Journal of Public Affairs and Development
Vol. 10 No. 1: 79–107 (2023), ISSN 2718-9228

Moving towards sustainable mining communities: The case of the Community-led Non-Cyanide Non-Mercury Gold Extraction Method (CLINN-GEM) in Compostela Valley, Philippines

Rowee Joy S. Decena[1]

ABSTRACT. The small-scale mining industry and communities are left behind in terms of development. They are confronted with economic, environmental, and social problems. Thus, to address these problems and move towards sustainable development, this social development research explores how CLINN-GEM, as a technological innovation, contributes to achieving sustainable mining communities. The researcher employs a single case study approach and adopts qualitative methods in data gathering and analysis. Data gathering methods include document reviews, guided tour, key informant interviews with seven informants, focus group discussions with the operations group and the members of the project staff, and a structured learning exercise with community leaders. The results show that CLINN-GEM technology is a synthesis and systematized articulation of local knowledge on mineral processing that aims to address the adverse impacts of mineral processing using traditional hazardous and low-end technologies in small-scale mining. As a technological innovation, it subscribes to the principles of responsible and sustainable mining, green mining, clean technology, and end-pipe technology. CLINN-GEM brought about several changes in the physical, knowledge, and social realms of small-scale mineral processing. Likewise, use of this technology has resulted in many changes in the economic, social, and environmental conditions of the community. Despite these changes, optimization of CLINN-GEM remains the primary challenge. Therefore, it is recommended that the stakeholders continue research and development efforts to address recovery issues to optimize the technology. Once optimized, policy review and subsequent amendments to the *People Small-Scale Mining Act of 1991* and the *Implementing Rules and Regulations of Republic Act No. 7076* shall be conducted to institutionalize these reforms.

Keywords: *CLINN-GEM, mining technology, sustainable mining communities*

---

[1]Davao de Oro State College, Compostela, Davao de Oro, Philippines
https://orcid.org/0000-0002-8895-4110
rj_subong@yahoo.com

INTRODUCTION

Mining as a global industry is often located in remote, ecologically sensitive, and less developed areas that include many indigenous land and territories. If properly managed, it can create jobs, spur innovation, and attract investments and infrastructure at game-changing scales over long periods. Otherwise, it leads to various challenges such as environmental degradation, displaced populations, inequality, and increased conflict (Sonesson et al., 2016).

The Philippines is one of the highly mineralized countries in the world, with 9 million ha considered to have high mineral potential (Senate Economic Planning Office, 2013). It also ranks 18th in the world production of gold (Mines and Geosciences Bureau, 2019). The country has a long mining history from the colonial to the current neo-liberal regime. Gold is mined by large and artisanal/small-scale miners. Artisanal or small-scale mining (ASM) is considered equally significant as large-scale mining (LSM) because of its contribution to gold production and rural employment (International Labour Organization (ILO), 1999]. In the first to third quarter of 2019, the gross production value of small scale mining is PhP 0.4 billion (Mines and Geosciences Bureau, 2019). Small-scale gold miners are estimated to number about 500,000 with some 1 million people relying on the income generated by the industry (Alexopoulos, 2014). The Alternate Forum for Research in Mindanao (2012) noted that the small-scale miners were operating in 30 provinces across the country.

Despite its contributions and potentials, the small-scale mining industry and the small-scale miners are left behind in terms of economic, social and environmental development. Small-scale mining is confronted with the issue of informality. Formalization efforts often focus on property-like mining claims and awarding of licenses to those with mining titles, which excludes the majority of small-scale miners. These efforts deprive the small-scale miners of their entitlements and rights. Moreover, small-scale mining is confronted with several issues resulting from low technology, poor practices, processing, and marketing or geo-prospecting (Hentschel et al., 2003; Hilson & Pardie, 2006).

