HOLOS
ISSN 1807 - 1600

ESTIMATIVA DA EMISSÃO DE GASES DO EFEITO ESTUFA (GEE) PRODUZIDOS POR UM MOINHO DE BOLAS PELO MÉTODO DE ANÁLISE DO CICLO DE VIDA (ACV)

C.E.D. MATA, A.C. SILVA
Universidade Federal de Alfenas[1], Universidade Federal de Ouro Preto[2]
https://orcid.org/0000-0002-8086-3580
carlos.engenheirodeminas@gmail.com

Submetido 22/02/2021 - Aceito 09/04/2022
DOI: 10.15628/holos.2022.12041

RESUMO

Uma quantidade significativa de gases do efeito estufa (GEE) relacionados ao consumo de eletricidade são gerados por processos de cominuição na indústria de mineração. Por isso, o presente estudo visa quantificar pelo método de Análise de Ciclo de Vida (ACV) a emissão de GEE produzido por um moinho de bolas dimensionado para processar a rocha fosfática da jazida de Angico dos Dias (BA). Esta categoria de impacto relacionada às mudanças climáticas foi avaliada em dois diferentes cenários: Fornecimento direto de energia para o moinho pelo sistema de energia elétrica público e energia gerada por motor a diesel abastecendo um gerador. O dimensionamento do moinho foi realizado pelo método de Bond e Rowland. Para tal, foram estabelecidos os seguintes parâmetros operacionais: moagem a úmido em circuito fechado, 480 t/h de alimentação, F_{80} = 2,204 mm, P_{80} = 0,212 mm e WI = 10,13 kWh/st. A unidade funcional selecionada para a estimativa de ambos os cenários é "Uma tonelada de rocha fosfática moída", considerando um processo do portão ao portão. A potência consumida pelo moinho dimensionado é de 5,29 kWh/t (3.402 hp). No primeiro cenário 0,661 kg de GEE são liberados para moer uma tonelada da rocha fosfática de Angico. A emissão anual de GEE estimada é de 2.779 toneladas. Por outro lado, em relação ao segundo cenário foi estimado uma produção de 1,29 $kg_{GEE}/t_{RochaMoída}$, resultando em uma emissão anual de 5.424 toneladas. Portanto, as emissões geradas pelo fornecimento de energia via motor a diesel são aproximadamente o dobro da quantidade de GEE emitidos quando se considera o fornecimento pelo sistema de energia elétrica público.

PALAVRAS-CHAVE: análise do ciclo de vida, gases do efeito estufa, mineração, moinho de bolas, eletricidade.

ESTIMATION OF GREENHOUSE GASES (GHG) EMISSIONS FROM A BALL MILL BY LIFE CYCLE ASSESSMENT (LCA) METHOD

ABSTRACT

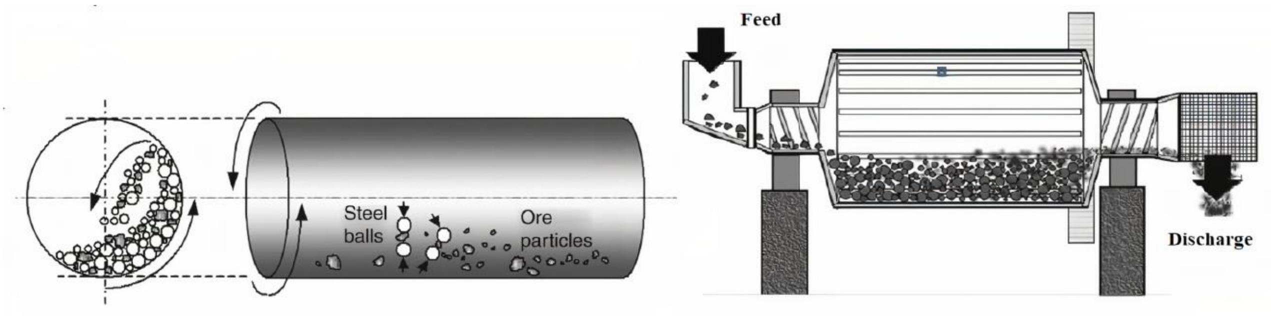
A significant amount of greenhouse gases (GHG) related to the consumption of electricity is generated by the grinding process in the mining industry. Therefore, in this study was quantified by the LCA method the GHG emission produced by a ball mill designed to grinding phosphate rock from Angico dos Dias deposit, Brazil. This impact category related to climate change was evaluated in two different scenarios: Electric power system supplying the mill, and a diesel fuel-based engine and generator powering the mill. The design of the ball mill for this study was carried out through the Bond and Rowland method. The followings operational parameters were established: wet grinding in a closed circuit, 480 ton/h of flow rate, F_{80} = 2.204 mm, P_{80} = 0.212 mm, and WI=10.13 kWh/ston. The Functional Unit selected for the estimation in both scenarios is "One ton of phosphate rock ground", considering a process gate-to-gate. The power consumption of the designed ball mill is 5.29 kWh/ton (3,402 hp of power). For the first scenario 0.661 kg of GHG is released to grind one ton of Angico's phosphate rock in the mill designed. The annual emission is 2,779 tons of GHG. On the other hand, concerning the second scenario was estimated 1.29 kg/ton_{ore} of GHG produced, resulting in an annual emission of 5,424 tons. Therefore, emissions of a diesel fuel-based engine and generator are approximately twice the quantity of GHG released by the electric power system.

