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Assessment of electricity carbon footprint and mitigation measures practiced in Benguet, Philippines: The case of Padcal Mining Project

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ABSTRACT. The study estimated the carbon dioxide equivalent (CO_2e) emissions from purchased electricity (Scope 2) of a mining project. It also identified the impacts of mitigation measures adopted on the amount of power consumed, savings on the cost of operations, and equivalent carbon emissions reduced. It demonstrated that there are strategies that can enable environmentally critical projects like mining to contribute to climate change mitigation. The project sourced its electricity from a coal power plant to supply its three major load centers, namely, mining operations, mill operations, and other loads. CO_2 emissions from electricity consumption were computed by multiplying the total electricity consumption with the emission factor of the power source. Using 2014 base data, the study found that the project has total electricity consumption of 279,897.85 MWh with an equivalent CO_2 emission of 238,400.85t. The bulk of electricity was supplied to mill operations (69%) while mining operations and other loads got 26% and 5%, respectively. Milling operations registered the highest emissions of 165,2018.64 tCO_2e followed by mine operations with 61,211.08 tCO_2e and other loads with 11,971.13 tCO_2e. To reduce its power consumption, the company implemented energy-saving measures which included power load shedding (PLS) and replacement of fluorescent with LED lamps similar to those used in industrial shops and offices. These schemes contributed a total annual reduction in power consumption amounting to 832.09 MWh equivalent to USD 117,417.77. This further resulted in 708.11 tCO_2e removed from the project's emissions in 2014, showing that the mining sector can also play an important role in climate change mitigation. In summary and as recommended, CO_2 emissions from electricity consumption can be reduced through energy conservation and by tapping into a power source with a low emission factor.

Keywords: CO_2e emission and reduction, energy-saving measures, LED lamps, Scope 2

INTRODUCTION

In 2020, the total global CO_2 emissions amounted to 30.6 Gt of which 142 Mt or 0.46% was accounted for by the Philippines. Ironically, the country bears much of the adverse impacts of changing climate brought about by elevated amounts of GHG in the atmosphere. Nevertheless, it intends to reduce GHG (CO_2e) emissions to about 30% by 2040 relative to its business as usual scenario of 2000–2030 as mentioned in its draft Nationally Determined Contributions (NDC) submitted to UNFCC.

The mining industry is one of the most economically important sectors, especially in developing countries. It is a major foreign exchange earner and it provides employment opportunities to thousands of people. However, it also causes various environmental problems such as landscape deterioration; air, land, and water pollution; as well as energy and resource depletion (Dubsok & Kittipongvises 2016; Peralta *et al*. (2016). In Australia, it is responsible for increased water consumption (Norgate & Haque 2010).

More importantly, mining operations produce greenhouse gas (GHG) emissions, contributing to global warming and climate change (Mudd 2010; Kittipongvises 2015; Dubsok & Kittipongvises 2016; Kittipongvises *et al*. 2016).

GHG emissions in mining are produced through intensive energy consumption operations requiring massive use of heavy equipment and facilities that need considerable amounts of electricity and fuel, particularly diesel (Mudd *et al*. 2012). Several authors cited factors that contribute to the increase in energy consumption in the mining sector, particularly in copper mining. These include declining grades of copper, greater hauling distances, changes in the commercial product portfolio, and technological change (Norgate & Haque 2010; Hunt 2009). Much of the energy consumed, which is about 97% of electricity, is used by the concentrating plants while 87% of fuel goes to mining facilities (Hunt 2009). Energy consumption and GHG emission in the mining industry are foreseen to increase significantly due to these factors. Hence, the mining industry is now under intense scrutiny to minimize its environmental impacts and reduce the amount of energy it consumes.

The Philippine Climate Change Commission (CCC) recognizes the significant role of the private sector, including the mining industry, as a partner in achieving the country's efforts to cut carbon emissions (CCC 2017). It enjoins the private companies to conduct GHG inventory and to report these at the organizational level in compliance with the NDCs that were identified as a signatory of the Paris Accord in 2017. It aims to pursue low-carbon development and to cut emissions in energy, transport, forestry, agriculture, industry, and waste sectors.

The initial (1994) and the second (2000) Philippine GHG inventory showed a similar trend of emissions from the non-LUCF sectors with the energy sector as the highest, followed by agriculture, industrial, and waste sectors. In comparison, between 1994 and 2000 emissions, the energy and waste sectors registered a 6% and 3% increase, respectively, while both agriculture and industrial sectors lowered emissions to about 4% (PINC 1999; PSNC 2000). The latest Philippine GHG emissions reported in 2012 were mainly shared by the energy sector (54%), agriculture (33%), industrial processes (8%), waste (7%), as well as land-use change and forestry (–1%) (WRI CAIT 2.0 2016). Within the energy sector, the main drivers of emissions were electricity and heat production (45%) followed by transportation. Electricity generation between 1990–2010 had tripled with the increased number of households (77%) accessing it. It was expected that the trend will continue to rise by 2017 with 99% of Filipino homes targetted to have an electric power supply (USAID 2016). It is based on this premise that the study focused on the electricity footprint of a mining project. It wanted to characterize the company's response to the government's call for the private sector to contribute to the reduction of emissions through a transparent GHG inventory and reporting mechanism. To meet these goals and minimize the impacts of mining operations, an accurate assessment of greenhouse gas emitting activities is necessary. Identifying these activities will also help us find ways to minimize, if not avoid its adverse consequences.

