

Feasibility of Applying Clean Development Mechanism and GHGs Emission Reductions in the Gold Mining Industry: A Case of Thailand

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Abstract – There is presently overwhelming scientific consensus that global climate change is indeed occurring, and that human activities are the primary driver. An increasingly resource and carbon constrained world will continue to pose formidable challenges to major industries, including mining. Understanding the implications of climate change mitigation for the mining industry, however, remains limited. This paper presents the results of a feasibility study on the implementation of a clean development mechanism and greenhouse gases (GHGs) emission reductions in the gold mining industry. It draws upon and extends the analysis of a case study conducted on gold mining operations in Thailand. The results from the case study indicated that total GHGs emissions by company A were approximately 36,886 tons carbon dioxide equivalents (tCO₂e) per annual gold production capacity that meet the eligibility criteria for small-scaled clean development mechanism (CDM) projects. The electrostatic separation process was found to release the lowest amount of GHGs, whereas comminution (i.e. crushing and grinding) generated the highest GHGs emissions. By scope, the emission from purchased electricity (scope 2) is the most significant source. Opportunities for CDM projects implementation in the gold mining sector can be found in employing energy efficiency measures. Through innovation, some technical efficiency and technological development in gold processing (i.e. high pressure grinding rolls (HPGR), vertical roller mills (VRM), gravity pre-concentration and microwave heating technologies) that have the potential to reduce energy use and also lower carbon footprint of the gold mining were further discussed. The evidence reviews found that HPGR and VRM abatement technologies have shown energy and climate benefits as electricity savings and CO₂ reduction of about 8–25.93 kWh/ton ore processed and 1.8–26.66 kgCO₂/ton ore processed, respectively. Implications for further research and practice were finally raised.

Keywords – CDM; GHGs emission reductions; gold mining industry; Thailand

1. INTRODUCTION

Global climate change poses a fundamental threat to sustainable development and human security in the 21st century. One major cause is anthropogenic emissions that cause a rapid increase in the atmospheric concentrations of greenhouse gases (GHGs), resulting in negative impacts on both environmental and socio-economic development [1]. From a mitigation perspective, there have been several efforts made by international partnerships to reduce or remove collective GHGs emissions under the Kyoto Protocol, including emission trading (ET), joint implementation (JI) and the clean development mechanism (CDM). Under emission trading, a country with more emission rights than it anticipates using can trade this surplus to countries that would otherwise exceed their permitted amounts. As noted, this trading of emissions is limited only to Annex I or

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industrialized countries. Under joint implementation and the clean development mechanism, an investor invests in an emission-reduction project abroad, emissions reductions are verified and in exchange for the investment, the project investor receives carbon credits (e.g., emissions reduction units for JI and certified emission reductions for CDM). Thus, the project can emit the total of its allowance under the protocol [2], [3]. In this context, the difference between JI and CDM is that the host country of the project is a developed country for JI and a developing country for CDM. Overview of the CDM's current status in Thailand is further illustrated.

An industry sector is an important source of emissions from both energy uses and industrial processes [4]. By way of explanation, industry-related GHG emissions have continued to increase and are higher than emissions from other end-use sectors. Globally, emissions are dominated by a developing region, in this case Asia, which was the region with faster GHG emissions growth between 2005 and 2010 [5]. In Thailand [6], mineral production (2A mineral products) is the largest source of GHG emissions in industrial processes (accounting for 97.9% in 2000). The International Council of Mining and Metals has recognized the particular impacts of GHGs as the most concerning environmental issue, without a doubt, to face the mining industry [7]. By combining these insights, mining management is definitely needed to reduce point sources of pollution, specifically GHG emissions that contribute to global climate change. However, implementation of mitigation activities by the mining industry has lagged behind its perceived potential. The purpose of this study was to explore the feasibility of applying CDM and GHG emission reduction in the gold mining industry in Thailand. Reviews of the literature on current status of CDM projects in Thailand, gold mineral resources of Thailand and the emissions of GHGs from industrial production process are firstly provided.