KEYWORDS: life cycle assessment, greenhouse gases, mining, ball mill, electricity

1 INTRODUCTION

The demand for mineral resources has been increasing substantially in the last decades. Therefore, more development in sustainable and low-cost technologies is mandatory for processing ores increasingly poor in terms of the valuable element content.

In mineral processing plants, the proper particle liberation and size distribution required by concentration stages, like flotation and magnetic separation, is achieved by grinding unit operations (comminution). Most of grinding circuits working in Brazil has predominantly tumbling mills with steel balls as grinding media, better known as ball mill (Figure 1). These machines are usually powered by electric motors. However, besides to the massive consumption of grinding media, another concern about this equipment is the significant consumption of electrical energy.



a) b)

Figure 1: Ball mil – a) Mechanisms of fragmentation; b) Representation of overflow discharge mill. Adapted from Gupta and Yan (2016).

For instance, in a large copper mine, these costs may reach well over 25% of the overall processing cost (Wills and Finch, 2016). In 1976 it was reported that 3.3% of the entire world's production of electrical energy was used in crushing and grinding processes (Schoenert, 1986). Furthermore, the ball mill is quite inefficient to perform the disruption of particles and bring forth new surface, mainly for finer particles. Almost all the energy spent by the mill (>99%) comes about as heat, mechanical vibrations, noise, and etc (Fuerstenau and Abouzeid, 2002). As a result, grinding operations are responsible for producing a considerable amount of greenhouse gases for energy generation.

Ferreira and Leite (2015) performed an LCA study of an iron ore mining in Brazil to evaluate the environmental impacts of mining activities, considering the whole production chain (cradle-to-gate). Electricity consumption in the entire process, production and transportation of grinding media are the primary responsible for impacts on climate changes in terms of greenhouse gas emissions (CO_{2eq}). Norgate and Haque (2010) also verified by LCA study that the most significant contributors for the total greenhouse gas emissions in a copper mine in Australia are the crushing and grinding stages (approximately 46%), especially the latter.

The methodology adopted by the Life Cycle Assessment (LCA) is a powerful tool to evaluate the environmental impact of the whole operations within a production process (cradle-to-grave) or partially (gate-to-gate) (Hauschild, Jeswiet and Alting, 2005). LCA method is standardized according to ISO14040/14044, and the approach might cover impacts generated from the raw material extraction and acquisition through to the final disposal and recycling. Development of LCA takes place throughout three stages: definition of goal and scope, inventory analysis, and impact of assessment.

Project boundary in terms of time and space, data requirements, and the functional unit are the most relevant issues to be determined in the study's scope. Specification of flows, inputs, and outputs parameters of a unit process within the production system must be established in the inventory analysis (Rebitzer et al., 2004). Finally, the definition of impact categories aligned to the goal's study is necessary for the impact assessment. Thus, stakeholders might take the most suitable decision to mitigate the likely harmful effects.

