Estimated energy use and CO2 emissions of a Philippine small-scale gold mine

*M.C. B. Cenia1), M.A.M. Tamayao\*2,3), V.J. Soriano1,2), M.K.C. Gotera4), B.P. Custodio2)*

*1)Environmental Engineering Program, National Graduate School of Engineering, University of the Philippines Diliman, Quezon City, Philippines, 1101*

*2) Department of Industrial Engineering and Operations Research, College of Engineering, University of the Philippines Diliman, Quezon City, Philippines, 1101*

*3) Energy Engineering Program, National Graduate School of Engineering, University of the Philipines Diliman, Quezon City, Philippines, 1101*

*4) Mineral Extraction and Refining for Sustainability (MINERS) Program Project G, College of Engineering, University of the Philipines Diliman, Quezon City, Philippines, 1101*

*\* mmtamayao@up.edu.ph*

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Introduction

80% of the Philippine’s annual gold supply is produced by small-scale gold mines (SSGM) employing amalgamation, cyanidation or combination of both. Gold requires significant amount of energy in its production mainly from direct use of fuels, or use of electricity that is produced through fossil fuel combustion (UNEP, 2013). Fuel combustion generates CO2, a major greenhouse gas that contributes to global warming. Global warming in turn causes climate to change, one of the top three environmental impacts of SSGM (Soriano, 2012). This study estimates the energy use and the CO2 emission per 100 g of Au produced of the different unit processes of an SSGM employing the combination method.

**Material and Methods**

Life Cycle Analysis principles were applied. Data on energy and labor inputs were gathered from an SSGM in Camarines Norte, Philippines. Unavailable data were either assumed, gathered from literature or from interview. Only energy directly associated with the stages in Table 1 were considered and include electricity use, combustion of fuel and calorie intake of laborers. Energy intake was factored in because SSGM operations are labor-intensive. Ore grade used is 15 g/ton and process yield is 91.6%. It is assumed that only gold is the product and no allocations were made. Embodied energy and emissions for material inputs were not included.

Energy use, *E* (*in Joules*), is given by Eq. 1. Eq. 2 was used in calculating energy use attributed to fuel, , where is the amount of fuel type used and is the energy density. Electric energy for equipment use, was determined using Eq. 3, where is the power rating of equipment *l* (in either *kW* or *hp*), is the unit conversion factor to *Joules*, is the operation time (in *hours*) of equipment *l* in unit process *j,* and is the assumed efficiency of the equipment. is the energy expenditure of laborers, where is the number of laborers in unit process *j*, c*m* is the metabolic equivalent (ACSM) of activity , , is the total labor time (in hours) in unit process *j,*  is the average weight of a Filipino man (in *kg*) (Murray, 2002), and is the conversion factor from kCal to *J* (see Eq. 4).

The CO2 emissions, , (in *kg CO2 /100g Au*) is the sum of the CO2 emissions due to direct fuel combustion and electricity consumption. It was assumed that all electricity used is from the Luzon-Visayas grid. Eq. 5 gives the emission estimation, where is the emission factor of fuel *k*, is the Luzon-Visayas grid electricity emission factor (in *kg* *CO2/kWh*), and is the conversion factor from *Joules* to *kWh*. The amount of gold per batch was obtained by using Eq. 6 where *o* is the amount of ore (*tons*) processed, *g* is the assumed average ore grade (*g Au/ton ore*) used in SSGM and *r*is the recovery rate. Lastly, aggregated energy use and CO2 emissions were divided by the amount of Au production and multiplied by 100 to bring values to the functional unit of *100g Au*.

(Eq. 1)

(Eq. 2)

(Eq. 3)

(Eq. 4)

(Eq. 5)

(Eq. 6)

**Results and Conclusions**

~3,501 MJ are need and ~398 kg CO2 are produced for every 100 g Au. The top three stages that necessitated the most energy are also the top 3 that emitted the largest amount of CO2 are mining, leaching, and milling as can be seen in Table 1. The mining stage required the most energy due to energy expenditure of laborers and electricity needed in operating the pump and compressor used. It is followed by the leaching stage wherein a motor is run for about 24-36 hours. Third highest energy user is the milling stage, which makes use of electric-powered rod mills. CO2 emissions are mainly attributed to electricity consumption of the equipment used in each stage.

**Table 1.** Energy use and CO2 emissions of the different stages of an SSGM using the combination method and their percent contribution to the whole process

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Stages** | **Energy Use (MJ/100 g Au)** | **Energy Use**  **%** | **CO2 emissions**  **(kg CO2 /100 g Au)** | **CO2 emissions**  **%** |
| Mining  Crushing  Milling  Blowtorching  Repulping  Leaching  Ashing  Smelting  Refining  Minting | 1,669  2  405  4  60  1041  14  83  20  204 | 48  <1  12  <1  2  30  <1  2  <1  6 | 129  -  67  <1  6  173  1  6  2  12 | 33  -  17  <1  1  44  <1  2  <1  3 |

Crushing has the least energy use and negligible emissions since in this stage no electrical equipment is required. The mined ores are pounded manually using a mallet before a more thorough size reduction is done in the milling process. Blowtorching, ashing and refining, also have minimal contribution to both energy use and CO2 emissions. In these four unit processes, only ashing makes use of an electrical equipment- a fan, which consumes little energy as compared to the equipment used in mining, leaching and milling.

Results reveal that the greatest contributor to energy use and CO2 emissions in an SSGM employing the combination method is the electricity consumption of equipment like motors, pump and compressors. These results can be used by small-scale gold miners who utilize the combination method in finding ways to reduce their energy use and emissions.

References

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