1.1. Current Situation of CDM in Thailand

CDM was principally created with the dual goals of achieving GHG emission reduction targets and promoting sustainable development in host countries [2]. As a non-Annex I member country, the Thailand Greenhouse Gas Management Organization (TGO) was established in 2007 to be responsible for sustainable development in Thailand through CDM activities. As of October 2013, Thailand has implemented about 221 CDM projects that have been issued a Letter of Approval (LoA) by the TGO, with expected average annual carbon credits of about twelve million tons carbon dioxide equivalent (tCO_2e). Among these projects, about 148 projects were registered by the CDM Executive Board (CDM EB) and 35 of these have received carbon credits issued by CDM EB [8]. Most registered CDM projects in Thailand are implemented through either biogas or biomass energy generation, as depicted in Fig. 1.

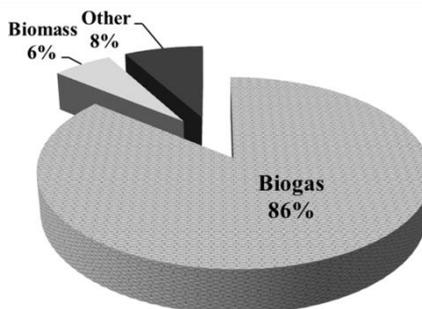


Fig. 1. Number of CDM projects registered in Thailand in 2013.

1.2. Eligible CDM Project Activities

CDM project activities must result in reducing GHGs that are real and measurable and would not have occurred in the absence of the proposed project activities. The eligible criteria for CDM projects are: (i) CDM project activities must be developed only through voluntary action, (ii) CDM projects must promote sustainable development in host countries, (iii) CDM projects are subject to stakeholder consultations and initial assessment of environmental impacts created by the project activities, (iv) CDM project activities must meet the “additionality” requirements, in terms of finance, technology and environmental aspects, and (v) all the processes of CDM projects must be transparent, efficient and accountable, under independent auditing and verification. Possible types of CDM project activities depend on the sectoral scope, as summarized in Table 1.

TABLE 1. POSSIBLE TYPES OF CDM PROJECT ACTIVITIES [9]

Scope	Project activities
1 Energy Industries	Coal switching to natural gas Solar PV, wind power, hydro, biomass, geothermal, etc.
2 Energy Distribution	Electric power transmission and distribution
3 Energy Demand	High efficiency energy equipment
4 Manufacturing Industries	Waste heat recovery, clean coal technology, high efficiency energy equipment
5 Chemical Industries	Industrial gas abatement
6 Construction	Metal substitution, energy saving
7 Transport	Improved the energy efficiency of vehicles
8 Mining/Mineral Production	Fuel substitution (i.e., clean coal technology), improved efficiency of process
9 Metal Production	Fuel substitution (i.e., clean coal technology), improved efficiency of process
10 Fuel Substitution	
11 Fugitive Emissions from Combustion	Gas recovery and utilization
12 Solvent Use	Material substitution
13 Waste Handling and Disposal	Waste-to-energy systems (i.e., wastewater treatment and landfill gas recovery)
14 Afforestation	Afforestation and reforestation
15 Agriculture	Avoidance of methane emission from biomass decay

1.3. Mineral and Gold Resources of Thailand

The mining and quarrying sector of Thailand was important in the country’s economy [10]. Acknowledging this fact, the mineral royalty revenues of Thailand in the fiscal year of 2013 was approximately 3,089.2 million baht (91.70 million USD). In 2013, limestone, lignite, gold, gypsum, and silver were the five most valuable minerals produced in Thailand (Fig. 2). Of this, gold royalty revenues of Thailand were approximately 597.5 million baht (17.74 million USD) in 2013 [11].

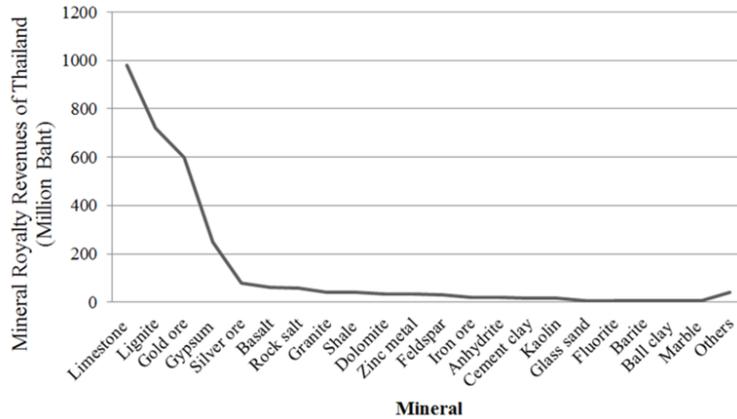


Fig. 2. Mineral royalty revenues of Thailand in 2013.