On the other hand, there are few cases of application of LCA in the mining industry. Even though the method is beneficial to assess the environmental impacts of mining activities, it might be a highly complicated assignment to get the proper quantitative data (inputs and outputs) among so many operational variables of a mine (Duruncan, Korre and Melendez, 2006).

As previously discussed, a significant amount of greenhouse gases related to the consumption of electricity is generated by the grinding process in the mining industry. Therefore, in this study was quantified by the LCA method the greenhouse gas emission (GHG), in terms of CO_{2eq}, produced by a ball mill designed to grinding phosphate rock from Angico dos Dias deposit, Brazil.

2 METHODOLOGY

2.1 Features of Angico's phosphate rock

The phosphate rock from the alkaline-carbonatite complex of Angico dos Dias is located in the city of Campo Alegre de Lourdes, state of Bahia, Brazil. The mining company responsible for extract and treat the phosphate ore from this deposit produce a concentrate enriched in P_2O_5 content (>35% wt.). This product is used mainly as raw material for the fertilizer industry.

According to characterization performed by Mata, Pereira, Silva and Sousa (2020), the ROM (Run of Mine) ore, which feeds the processing plant of Angico, has 19.34% of P_2O_5 content, the density of 2.98 g/cm^3, low content of carbonates while it is enriched in silicates and iron oxyhydroxides. About 80% of the ore mass, after the crushing process in jaw crusher, is below the particle size of 2.204 mm (d80). The mentioned material corresponding to the feeding of the ball mill.

2.2 Ball mill design

The ball mill was designed through the Bond and Rowland method for this study. The grinding parameters and conditions assumed to calculating the mill dimensions are listed in Table 1. Mill feeding is a product from the crushing process operating in a closed circuit (recirculation of coarser particles) as well as grinding. Wet grinding will be the operational condition for this case (most of the tumbling mills work in wet conditions).

The estimated power consumed W (kWh) for grinding 1 ton of phosphate rock through conditions above-mentioned was calculated by Equation 1 (Bond and Rowland method). It is important to consider that the real grinding process demands the use of eight correction factors

(CF_1 to CF_8) for mill design and calculation of power consumed developed by Rowland. Machine power E (hp) required for this process was determined by Equation 2.

Table 1: Parameters assumed for mill design.

Mill Parameters	
Mill feeding (flow rate)	480 ton/h
[1]F_{80}	2.204 mm
[2]P_{80}	0.212 mm
[3]WI	10.13 kWh/[4]ston

[1]F80: particle size considered for mill feeding.

[2]P80: particle size required to be achieved after grinding (product size).

[3]WI: work index – average value for grinding of phosphate rock.

[4]ston: short tonne = 0.907 ton.

$$W = (\frac{10\,WI}{\sqrt{P80}} - \frac{10WI}{\sqrt{F80}})\frac{1}{0.907} \tag{1}$$

$$E = 1.34W(CF_{1-8})Q \tag{2}$$

Parameter Q of Equation 2 corresponds to the flow rate of mill feeding.

2.3 Development of life cycle assessment

The scope of this study was established only one impact category in two different scenarios to be evaluated: Impacts on climate change – greenhouse gas emissions. Scenario one considers the energy supply from the electric power system, and in scenario two was stipulated a diesel fuel-based engine and generator power the mill.

The data concerning the emission factor of greenhouse gases (GHG) of the electric power system was acquired from Miranda (2012) work. In this study was estimated the overall emission factor (EF_{system}) of GHG for the Brazilian electricity matrix through a systematic review and metanalysis of all energy supply technology available in Brazil. For the second scenario was chosen two diesel fuel-based generators of 450 KVA, each one capable of using 9.13×10^{-2} litters (V) of diesel to produce 1 kWh. The Emission factor to burning diesel (EF_{diesel}) through stationary combustion was quantified using the IPCC-2006 (Intergovernmental Panel on Climate Change) method, calculated by Equation 3.

$$EF_{diesel} = CO_{2eq(wt.)}\ x\ \rho_{diesel}\ x\ V \tag{3}$$

Where:

$CO2_{eq(wt.)}$ is the sum of all GHG’s weight contributions (CO_2, CH_4, and N_2O) obtained from IPCC-2006 in g/kg;

ρ_{diesel} is the density of diesel – 0.853 kg/L; and

HOLOS ISSN 1807 - 1600

V is the volume of diesel within the engine to produce one kWh of power in L/kWh.