CO_2e emissions vary according to the amount of energy consumed at the different stages in mining operations. Most of the life cycle assessments of mining and mineral processing are lumped as a single process due to lack of publicly available data (Norgate & Haque 2010). This could also mean that most GHG accounting studies are generally applied to a single-stage emission without considering the detailed emission per activity or process within the mineral life cycle. Thus, there is a need to follow a step–by–step process of GHG accounting to come up with comprehensive results.

Like any other mining project, Padcal mine is highly dependent on energy in terms of fuel and electricity that are used to extract metallic minerals from ore bodies like copper, gold, and silver through the underground block caving method. This method requires heavy types of machinery and equipment to extract and process ores. The study sought to: a) estimate the carbon footprints with focus on the electricity consumption (Scope 2) of the company and b) determine the impacts of mitigation measures being practiced by the project on the amount of power consumed, operation cost, and equivalent carbon sequestered.

Moreover, determining the carbon flow among these potential carbon sources will help identify what specific process has high carbon emission. Thus, it could be a good basis to come up with strategies and approaches for sustainable and carbon-neutral or low-carbon mining activities.

METHODOLOGY

The study was conducted in 2015 using 2014 baseline data on electricity consumption. It carried out a detailed inventory of the carbon footprints of the project from electricity consumption covering the major mining and milling operations and its support services. Moreover, it estimated the equivalent amount of electricity saved and carbon emissions reduced/avoided, and cost discounted from operating expenses as affected by energy-saving measures including the shift from fluorescent lamps to light–emiting diode (LED) and the practice of streamlining the electricity consumption of staff houses. **Figure 1** describes the structure of the study reflecting the sources of emissions and the carbon offsetting measures applied, which will both determine whether the entire operation is carbon neutral or not in terms of electricity consumption.

In the IPCC (2006) categorization of CO_2e sources, mining activities primarily fall under the energy sector. Being

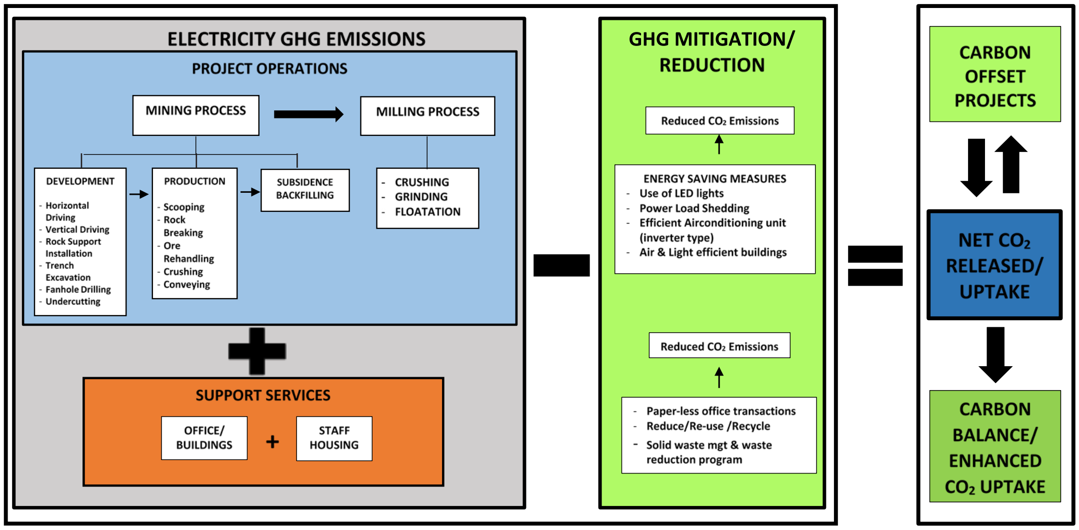

Figure 1. The framework of the study.