1.4. GHGs Emissions From Industrial Production Process

As a part of its Second National Communication to the UN Framework Convention on Climate Change [12], in 2000, Thailand’s net CO₂ emissions were 229.08 Tg CO₂eq. The energy sector was the largest contributor at about 69.6 %, followed by the agricultural sector at 22.6 %. The remaining proportion was shared among industry and waste management. In terms of the industrial sector, most of the emissions were from mineral production processes, as illustrated in Fig. 3.

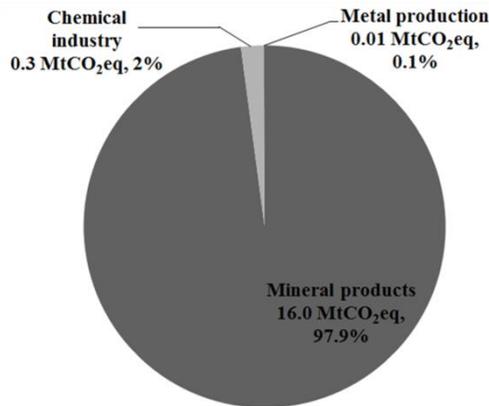


Fig. 3. Thailand’s GHG emissions in 2000, by the industrial sector.

2. MATERIALS AND METHODS

2.1. Case Study

This paper extends the analysis of a case study that examined gold mining operations in Thailand. Company A, located in the northern region of Thailand approximately 280 kilometres north of Bangkok was selected as a key case.

2.2. Method for GHGs Quantification in the Industry Sector

Generally, there are several methods that can be used to quantify GHG emissions from industrial sources. The appropriate calculation method to use mainly depends on available activity data, suitable emission factors (EF) and also assumptions made. According to [13], [14], the GHG emissions generated by an organization can be classified into three scopes (Table 2):

TABLE 2. THREE-SCOPES OF GHGS EMISSIONS

<i>Scope 1</i> (<i>Direct emissions</i>)	Emissions are direct GHG emissions from sources that are owned by the entity. For instance, emissions from fossil fuels burned on-site (stationary emission), emissions from entity-owned vehicles (mobile emission), etc.
<i>Scope 2</i> (<i>Indirect emissions</i>)	Emissions are indirect GHG emissions resulting from purchased electricity, heat, or steam consumed but not directly generated by the entity.
<i>Scope 3</i> (<i>Indirect emissions</i>)	Emissions include indirect GHG emissions from sources not owned or directly controlled by the entity but related to the entity's activities. For instance, employee commuting contracted solid waste disposal and wastewater treatment, etc.

Note: Only scope 1 and 2 are defined for GHGs accounting in this study.

Further to this, regarding to the guidance manual for estimating GHG emissions [14], [15], the calculation of GHGs from the potential sources can be done by the following approach:

(i) *Direct emissions from mobile combustion source*

Equation 1 can be used to estimate the amount of direct emissions related to on-site mobile combustion activities.

$$\text{Emissions (tCO}_{2e}) = \text{Quantity of fuel combusted}_{ab} \cdot \text{EF} \quad (1)$$

where a – fuel type; b – vehicle type

(ii) *Direct emissions from non-combustion activities* (e.g., industrial processes)

In the mining industry, these emissions can be quantified using the mass of explosives and appropriate EF of the explosive type. For an explosive mixture, as ANFO (ammonium nitrate/fuel oil), a CO₂ EF of 0.189 ton of CO₂ per ton of ANFO can be used to assess the GHG emission [16].

(iii) *Indirect emissions from electricity purchased*

Equation 2 can be used to estimate the amount of indirect emissions related to the consumption of purchased electricity from the grid.

$$\text{Emissions (tCO}_{2e}) = \text{Quantity of electricity purchased from the grid (kWh)} \cdot \text{EF} \quad (2)$$

All EFs used in this study derived from Thailand Greenhouse Gas Management Organization (TGO). These data were calculated based on a one-year inventory period.