The Functional Unit selected for the estimation in both scenarios is “One ton of phosphate rock ground”, considering a process gate-to-gate (just grinding stage). Thus, impact quantification of GHG emission per Functional Unit (CO_{2eq}/FU) was determined by Equation 4.

$$CO_{2eq}/FU = EF\ x\ W \qquad (4)$$

CO_{2eq}/FU is expressed in kg/ton_{ore};

EF is the emission factor of electric power system for the first scenario and diesel combustion in the generator for the second scenario in kg/kWh; and

W is the power consumed by mill in kWh/ton.

Finally, the annual amount of GHG produced in both cases was calculated, admitting the ball mill works for 24 hours per day and 365 days per year.

3 RESULTS AND DISCUSSION

The power consumption W of the ball mill determined by equation 1 is 5.29 kWh/ton. In this case, the conditions specified for grinding resulted in null values for the eight correction factors CF of Equation 2. As a result, the mill power required to reduce the particle size of 480 ton/h of ROM ore is 3,402 hp. Evidently, the engine power of the mill should be slightly higher than calculated, once a stock power is necessary to turn on the mill when it is stationary with a dense load of balls and ore. In consequence, the determination of GHG emissions does not consider this extra power. It can be verified that the electrical energy demanded by this operation is quite meaningful, which explains the high consumption within a mineral processing plant.

Concerning the first scenario, the EF_{system} of the electric power system estimated by Miranda (2012) is 125 g CO_{2eq}/kWh. The major contribution, according to the author, for the energy supply and, as a consequence, the GHG emission in Brazil is the hydroelectrical (61%), followed by NG thermoelectrical (22%). It is advantageous in terms of GHG emission, once thermoelectric power plants are more polluting and use non-renewable raw material as fuel. A portion of the CO_2 emitted by hydroelectric coming from organic matter decomposed on the reservoir’s bottom. Therefore, the CO_{2eq}/FU calculated through Equation 4 is 0.661 kg/ton_{ore}. In other words, 0.661 kg of GHG is emitted to the atmosphere to grind 1 ton of Angico’s phosphate rock in the mill designed. The annual emission generated by only one machine to the production scale stated is 2,779 tons.

Concerning the second scenario, according to IPCC data, the $CO_{2eq(wt.)}$ released by the combustion of diesel A (B0) is 3,144.1 g/kg_{diesel}. The main sharing for that amount of GHG is fossil CO_2, which is reasonable, once the diesel is a liquid fossil fuel. Thus, the EF_{diesel} of diesel fuel-based generators determined by Equation 3 is 244.8 g CO_{2eq}/kWh. This value is approximate twice the quantity of GHG released by the electric power system. Finally, the CO_{2eq}/FU is 1.29 kg/ton_{ore} for the second scenario, also calculated through Equation 4. In this case, the annual emission is 5,424 tonnes. It has been shown in Table 2 the results comparing the two scenarios.

Table 2: Comparison of the two scenarios.

Parameters	Scenario 1	Scenario 2
EF (g CO_{2eq}/kWh)	125	244.8
CO_{2eq}/FU (kg/ton$_{ore}$)	0.661	1.29
Annual (ton/yr)	2,779	5,424

Although the diesel generator is widely applied in the mining industry, as an alternative to the conventional electric power system to power up robust machines as tumbling mills, such energy source is unsustainable in terms of climate changes. 5,424 tons of GHG released per year in the atmosphere just by one equipment is data that cannot be omitted and should be taken into consideration on the design of mineral processing plants.

CONCLUSIONS

The life cycle assessment method proved to be useful and efficient in the analysis of environmental impacts yielded by mining activities. Even though ball mills are the most essential equipment used in mineral processing plants for grinding purposes, it is not environmentally friendly, mainly when there is a worldwide concern about climate change.