regarded as a top energy consumer, most of its emissions come from energy for the use of fuel and power for its operations. The study traced the potential sources of GHG discharges from each of these activities. Calculations were made on the attendant CO_2e released during the execution of these processes. It modeled the electricity consumed in its step–by–step process of production following a bottom-up approach of CO_2e emission accounting. It calculated the actual consumption of a specific activity chain in terms of electric power generation from extraction, processing, utilization, distribution, and domestic uses or support services with the end purpose of aggregating these activities into one whole project operation. This type of carbon accounting followed the "cradle–to–gate" concept for a thorough and reliable carbon emissions calculation. It utilized estimates of direct on-site fuel, power, and explosives consumptions plus the indirect emissions associated with the identified power supplier. Defining boundaries for the project emissions through the scoping process was also done to accurately delineate direct and indirect emission sources, improve transparency, and provide utility for different types of organizations and different types of climate policies and business goals. Scoping should be carefully defined to ensure that two or more companies will not account for emissions in the same scope or to avoid double counting (WRI & WBCSD 2004; DENR–EMB 2014). The scoping of sources of GHG emissions are the following: Scope 1 – fuel and fugitive emissions (direct); Scope 2 – purchased electricity (indirect); and Scope 3 – staff air travels, sold or rented electricity, LPG, and waste (indirect with third party participation). This study focused on Scope 2, which covers the indirect emissions of the project from purchased electricity. Scope 2 carbon emissions of the project were further classified into two major components: project operation and office and staff services carbon footprints with a separate inventory for each type. Project operation covers the production chain or processes including excavation, extraction, hauling, and processing. The support component included office buildings, facilities, and staff housing or domestic entity.

Project profile

Padcal Mine is one of the mining projects of Philex Mining Corporation that produces copper concentrates with copper, gold, and silver as by-products. Padcal began operations in 1958, initially through open-pit mining, later replaced by the Block Caving Method of underground mining.

It is situated at the southern tip of the Central Cordillera region which spans the municipalities of Tuba and Itogon in the Province of Benguet at 16°16′18" North latitude and 120°137′25" East longitude. **Figure 2** shows the location of the project site. It has a total mined area of 13,366.8436 ha with 52% (6,886.84 ha) covered by the Mineral Production Sharing Agreements (MPSA) and 48% (6,480 ha) under Exploration Permits (ExPA). Only 5% or 580 ha of the total area covering the mineral extraction site, mill, office, tailing facilities, residential and other industrial areas, is affected by mining activities (Philex–Padcal 2014). **Figure 3** shows the panoramic view of the site.

Calculation of electricity carbon footprints

Electricity is consumed both in the operations and support activities of the project. Data on electric consumption was based on the lump sum monthly consumption of the project on a per operation basis, *e.g.* mine, mill, and others. The total annual electricity consumption and the equivalent cost were derived out of the monthly consumption. Direct measurements of carbon emissions are ideally the most precise and accurate methods. However, due to the unavailability of some data, calculation methodology, which is widely used and recommended (Gao *et al*. 2013; CCC 2017) was used in the study. This method applies activity data and appropriate emission factors for each activity type based on the GHGs protocol. The basic formula for estimating carbon emissions (IPCC 1996), is:

Equation 1:

Electric CO2e (kg of CO2) = Electricity Consumption (kWh yr^{-1}) x (Emission Factor)

Padcal Mine mainly sources its power supply from the Sual Power Station in Pangasinan. It is a coal power plant owned and operated by the Tokyo Electric Power Company and Marubeni (TEaM Energy Corporation) Coal power has a computed emission factor of 0.851 t CO_2MWh^{-1} (Nagata 2012).

In the case of electricity sourced from the national grid, the emission factor used was based on the Department of Energy-computed operating margin emission factor as of 2009–2011 power statistics. The Luzon–Visayas power grid has an equivalent emission factor of 0.6032 t–CO_2 MWh^{-1} and the Mindanao grid, an emission factor of 0.2864 t–CO_2 MWh^{-1} (DOE Portal 2015).

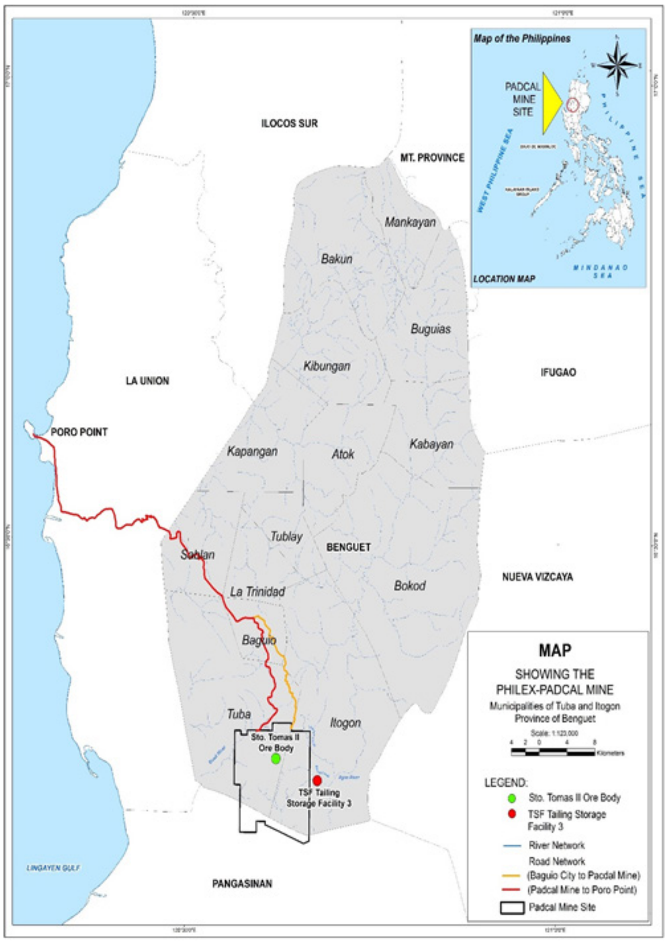

Figure 2. Location map of the Padcal Mine project.