Hilson and Pardie (2006) explain that low technology and poor geo-prospecting result in low recovery and productivity for operators, which, in turn, also lead to low income for small-scale miners, who remain unskilled laborers with no capacity to invest. Damage to the environment and deterioration of health and quality of life are additional consequences.

Open pit and tunneling or rock mineral extraction that use mercury, cyanide, and other hazardous chemicals have exposed small-scale miners to health and occupational problems (Asirot, 2000; Colina, 2008; Decena et al., 2016) while their communities suffer from the pollution of rivers and the destruction of agricultural lands, mangroves and coral reefs (Baggo, 2015; Doyle et al., 2007). These conditions exacerbate poverty, which compel small-scale miners to further exploit limited resources. This cycle continues and results in what is called the "poverty trap" (Hilson & Pardie, 2006).

The economic, environmental, and social problems cited in the literature reveal the unsustainable practices of small-scale mining in the country. The challenges faced by the mining sector have led to several innovations in policy and technology including the signing of Executive Order 79 in 2012, which underscores environmental protection in mining and use of mineral resources (Official Gazette, 2012). Along with this is the campaign to develop alternative technologies through research and development. In 2015, the University of the Philippines Department of Mining Metallurgical and Materials Engineering (UP DMMME) and the Department of Science and Technology (DOST) through the BetterMine Program of the Environment and Infrastructure track of the Engineering Research and Development for Technology (ERDT) developed the Community-led Integrated Non-Cyanide, Non-Mercury Gold Extraction Method (CLINN – GEM) technology as an alternative method to amalgamation and cyanidation in the recovery of gold (DOST Region XI, 2015). These also led to establishing the Integrated Gold-Copper Mineral Processing Pilot Plant in 1) Sitio Basil, Barangay Gumatdang, Itogon, Benguet in Cordillera Administrative Region (CAR); 2) Barangay Sta. Rosa Norte, Jose Panganiban, Camarines Norte (Bicol); 3) Barangay Del Pilar, Cabadbaran City, Agusan Del Norte (CARAGA); and 4) Barangay Katipunan, Nabunturan, Compostela Valley (Davao Region).

The goal to address environmental problems and move toward long-term sustainable development in mining communities is a significant challenge globally (Dubinski, 2013). However, most recent publications related to mining and sustainability still focus on the environmental dimension of mining (Mesquita et al., 2017). To date, there remains a dearth of empirical research documenting the sustainability of small-scale mining and how innovative systems and strategies can promote sustainable development. Thus, this study aims to describe and compare the traditional and the Community-led Integrated Non-Cyanide Non-Mercury Gold Extraction Method (CLINN-GEM) mineral processing practices, describe the features of CLINN-GEM as mining technological innovation, identify changes brought about by CLINN-GEM and its contributions to achieving sustainable mining communities, and identify lessons, theoretical constructs, and policy recommendations that can be used in understanding technology innovations for sustainable development.

METHODOLOGY

This study aimed to provide general characteristics and establish patterns in understanding the technological innovations in small-scale mining communities. Considering that the study was exploratory and descriptive, the researcher employed a single case study approach. This approach is heuristic – a term for self-guided learning that employs analysis to help conclude the situation (Ellet, 2007). Yin (2014, p. 19) stated a two-fold technical definition of a case study: 1) an empirical inquiry that makes an in-depth investigation of a contemporary phenomenon with real -life context, especially when the boundaries between phenomenon and case context are not evident, and 2) an inquiry that copes with a technically distinctive situation where there are more variables of interest than data points. It relies on multiple sources of evidence, with data needing convergence in a triangulating fashion prior to the development of theoretical propositions to guide data collection and analysis.

Thus, in essence, the two-fold definition of how case study research comprises an all-encompassing method – covering the logic of design, data collection techniques, and specific approaches to data analysis, justify its appropriateness and application in this study. Moreover, a case study was used to explain the presumed causal links in real-life interventions. It was used to illustrate specific topics under investigation and enlighten situations as well as to describe an intervention and the real-life context in which it occurred. Lastly, a case study was used because it allows detailed process tracing and exploration of patterns, which are essential for investigating transition phenomena.