Ferreira and Leite (2015), as well as Norgate and Haque (2010) also verified in their works the considerable contribution of grinding activities on the environmental impacts compared to a range of mining operations as blasting, hauling and loading material from the open pit, concentration process and so on. Besides the considerable amount of GHG released in this sort of process, it could be a clear opportunity for mining companies to saving energy as well as reduce costs by implementing more sustainable grinding technologies. In addition, cleaner technologies for electricity supply as solar energy are welcome and should be rethought as an alternative source to be applied on the mining industry.

REFERENCES

Duruncan, S.; Korre, A.; Melendez, G. M. (2006). Mining life cycle modelling. A Cradle-to-gate approach to environment management in the minerals industry. Journal of Cleaner Production, v. 14, p. 1057-1070.

Ferreira, H.; Leite, M.G.P. (2015). A life cycle assessment (LCA) study of iron ore mining. Journal of Cleaner Production, v. 108, p. 1081-1091.

Fuerstenau, D. W.; Abouzeid, A. Z. M. (2002). The energy efficiency of ball milling in comminution. Int. J. Miner. Process, v. 67, p. 161 – 185.

Gupta, A.; Yan, D.S. (2016). Mineral Processing Design and Operations. An Introduction. Elsevier, 2 ed., p.882.

Hauschild, M.; Jeswiet, J.; Alting, L. (2005). From life cycle assessment to sustainable production: status and perspectives. Annals of the CIRP, v. 54, n. 2, p. 1-21.

Mata, C. E. D.; Pereira, C. A.; Silva, A. C.; Sousa, P. L. R. (2020). Characterization of the Angico dos Dias alkaline-carbonatite complex for phosphate rock processing. Journal of Material Research and Technology, v. 9, n. 6, p.12236–12243.

Miranda, M.M. (2012). Fator de emissão de gases de efeito estufa da geração de energia elétrica no Brasil: implicações da aplicação da avaliação do ciclo de vida. [Master's thesis]. Escola de Engenharia, USP, São Carlos, p.162.

Norgate, T.; Haque, N. (2010). Energy and greenhouse gas impacts of mining and mineral processing operations. Journal of Cleaner Production, v. 18, n. 3, p. 266-274.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Pennington, D. W. (2004). Life cycle assessment. Environment International, v. 30, n. 5, p.701–720.

Schoenert, K. (1986). On the limitation of energy saving in milling. 1st World Congress Particle Technology, Part II, Comminution, Nurnberg.

Wills, B. A.; Finch, J. A. (2016). Wills'Mineral Processing Technology – An introduction to the practical aspects of ore treatment and mineral recovery. Elsevier, 8° ed., p.495.

COMO CITAR ESTE ARTIGO:
da Mata, C. E. D., & Silva, A. C. (2022). Estimation of greenhouse gases (GHG) emissions from a ball mill by life cycle assessment (LCA) method. *HOLOS*, *8*. Recuperado de https://www2.ifrn.edu.br/ojs/index.php/HOLOS/article/view/12041

SOBRE OS AUTORES:

C.E.D. MATA
Possui graduação em Engenharia de Minas e Bacharelado Interdisciplinar em Ciência e Tecnologia pela Universidade Federal de Alfenas (UNIFAL-MG) e Mestrado em Engenharia Mineral pela Universidade Federal de Ouro Preto (UFOP). Tem experiência nas áreas de educação, mineração, metalurgia, meio ambiente e geoprocessamento.
E-mail: carlos.engenheirodeminas@gmail.com
ORCID-ID: https://orcid.org/0000-0002-8086-3580

A.C. SILVA

Possui graduação em Engenharia de Minas (2000), mestrado em Engenharia Mineral (2003) e doutorado em Engenharia de Materiais (2010) pela Universidade Federal de Ouro Preto. Pós-doutorado na Universidade Federal de Minas Gerais (2013-2015) e na Technische Universität Clausthal (2017-18).
E-mail: ancarsil@ufg.br
ORCID: https://orcid.org/0000-0002-9760-0728

Editora responsável: Francinaide de Lima Silva Nascimento

Recebido: 22 de fevereiro de 2021
Aceito: 9 de abril de 2022
Publicado: 22 de dezembro de 2022