Determination of amount saved in the operating cost and CO_2 emission reduction of energy-saving measures adopted by Padcal Mine

Power load shedding (PLS). The electric power requirement of the staff housing units is fully subsidized by the Padcal Mine company. Part of the austerity measures of the company is to reduce its energy consumption through PLS. Trial implementation of PLS at the Padcal Mine residential areas was introduced in late 2014. A 2.5–hr power cut-off in the staff housing was imposed daily every afternoon. The total amount of kWh of electricity saved was computed based on the equivalent kWh saved per day multiplied by 20 days of implementing the PLS per month. The benefit-cost analysis was computed based on the annual consumption saved using the formula below.

Equation 2:

Annual PLS power savings (kWh) = kWh saved day^{-1} (for 2.5 hrs.) x 20 days mo^{-1}. x 12 mo yr^{-1}

An estimate of the equivalent cost of the annual PLS kWh saved was derived by multiplying it with the cost per kWh which is PhP 6.35 (USD 0.14). Subsequently, the amount of CO_2 emissions that was reduced out of the PLS power savings was also computed using the formula below:

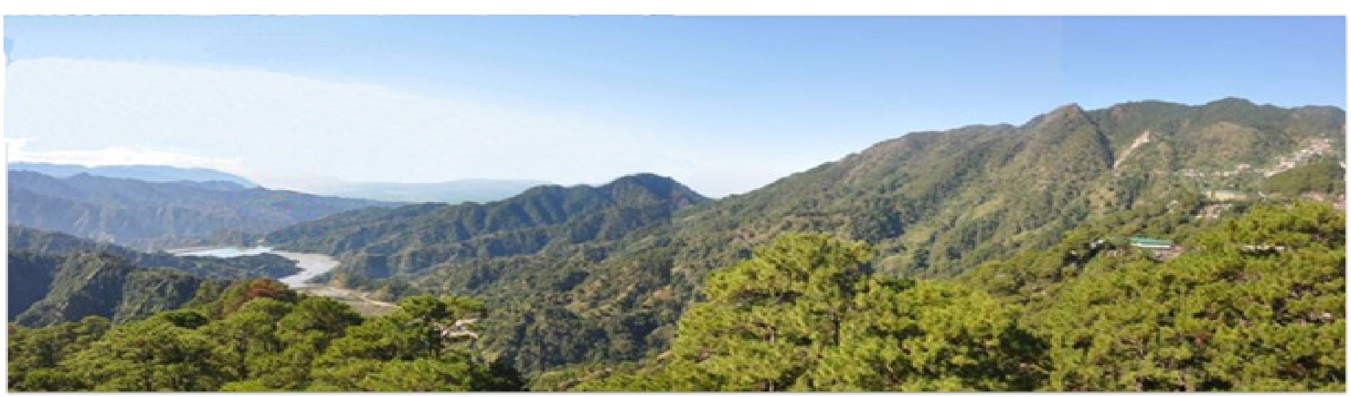

Figure 3. Panoramic view of the project site.

Equation 3:

$$CO_2e\ Removed\ (t) = Total\ annual\ PLS\ MWh\ saved\ x\ 0.851\ t\ CO_2 MWh^{-1}\ (EF)$$

Shift to energy efficient lighting system. The advantages of using technological advances in terms of lighting systems were based on the energy efficiency and life span of common light lamps (*i.e.* CFL, incandescent, and LED). The computation considered the kWh used and the purchasing cost per unit of the light lamp.

One of the limitations of the study is that it is only considered as a snapshot of the 2015 annual electricity of the company owing to limited time and resources available.

RESULTS AND DISCUSSION

Emissions from purchased electricity

The power supply of the project comes from a coal power plant owned and operated by TEaM Phil. Energy Corp. The electricity is distributed to three major load centers, categorized as mine, mill, and other loads. For 2014, the project had a total electricity consumption of 279,897.86 MWh with an average use of 23,324.82 MWh mo^{-1} (**Table 1**).

Table 1. Monthly electricity consumption of Philex–Padcal Mine in 2014.

