank rate in Brazil (SELIC), which is used as a reference for loans and other economic operations, is presently around 6.5% but it has remained unstable during the past years (https://www.bcb.gov.br/controleinflacao/taxaselic). As such, the company must address this issue as a risk factor to be considered on a more detailed analysis. Nevertheless, results for 10%, which is already well above SELIC, are still positive for scenario 2.

Table 3. Economic evaluation

	Scenario 1	Scenario 2	Scenario 3 (pessimistic)	Scenario 3 (optimistic)
NPV at 5% (USD)	7557	22356	13755	30451
NPV at 10% (USD)	-63	3305	-7553	4973
NPV at 15% (USD)	-4032	-6616	-18363	-8105
IRR (%)	9.9	11.4	7.8	11.6

As for scenario 3, it is evident that the cost of the storage system is a key aspect to be considered in the analysis. The results are highly dependent on these values as under a pessimistic approach scenario 3 would be the worst option for the case of both 10% and 15% discount rate. It can however become the best option, for lower prices of the storage system. Studies such as IRENA (2017) already point to a promising decline of the costs for these lead acid systems and to the development of other storage options. This scenario underlines the future perspectives for the renewable producers which not only can benefit from a reduction of their costs but can also benefit from the strategic management of their PV and storage assets to better couple with the dual tariff schemes.

5. Conclusion

Conclusion should present one or more conclusions that have been drawn from the results and subsequent discussion. This study addresses the integration of renewable solutions into mining activities, which can be seen as an important route to increase the companies' competitiveness and contribute to meet sustainability objectives. However, costs and even the lack of awareness are still major barriers which have limited the renewables investments.

This study used a case study, to show how using PV system can contribute to reduce electricity costs on a mining company in Brazil. The economic viability of the system is demonstrated and the possibility of using renewable-storage-mining strategy is also highlighted. For this study only direct benefits (measured as avoided costs) were considered but aspects related to the contribution to the security of supply for the company can also be relevant. Moreover, the social contributions should not be overlooked such as the environmental benefits or even the potential impact on regional development and job creation that this local renewable-mining strategy implemented at large scale can have on the region.

However, some limitations of the study should be also pointed out namely the scarcity of detailed information that characterizes most of these companies. Moreover, the analysis is based on cost assumptions collected from the literature which must be validated by a local study of the plant and of the equipment suppliers. Additional costs, such as O&M and end of life expenses must be considered. The issue of storage cost assumptions is particularly important to be addressed as it is still a major source of uncertainty.

Acknowledgment: This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2019; and CAPES and Science Without Borders scholarship, BEX Process 10.190-13-9.

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