3. RESULTS AND DISCUSSION

3.1. Gold Mine ore Processing of the Company A

Gold company A is a conventional open-pit mining enterprise. Gold at the mine, on this basis, is extracted from an open pit (C-H pit) that uses a stripping process to uncover the reef layer-by-layer. The main rock types at the C-H pit are classified as andesitic lithic breccia, plagioclase-pyroxene-porphyrific andesite and crystal-lithic breccia units, which are overlain by laterite and alluvial deposit. Annual gold production is roughly 2,500,000 tons per annum of ore. Altogether, the process of producing gold can be divided into 5–6 main phases (see Fig. 4):

Site development: After finding the orebody (exploration), there are several activities that will help facilitate the development of the mining site, including preparing the site for production by mine shaft sinking or pit excavation, constructing facilities and building mine access roads.

Drilling and blasting: Drilling and blasting are usually necessary to break the orebody, prior to mining. Gold ore is then mined using large diesel hydraulic excavators, loading a combination of 20- and 35-ton haul trucks.

Digging up and transport: After breaking the orebody, the broken material from mining face is consequently transported to the concentrator or processing plant using haul trucks.

Crushing and grinding: Crushing and grinding are done to break the ore up into particles as small as the grain size of the desired mineral component. This is undertaken by a combination of multi-stage crushing and milling circuits with associated classification and screening processes. Company A's processing plant consists of a single stage crusher followed by a two-stage grinding circuit comprising a semi-autogenous grinding (SAG mill) and ball mill. Orebody is fed into the SAG mill along with water and steel balls. The grinding process reduces the ore particles to slurry that is fine enough (<75 micrometers) to pass through the primary and secondary cyclone.

Magnetic separation: After crushing and grinding, the slurry then moves through a series of carbon adsorption tanks. Gold is recovered by gravity force using a centrifugal concentrator followed by an intensive leach reactor where a sodium solution is added. Company A, the leach ore circuit comprises 12 tanks, 11 of which contain carbon to recover gold in solution. The tank provides sufficient retention time (12–20 hours) to allow the gold to be dissolved by cyanide. Accordingly, carbon is fed into the circuit in the opposite direction to the slurry flow, moving from the last tank to the first. Most of the precious metals have then been removed by the time slurry reaches the final tank. Pregnant eluate (the washed solution) is then passed through a series of electro-winning cells. The barren slurry, called tailing, is either pumped to the Tailings Storage Facility (TSF) or treated to neutralize or recovery the cyanide.

Electrostatic separation: After magnetic separation, pregnant eluate solution is passed through electrowinning cells, containing a set of cathodes (negative electrodes) in the form of stainless steel plates. Gold attaches itself to the stainless steel cathodes. The cathodes are then removed and rinsed to yield a muddy sludge before reuse. Muddy sludge is then dried and put into the furnace at high temperature and, after several hours (16–20 hours), the molten material is poured into a cascade of molds to produce gold bars called “doré bars”.

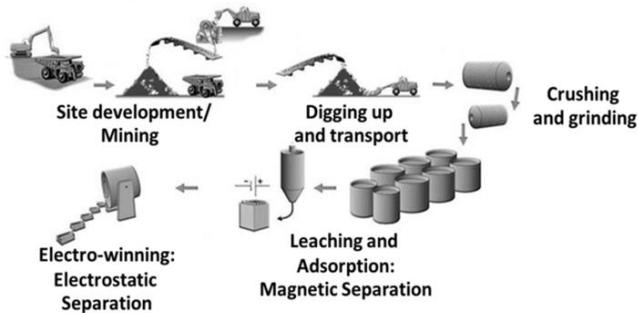


Fig. 4. Flow diagram of gold ore processing (Modified from [17]).

3.2. GHG Emissions of Gold Production

Identification of emission sources.

Theoretically, GHG emissions can be calculated as the quantity of substance going in and out of an entire facility and process of gold production per annum (Fig. 5). As noted, scope 1 (see Table 2) covers direct GHG emissions from sources owned by the Company A (e.g. the amount of diesel fuel consumed and the amount of chemical used in gold production process). Scope 2 covers indirect emissions of GHGs from the purchase of electricity from the grid.