Month	Electricity consumption (MWh)			Total (MWh)
	Mine operation	Mill operation	Other loads	
January	5,864.64	16,688.89	1,178.58	23,732.11
February	5,991.44	15,144.88	1,066.74	22,203.07
March	6,255.98	17,260.07	1,124.66	24,640.70
April	5,759.32	16,249.68	1,038.85	23,047.85
May	6,809.97	17,991.50	1,080.71	25,882.18
June	6,383.59	16,936.47	1,088.39	24,408.45
July	6,358.50	16,685.14	1,330.45	24,374.09
August	6,042.92	15,232.53	1,281.20	22,556.65
September	5,351.83	14,861.59	1,147.61	21,361.04
October	5,790.83	16,348.94	1,214.06	23,353.83
November	5,505.47	14,741.10	1,154.34	21,400.91
December	5,813.92	16,005.68	1,117.38	22,936.97
Total	71,928.41	194,146.47	13,822.98	279,897.86
Average	5,994.03	16,178.87	1,151.91	23,324.82

Mine operations. The mine operations primarily involved extracting the ore through the underground Block Caving method which applies caving, hole drilling, excavation, and undercutting processes. In 2014, this activity registered a total electricity consumption of 71,928.41 MWh. Electricity was used to operate the different activities and equipment like exhaust blowers, compressors, shaft hoist, upper level, batching plant, subsidence, bus totalizer, drive motor, auxiliary lighting, dump bin and shops, office, and the aggregate plant. The bulk of the power requirement went to the caving process and the compressors, ranging from 10,200–12,000 MWh. The rest of the activities utilized electricity during operations in the range of 75–9,030 MWh.

Mill operations. The mill operations involve the processing of extracted ore with filtered copper concentrates as its end product (**Figure 4**). It comprised more than half (69%) of the total power usage of the entire project with total electricity consumption of 194,146.47 MWh. This was expected as the bulk of the production and processing of ore of the project is lodged at the Mill division. The power supply that went into mill operations was supplied mainly to the three stages of crushing plant: primary, secondary, and tertiary crushing. It also includes the grinding section, ball mill auxiliaries and pumps (floatation and copper filter), compressor, gold recovery, and the tailing ponds 2 and 3.

Figure 4. The milling process.

The electricity usage during the mill processes was further categorized into mill concentrator, loading of tailings into tailing ponds 2 & 3, and the raw drill storage shops. **Table 2** shows that 191,611.89 MWh or 99% of the power supply was used up by the mill concentrator activities and only 1% was used for dumping of tailings, and partly, for storage of raw concentrates.

Table 2. Electricity consumption under mill operations.

Mill major load	Electricity consumed (MWh)	Percent
Mill concentrator activities	191,611.89	99
Tailings pond No. 2 & 3	2,164.89	1
Raw/Diamond drill shop/ storage 1,2, & 3	369.69	0
Total	194,146.47	100

Among the mill concentrator activities starting from primary crushing to gold recovery, grinding using ball mills has the highest power consumption equivalent to 60% of the total electricity used, followed by flotation and copper filter activities at 24%. The remaining 16% was divided among secondary/tertiary crushing (7%), pumping (5%), primary crushing plant and compressor (both 2%), flotation plant (1%), and very minimal or zero percent for gold recovery.

Other load centers. Other power loads of the mine site included units or service centers like administration and office buildings, laboratories, corehouse, warehouses, water pumps, motor pools, residential buildings, hospitals, and power plant auxiliaries. These loading units registered a total power consumption of 13,822.98 MWh. **Table 3** summarizes the major load units under this category. Among the power units, residential buildings topped the list with 9,435.88 MWh which used about 67% of the total power supply.

Table 3. Electricity consumption of major loading units under other loads category.

Loading unit	Electricity consumption (MWh)
Motorpool	195.13
Domestic water supply	3,464.25
Residential building	9,435.88
Hospital building	56.83
Assay metallurgy/corehouse	321.73
Power plant auxiliaries	42.51
Administration compound	306.65
Total	13,822.98

This was followed by running the water pumping stations which utilized a total of 3,464.25 MWh of electricity or 25% of the total power supply. The remaining units used 8% of the total electricity supply ranging from 42.51 to 321.80 MWh. The power plant auxiliaries used the least power. **Figure 5** shows the percent usage per loading unit.

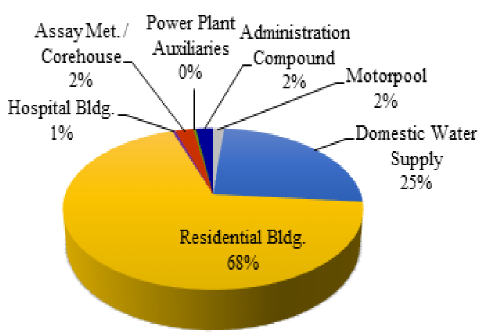

Figure 5. Percent share of electricity usage per unit.

Total GHG emissions from electricity consumption

The company taps its power supply from a coal power plant which has a computed emission factor of 0.851 tCO_2 MWh^{-1}. Using the emission factor of 0.851 tCO_2 MWh^{-1}, the entire Padcal Mine operation was found to have a total CO_2 electricity footprint of 238,400.85 t. Out of this, 165,218.64 tCO_2 was released during mill operations. The mine operation has a total electricity CO_2 emission of 61,211.08 t while the other loads have a CO_2 equivalent of 11,971.13 t (**Table 4**).

Table 4. Equivalent CO_2 emissions of electricity per source.