The study adopted qualitative methods in data gathering and analysis. Data gathering and analysis were divided into three interrelated phases: preparatory, data gathering, and data analysis. Multiple data-gathering methods were used in each of these phases. The research participants were the stakeholders of the community selected through criterion sampling. The respondents include small-scale miners, local government officials, members of different community organizations, especially those who initiated and implemented the field-testing project, and community members. The criteria in selecting the research participants were: 1) knowledge of the research topic; 2) availability during data gathering period; 3) willingness to participate in the study; 4) for residents, representation of the different sectors of the community; 5) for miners, direct or indirect involvement in mining activities in the community; and 6) for representatives of the PMC, at least a year's experience in the project. There were seven key informants, 11 FGD participants, and 29 participatory rapid appraisal participants.

RESULTS AND DISCUSSION

Traditional and the CLINN-GEM Mineral Processing Practices Compared

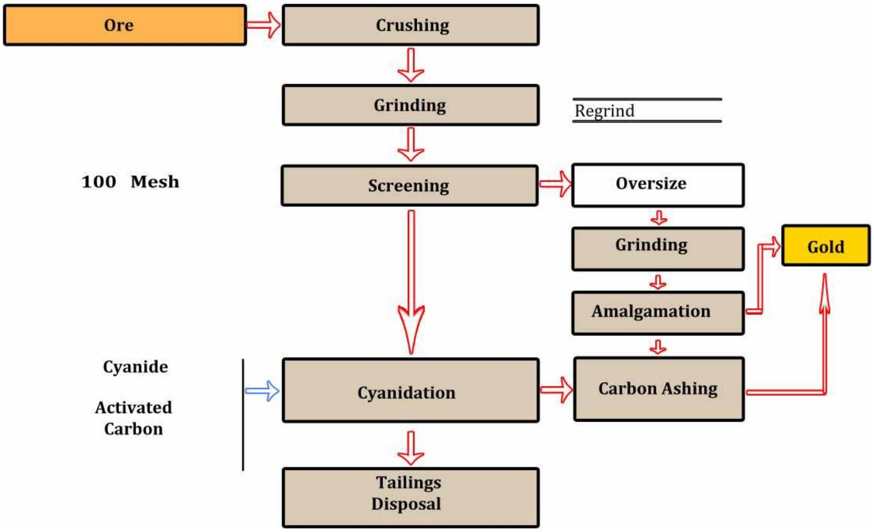
Traditional mineral processing technologies. The small-scale miners practice two gold extraction processes: extraction from primary and extraction from secondary deposits (Figure 1). Extraction from primary deposits means that the ore is taken directly from the rock, which is commonly known as "tunneling". Tunneling activities include exploration, assaying, drilling, sacking and mucking, timbering, dragging, and plooming (sluicing). On the other hand, extraction from secondary deposits means that the ore is found in sand and gravel in rivers and torrents, and this is also known as free – gold or "Margaha." When miners

Figure 1
A miner extracting gold from the rocks (tunneling) (left) and a miner positioning for panning (mariming) (right)
(Source: Decena et al., 2016)

start their operation in the tunnels, others take their position along the river and start panning also known as "mariming". In this process, miners separate carbon-filled rocks (darker gray in color) from the usual rock (Decena et al., 2016).

With regards to mineral processing, Figure 2 shows the process flow of traditional mineral processing technologies including amalgamation and cyanidation. Fresh ore is crushed using a jaw crusher prior to grinding in several batches. Batch grinding in the traditional process uses a rod mill. Crushing and grinding of ore is done in 54.75 hours and in several batches. Samples are collected for every batch discharge from the rod mill. Regrinding of coarse particles from sluicing is also conducted to further liberate gold values from the ore.