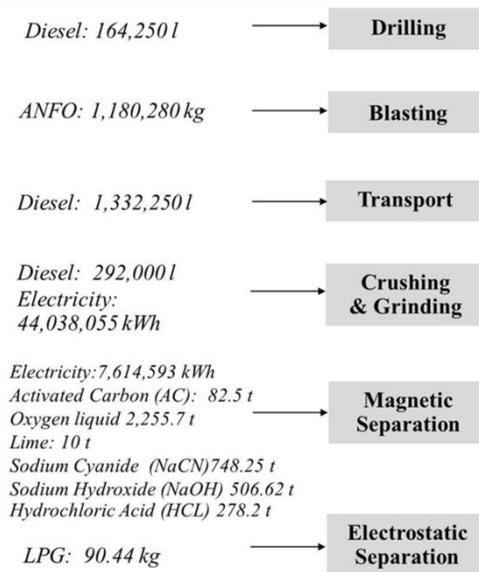


Fig. 5. Potential sources of emissions in each process of the company A [18].

Quantification of GHGs emission.

EFs (kgCO₂eq per unit) issued by [16], [19], [20] were used to estimate emissions of GHGs by Equations 1 and 2. As a result, total GHG emissions from both direct and indirect sources were approximately 36,886 tCO₂e per annual gold production capacity. Comminution (i.e. crushing and

grinding) process releases the highest GHG emissions (26,387 tCO_{2e} per annual production capacity), whereas the electrostatic separation process generates the lowest emissions (281 tCO_{2e} per annual gold production capacity) (Table 3). These findings are in line with a study conducted by [21] found that crushing and grinding processes make the largest contribution (about 47 %) to the GHGs emissions for the copper mine production.

TABLE 3. GHGS EMISSIONS OF GOLD PRODUCTION PROCESS OF THE COMPANY A

Production processes	Scope 1: Direct emissions			Scope 2: Indirect emissions			Net CO _{2e} emission (direct and indirect; kgCO _{2e})
	Energy and chemical used (unit)	EF (kgCO _{2eq} per unit)	CO ₂ emission (kgCO _{2e})	Electricity consumed	EF (kgCO _{2eq} per unit)	CO _{2e} emission (kgCO _{2e})	
Drilling	Diesel: 164,250 (l)	2.7446	450,800	–	–	–	450,800
Blasting	ANFO: 1,180 (t)	0.189	223,073	–	–	–	223,073
Transport	Diesel: 1,332,250 (l)	2.7446	3,656,493	–	–	–	3,656,493
Crushing & grinding	Diesel: 292,000 (l)	2.7446	801,423	Electricity: 44,038,055 (kWh)	0.581	25,586,109	26,387,532
	AC: 82.5 (t)	N/A	–				
	Oxygen liquid: 2,255,000 (kg)	0.4690	1,057,923				
	Lime: 10,000 (kg)	0.7820	7,820	Electricity: 7,614,593 (kWh)	0.581	4,424,078	6,168,495
Magnetic separation	NaCN: 74,825,000 (kg)	N/A	–				
	NaOH: (kg)	1.1148	564,779				
	HCL: 2,782,000 (kg)	0.4094	113,895				
Electrostatic separation	LPG: 90.44 (kg)	3.1131	281	–	–	–	281
Total			6,876,487	Total		30,010,187	36,886,674

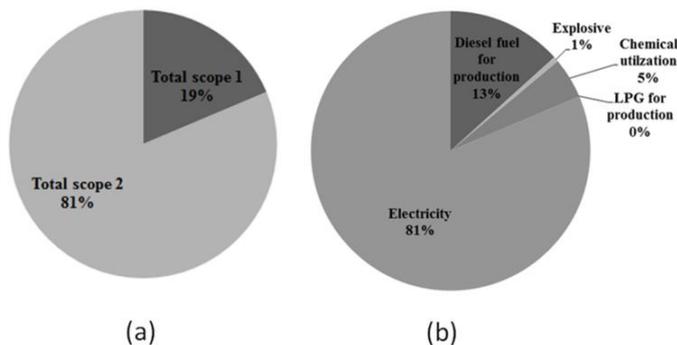


Fig. 6. GHG emissions by scope and main sources.

Furthermore, the distribution of GHG emissions by scopes clearly indicates that the emissions from scope 2 are the most significant source (Fig. 6a). Other emissions from used explosives and materials production are very small compared to emissions from electricity (Fig. 6b). This result is consistent with previous studies [22]–[24] that the combustion of fossil fuels to generate electricity is the largest source of CO₂ emissions. Of these, more than 50 % of total electricity was used for crushing and grinding processes [25]. In comparison with other mines, [18] found that GHG emissions from lignite and limestone mining in Thailand were approximately 571,539 and 20,878 tCO₂e per annual production capacity, respectively.