Center/Unit	2014 Electricity consumption (MWh)	Total CO_2 emissions (t)
Mill operations	194,146.47	165,218.64
Mine operations	71,928.41	61,211.08
Other loads	14,067.13	11,971.13
Total	280,142.01	238,400.85

Figure 6 displays a graphical presentation of the equivalent amount and percent CO_2 releases of each source. It shows that mill operations shared 69% of the total emissions while 26% and 5% were emitted by mine operations and other load centers, respectively. The graph further illustrates that the mill operation is the largest carbon emitter among the three major load centers in the study. This result corroborates Norgate & Haque's (2010) study on Australian copper ore processing which found that crushing and grinding under mill operations has the largest contribution of about 47% of the total GHG emissions to produce copper concentrate.

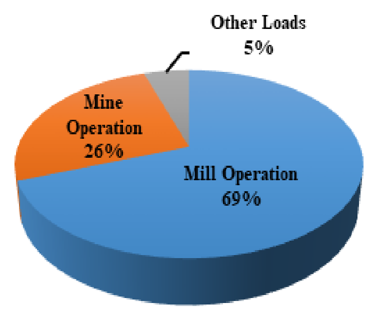

Figure 6. Graph showing the percent emission per carbon source.

Similarly, the result of the study, particularly under mill operation, falls within the range cited by Kittipongvises *et al*. (2016) from two separate studies of Yahaya *et al*. (2012) and Kittipongvises (2015) that utilization of electricity for crushing and grinding processes for gold mining ranges from 50 to 80%. Norgate & Haque (2010), Yahaya *et al*. (2012), and Boyan & Peter (2014) concluded that the use of electricity in the mineral processing and mining operation was the largest contributor to total carbon emissions. In the overall assessment, the type of energy source was identified as the major contributing factor that resulted in a higher emission rate. Among energy sources, electricity taken from coal plants has the highest equivalent emission factor compared to other sources. The carbon footprint of electricity used in the process depends on the energy source or power generation which could be coal, diesel, or natural gas (for an off-grid generator), hydro, or other renewables, (Mudd *et al*. 2012). A study on the energy consumption and GHG emissions in the Chilean Copper Mining Industry found that there was a 37% increase in emision of Sistema

Interconectado del Norte Grande (SING) grid alone, from 696.0 tons CO_2 in 2004 to 952.5 tons CO_2 in 2008. This development was due to changes in the energy mix used by the grid from natural gas which has a lower unit GHG emission footprint to electricity generated from or a combination of coal and pet coke. A similar trend happened to the Central Interconnected System (SIC) grid wherein thermal generation source was increased to offset lower hydroelectric generation, which resulted in 31% CO_2 emissions increase of unit grid emissions in 2008 (Hunt 2009). Thailand's mining of limestone and basalt rock reported indirect emission from grid-electricity (Scope 2) ranging from 34 to 40%, ranking it next to fuel (Scope 1), particularly diesel (Dubsok & Kittipongvises 2016). Piskernik (2014) mentioned the case of Austria's sole copper refinery, the Brixlegg Copper Refinery in Brixlegg whose energy requirements are entirely supplied by hydroelectric power (three small hydroelectric power stations: Alpbach, Reith, and Alpsteg as well as TIWAG a big hydroelectric power plant). This means that no carbon dioxide is emitted due to the type of energy source which has zero emissions factor. Mudd *et al*. (2012) further claimed that the switch to renewable energy can have a profound impact on the carbon intensity of copper supply and the total conversion to renewable energy. It will enable the copper industry to meet its goal of annual reduction of GHG emissions. Mudd *et al*. (2012), concluded that mining, milling, and smelting are responsible for a major portion of copper mining carbon footprint. The study even presented the percent share of their CO_2 contributions, combining the mine and mill operations, which resulted in 65% and 27%, respectively, of the total emissions. In the case of Padcal Mine, since smelting is not part of the process, almost all of the emissions were from the mine and mill operations. CO_2 released by Padcal Mine was further enhanced due to its use of coal as an electricity source which has a higher carbon footprint. Mudd *et al*. (2012) further stated that electricity used during the mining stage through open cuts typically consumes more electricity than the underground method. This implies that the energy footprint of Padcal Mine would have been higher if the company had employed open-cut mining. With the project adopting the underground block caving method since the beginning of its operation, it has minimized its emissions.

Valuation of costs and CO_2e reduction potential of energy-saving measures

Power load shedding. In 2014, Padcal Mine conducted a trial implementation of power load shedding (PLS) in the residential areas to reduce its electricity consumption. Based on data, the residential area is the highest consumer of electricity under the other load category. Through PLS, the management imposed a daily power shut down of 2.5 hr at the housing units. This resulted in electricity savings of 1.93 MWh day^{-1} or USD 272.92 at USD 0.14 kWh^{-1}. A 1–yr implementation of this scheme using an average of 20 effective days mo^{-1} resulted in a reduction of 464.17 MWh. This is equivalent to USD 65,500.17 cost savings for the company. The total MWh cut would be further interpreted into its CO_2 equivalent which would amount to about 395.01t of CO_2 removed from its annual emissions through PLS scheme. **Table 5** shows the detailed computation of PLS energy savings.

Table 5. Energy (kWh/MWh) saved, cost, and CO_2e emissions avoided from PLS.

kWh saved for 1 Yr				
Hour day^{-1}	Days mo^{-1}	kWh saved day^{-1} @ 2.5 hr. day^{-1}	kWh saved for 1 mo	kWh saved for 1 yr
2.50	20.00	1,934.06	38,681.20	464,174.40
Cost saved for 1 Yr @ USD 0.14 kWh				
kWh saved for 1 yr		Price kWh^{-1}	Cost saved for 1 yr.	
464,174.40		0.14	USD 65,500.17	
Equivalent CO_2 emissions discounted				
kWh saved for 1 yr			Equivalent MWh	
464,174.40			464.1744	
Emission factor (tCO_2 MWh^{-1})				
MWh saved per yr		EF (tCO_2 MWh^{-1})	Total CO_2 emissions avoided (t)	
464.1744		0.851	395.01 t	

Conversion rate: 1 USD = PhP 45.00 (2015)

Enhancing energy efficiency of office lighting system. Another energy savings measure that the project ventured into was the shift from fluorescent lamps to LED lamps. The project purchased 3,000 units of LED lamps with a total cost of USD 66,666.67. Each of the lighting lamps used had the following specifications (**Table 6**).

Table 6. Specifications of the fluorescent lamp versus LED lamp.

	Flourescent lamp	LED lamp
Power	40W with additional 18W for ballast	16W
Life span	10,000 hrs = 417 days	40,000 hrs = 1,667 days

Comparing the energy efficiency of the two lighting units, LED lamps gave the project an additional energy savings of 367.92 MWh yr^{-1}. This is equivalent to a total savings of USD 51,917.60 annually or USD 237,114.08 within the life span of the LED lamp. From the total MWh reduction from using the LED lamps per year, the amount of CO_2 emissions that was prevented was computed at 313.10 t yr^{-1}. **Table 7** demonstrates the detailed computation for the total annual energy and equivalent peso savings in terms of electricity consumption with the shift to LED lamps.

Table 7. Computation for total energy and cost saved per year of the Padcal Mine project.

Energy consumption of a 40W flourescent lamp (with additional 18W consumption of its ballast) for an ave. of 8 hrs used day^{-1}		
Energy consumed lamp^{-1} day^{-1}		
kWh consumed lamp^{-1}	Use of lamp day^{-1}	Energy used lamp^{-1} day^{-1}
0.058 kWh	8 hrs.	0.464 kWh lamp^{-1}
Total energy consumed by 3,000 units of a fluorescent lamp (kWh)		
No. of lamps	Energy consumed lamp^{-1}	Total energy consumed
3,000	0.464	1,392 kWh
Energy consumption of 16W LED lamp at 8 hrs day^{-1}		
Energy consumed LED lamp^{-1} day^{-1}		
kWh consumed lamp^{-1}	Use of lamp day^{-1}	Energy used LED lamp^{-1} day^{-1}
0.016 kWh	8 hrs.	0.128 kWh lamp^{-1} day^{-1}
Total energy consumed by 3,000 units of LED lamp (kWh)		
No. of lamps	Energy consumed lamp^{-1} day^{-1}	Total energy consumed day^{-1}
3000	0.128	384 kWh day^{-1}
Energy savings by replacing 40W flourescent lamp with 16W LED lamp		
Total energy saved (kWh) day^{-1}		
Total energy used by fluorescent lamps day^{-1}	Total energy used by LED Lamps day^{-1}	Total energy saved
1,392.00	384.00	1,008.00 kWh day^{-1}
		367,920.00 kWh year^{-1}
Cost of energy saved at USD 0.14 kWh^{-1}		
Cost USD kWh^{-1}	Total energy saved day^{-1}	Cost of energy saved
0.14	1,008.00	142.24 day^{-1}
Savings per year and for the life span of LED		
Total days of the year	Total cost of energy saved day^{-1}	Amount saved year^{-1}
365	142.24	USD 51,917.60
Life span of LED	Amount saved year^{-1}	Amount saved within the life span of LED
1,667 days or 4.567 yrs	USD 51,917.60	USD 237,114.08

Conversion rate: 1 USD = PhP 45.00 (2015)

Summary of energy costs saved and CO_2e emissions reduced from energy-saving measures

Table 8 summarizes the yearly estimates of electricity saved, savings in operating expenses, and the equivalent CO_2 emissions reduction out of the energy efficiency schemes initially introduced by the project in its operations beginning in 2015. The results imply that a total of 832.09 MWh was deducted from the overall electricity consumption of Padcal Mine with an equivalent savings of USD 117,417.77 annually from its electricity bill. Similarly, a 708.11 t of CO_2 was removed from the amount of CO_2 emitted per year thereby increasing the project's total CO_2 uptake per year from its potential C sinks.