3.3. Feasibility of Applying CDM and GHG Reduction Technologies to the Gold Mining Industry

Small-scale CDM projects, basically, include those which reduce less than 60,000 tCO₂e in emission reductions per year, renewable energy project activities with a maximum output capacity equivalent of up to 15 megawatts or energy efficiency improvement projects reducing energy consumption by up to 60 gigawatt hour (GWh) per year (both at supply and demand side) [26]. Therefore, it is possible for Company A to apply a small-scale CDM project, because total GHG emissions were about 36,886 tCO₂e per annual gold production capacity (<60,000 tCO₂e). With the highest CO₂ emissions, comminution and magnetic separation present a significant opportunity for the application of a CDM project in gold mining. GHG emissions are mainly associated with electricity use and chemical reactions during gold production. As a general concept, opportunities for CDM projects in the gold mining sector can be found in employing energy efficiency measures, fuel switching, generating electricity from renewable energy sources and improving the efficiency of the magnetic separation procedure. By way of illustration, [24] reported that small-scale CDM project involves switching fuel from coal to cleaner fuels and renewable energy. Currently, as part of the gold extraction process, geothermal power station was constructed to supplement the existing facilities with renewable energy. The project reduced GHG emissions, energy costs as it improved the reliability of the power supply [27].

To addressing environmental and climate change problems, there are a number of technological developments occurring in the mining and mineral processing that have shown the potential to minimize resource utilization, particularly, reduce their electricity consumption and carbon footprint [28]. US Department of Energy [29] also reported that the metals and mining industry in the US has the potential to reduce energy consumption by about 61 % from current state to the best-estimated practical minimum energy consumption. Table 4 shows the potential energy savings for the various states of mining and mineral processing over their entire life cycle.

TABLE 4. POTENTIAL ENERGY SAVINGS FOR THE MINING AND MINERAL PROCESSING LIFE CYCLE (MODIFIED FROM [29])

Stage	Potential energy savings	
	MJ/t ore	%
Drilling	1.2	43
Blasting	6.7	59
Loading and hauling	45.7	52
Crushing and grinding	157.4	71

It can be seen from Table 4 that the comminution (i.e. crushing and grinding) process offers the greatest opportunity for energy savings per ton of ore processed [21]. Some of the emerging technologies that could contribute to energy saving for those processing stages are described below:

High pressure grinding rolls (HPGR) technology

Electricity consumption in crushing and grinding processes of gold production, as noted earlier, made the greatest contribution to the GHG footprint. HPGR, a very efficient in terms of energy savings, presents the general idea that applying high pressure to a bed of particles may bring environmental gains regarding energy efficiency (60–80 percent) and gold recovery (70–80 percent) (Table 5) [30], [31]. This technology has been considered for metalliferous minerals, such as iron, copper and gold [32]. In gold mining, the applications of HPGR technology are: (i) replacing crushing and grinding stages, (ii) replacing AG/SAG grinding aiming at increased capacity and lower energy consumption.

TABLE 5. PERCENTAGE OF GOLD RECOVERY FROM CONVENTIONAL COMMUNITION AND HPGR [23]

Particle size P80 (µm)	Conventional		HPGR	
	Residue (g/t)	Gold recovery (%)	Residue (g/t)	Gold recovery (%)
4000	0.10	79.0	0.22	57.9
425	0.12	78.3	0.17	69.0
325	0.11	2.1	0.13	73.1

Vertical roller mills (VRM) technology

Vertical roller mills are an energy-efficient alternative to conventional grinding technology in the mining industry. Energy saving of about 6–7 kWh/t-raw materials are assumed through the installation of VRM technology [33]. On the greenhouse gas front, [34] reported that CO₂ emissions can be reduced by 7.9 to 19 kg/t-cement capacity and 8.1 to 19.4 kg/t-cement capacity with the use of this technology in China and India, respectively.

Gravity pre-concentration method

Norgate & Haque [22] argued that although gravity concentration is not a new technique, recent studies on development of equipment type (i.e., inline pressure jigs, the Knelson and Falcon centrifugal separators [35]) have been used for pre-concentration of gold ores for conventional carbon adsorption. The aim of this approach is to maximize the recovery of the liberation of the gold-bearing minerals at coarse particle sizes, thereby reducing energy requirements for comminution and also increasing gold recovery.