Table 8. Summary of energy saving, cost, and CO_2 emission reduced from PLS and conversion of the lighting system.

Energy-saving measures	Energy saved (MWh yr^{-1})	Cost saved (USD yr^{-1})	Equivalent CO_2e removed (t CO_2e yr^{-1})
Power load shedding	464.17	65,500.17	395.01
Lighting shift: fluorescent to LED lamp	367.920	51,917.60	313.10
Total	832.09	117,417.77	708.11

Conversion rate: 1 US D = PhP 45.00 (2015)

CONCLUSION AND RECOMMENDATIONS

GHG emission of a mining project is integral in its operations. Specifically, mining is one of the top energy consumers because it uses heavy types of machinery and equipment that require high energy inputs. The increased energy requirement of the mining industry leads to significant GHG emissions. Similarly, it also entails higher waste production due to increased intensity of operation. Furthermore, the type of energy source also determines the carbon emission potential based on the equivalent emission factor and GWP of the source. The Padcal Mine, in particular, has high emissions due to huge power consumption mainly to run its massive and heavy equipment. Specifically, its power consumption comprised the bulk of the total project CO_2e emissions, which is about 89%. The increased emission was mainly attributed to the project's electricity source from coal which has the highest computed emission factor among the various power sources.
Given this many power inputs that translate to high production cost and carbon intensity, the company realized the need to adopt mitigation measures. These measures, power shedding in residential areas, and the replacement of fluorescent lamps with LED lamps proved beneficial to address the problems. Combining these two mitigating measures showed that the project will benefit from a total of 832.09 MWh that will be deducted from its overall electricity

consumption with an equivalent savings of USD 117,417.77 taken off its electricity bill. Similarly, 708.11 t of CO_2 will be added to the net amount of CO_2 sequestered by the project per year. It is also important to highlight the major contribution of replacing fluorescent/incandescent lamps with LED lamps, which gave a total savings of USD 51,917.60 annually or USD 237,114.08 within the five-year life span of the LED lamp. These interventions not only contribute to a decrease in energy consumption coupled with reduced emissions but also afford considerable savings in the operating expenses of the project based on its computed cost. Hence, these technological measures explored by the project to lessen its energy inputs could be expanded and fully implemented. These measures could also be applied to other areas such as the housing units within the Padcal Mine community given the positive results. The company could also explore other mitigating measures that will reduce power consumption particularly in the milling process, which had proven to be a major consumer of electricity. Norgate & Haque (2010) identified high pressure grinding rolls and stirred mills as new emerging technologies that can contribute to energy savings. Furthermore, proper maintenance of these facilities and equipment will maximize equipment life and thus, sustain production efficiency, in turn reducing capital and operation costs. As Peralta *et al*. (2016) pointed out, ensuring equipment reliability would help reduce energy consumption and emissions. Moreover, sourcing electricity from power sources with lower emission factors such as hydroelectric and LNG–fired power plants could significantly increase the electrical efficiency and reduce the CO_2 emissions of the company.

Management-wise, balanced accounting of both the CO_2 emission and mitigation aspects of the project enabled the study to trace sources or activities within the mining operations that have high CO_2 emissions. These data inputs could serve as a planning tool on approaches to further reduce its emissions while enhancing its carbon sink potentials. Emission sources with high CO_2 contribution could readily be identified in the model. Hence, specific measures could be adopted to curb a particular carbon-emitting activity. This is exemplified by the high emission rates from the energy source of the project. The study showed that cutting half of its emission will redound to a net CO_2 uptake instead of net emission. This can be achieved if the project will use a renewable energy source that has zero emission factor. The project could consider adopting the proposal of Mudd *et al*. (2012) for a solar thermal with biodiesel as the best energy solution for sustainable mining. The use of their model showed about a 99% reduction in annual GHG emissions and intensity. The study further demonstrates that the destructive effects of mining on the environment can be minimized by adopting advances in technology and changes in management techniques. It was reported that mining companies have the potential to save about 61% of their energy consumption by improving the energy efficiency of mining and mineral processing technologies (US-DOE 2007). Mining companies like Padcal Mine are exerting efforts to reduce the environmental impacts of mining and minimize the carbon footprint of their activities throughout the mining cycle. These are beneficial not only to the mining company itself but also to the environment and surrounding communities, as well. The role of the government and the entire citizenry as guided by relevant policies and regulations will also serve as control measures to minimize or avoid these negative impacts. Compliance with these requirements is even highly reinforced in the environmental impact statement policy. Furthermore, mining or mineral processing can become more environmentally sustainable by developing and integrating practices that reduce adverse impacts (Dubsok & Kittipongvises 2016) like GHG emissions from mining operations. These practices include reducing water and energy consumption, minimizing land surface disturbances and waste production, preventing soil, water, and air pollution in mine sites, and conduct of successful mine closure and reclamation activities. Moreover, the use of zero or carbon-neutral technologies (*e.g.*, renewable energy sources) will significantly reduce carbon emissions.

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