Microwave heating technology

To improve the efficiency of conventional grinding which is the most energy-intensive step in gold processing, microwave heating technique can be used to induce thermal-stress cracking to decrease energy requirements of the grinding process. A study done by [36] found that over 95 % ore extraction was achieved within 12 hours as against 22 hours for non-microwave samples. This technique could therefore lead to a decrease in the greenhouse footprint of gold ore mining [22].

Table 6 compares energy savings and CO₂ emission reduction potential for each abatement technology, especially for the grinding process in the mining and mineral industry (i.e. cement production). Both HPGR and VRM have shown energy and climate benefits as electricity savings and CO₂ reduction of about 8–25.93 kWh/ton ore processed and 1.8–26.66 kgCO₂/ ton ore processed, respectively [37]–[39]. Whereas, use of gravity system in preparation of raw material

made only a small contribution to the overall energy conservation and CO₂ reduction, amounting to 2.64 kWh/ton ore processed and 1.37 kgCO₂/ ton ore processed, respectively [37]. Eventually, due to limited number of studies available, these findings emphasize the need to focus on energy efficient technology as a low carbon development in the mining sector, especially gold mining.

TABLE 6. CO₂ REDUCTION POTENTIALS AND ENERGY SAVINGS IN THE GRINDING PROCESS

Energy savings measures	Energy savings (kWh/t ore processed*)	CO ₂ emission reduction (both direct and indirect sources; kgCO ₂ /t ore processed*)	Reference
	16	8.30	[37]
HPGR technology	24.41	25.09	[38]
	8-28	1.8–6.3	[39]
VRM technology	17	8.82	[37]
	25.93	26.66	[38]
Use of gravity system for material preparation	2.64	1.37	[37]

*ton clinker

4. CONCLUSIONS AND IMPLICATIONS

Reducing GHG emissions arising from human activities is central to achieving a low-carbon society and restricting average global temperature increases. To the extent possible, the mining industry is endeavoring to find opportunities to develop technologies to achieve the sustainability goals [40]. CDM is one of the flexibility mechanisms that offers emission reduction projects which generate carbon credit (or certified emission reduction units) that may be traded in emission trading schemes and used to meet mandatory obligations under the Kyoto Protocol. In Thailand, the implications for climate change mitigation projects in the mining industry, however, remain limited.

This paper explores the feasibility of CDM implementation and GHG emission reductions in the gold mining industry. The results found that comminution- the grinding and crushing of gold ore is the most significant source of GHG emissions and also the most energy intensive step in gold mining. Potentially, there are four technologies to reduce energy consumption and also CO₂ emissions: i) HPGR, ii) VRM, iii) gravity pre-concentration, and iv) microwave heating technology. Meanwhile, the results of this study demonstrated that small-scale CDM project activities are very viable for the gold industry.

Recommendations for all relevant stakeholders and possible directions for further study were raised as follows: (a) Apart from the deployment of biogas and biomass projects, Thai authorities should consider the opportunities for expanding CDM projects into the mining industry; (b) Relevant provincial and central government agencies should provide adequate financial and human resources support for the implementation of climate change mitigation projects in the mining sector. Both actions and support would need to be Measurable, Reportable and Verifiable (MRV); (c) In the cost benefit analysis, it is important to carefully consider both GHG emission reduction potential and its abatement costs (i.e. estimation of CO₂ abatement cost curve; ACC). For instance, [37] found that, by using a bottom-up ACC as the analytical tool, the cost effective annual CO₂ abatement for the cement industry in Thailand during the 15-year scenario period (2010–2025) is approximately 3,095 ktonnes CO₂/year. Additionally, carbon trading information should also be accessible for all project developers; (d) Raising awareness of community partners and fostering cooperation across public and private sectors in responding to climate change, by

reducing GHG emissions and enhancing its sinks and reservoirs, could be important; (e) To expand implementation of CDM projects in Thailand, it is necessary to build mechanisms and promote better coordination between the private and public sectors to facilitate private investment in GHG emissions reduction projects i.e. Emission Trading Scheme [41], [42]. Further research and development on the concept of carbon capture and sequestration (CCS) technologies [43]–[47], Life Cycle Assessment (LCA) studies [48] and GHG mitigation associated with mining and mineral processing is urgently needed.

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