Figure 2
Traditional process flow



Remaining coarse particles obtained from the screen used after re-grinding is collected. The collected oversized ore, approximately 100 kg, are fed to a small ball mill with mercury to form amalgams of gold. After grinding, the amalgam is collected, and excess mercury squeezed out. The amalgam is directly fired resulting in a gold bead. Mine tailings are collected and processed using cyanidation in carbon-in-pulp (CIP) mineral processing plant.

The slurry from grinding is loaded into a leaching tank to undergo cyanidation. The cyanidation process takes more than 3 days. On the third day, loaded activated carbon is harvested and subjected to ashing and smelting to extract the gold. Gold extraction takes 144.63 hours or a little over 6 operating days. The bulk of operating time is attributed to the leaching process that lasts for more than 3 days. The tailings are disposed in tailings pond, which will later on be released in rivers, creeks, and other bodies of water.

The CLINN- GEM technology. The CLINN-GEM technology is a systematic articulation of the small-scale miners' mineral processing methods. It is anchored on gravity and flotation techniques, which are commonly used by the small-scale miners. It was developed by UP DMMME in response to the call of providing alternative technology for small-scale miners, which uses environmentally friendly and non-hazardous methods of gold and/or copper extraction (Gamba, 2019).

CLINN-GEM technology was developed through Copper Flotation Technology for Small Scale Mining Project and Alternative Methods to Amalgamation and Cyanidation in the Recovery of Gold Project of the BetterMine Program of the ERDT. This technology is undergoing field-testing in Gold-Copper Integrated Mineral Processing Pilot Plants that were established in 1) Sitio Basil, Barangay Gumatdang, Itogon, Benguet (CAR; 2) Barangay Sta. Rosa Norte, Jose Panganiban, Camarines Norte (Bicol); 3) Barangay Del Pilar, Cabadbaran City, Agusan Del Norte (CARAGA); and 4) Barangay Katipunan, Nabunturan Compostela Valley (Davao). The field-testing projects were funded by the Department of Science and Technology – Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) with PhP 35,000,000 to PhP 40,000,000 (USD 628,366 to 718,132) as project cost for each site.

Aside from gold, CLINN-GEM can recover other valuable minerals such as silver, copper, lead, and zinc. The CLINN-GEM technology has six features: size reduction circuit (crushing and grinding), enhanced gravity concentration circuit, flotation circuit, hypochlorite leaching and staged precipitation circuit, tailings disposal and wastewater treatment facility, and analytical (fire assaying) laboratory. The features are described as follows:

1) Size reduction circuit (crushing and grinding) – The crushing circuit is comprised of a jaw crusher, vibrating screen, double roll crusher, and fine ore bin. Crushing is undertaken to reduce the size of the ores such that grinding can be carried out until the

minerals are liberated from the gangue. The grinding circuit is comprised of a ball mill and a hydrocyclone. With the use of a belt feeder, crushed ore from the fine ore bin is transported to the ball mill spout. Ball mills are used in the grinding of ores and other materials. The ball mill is in a closed circuit with a hydrocyclone, a piece of classification equipment that enables the separation of coarse and fine particles in the slurry.

2) Enhanced gravity concentration circuit – This circuit is composed of two types of gravity concentrator, the Falcon SB400 concentrator, and the shaking table. The Falcon SB400 concentrator is used for the recovery of valuable minerals, while the shaking table enables the separation of light and heavy minerals by using a flowing film of water and a table vibrating longitudinally.

3) Flotation circuit – This circuit uses self-aerating mechanical flotation cells and reagents such as collectors, frothers, and pH modifiers to separate valuable minerals from unwanted minerals (gangue).

4) Hypochlorite leaching and staged precipitation circuit – This circuit is comprised of leaching and precipitation tanks. The leaching tank is used for the chlorination process where sodium chloride, hypochlorite, and hydrochloric acid are added to the flotation concentrate. Gold and silver tanks are connected in a series. In the gold precipitation tank, sodium metabisulfite and ascorbic acid are added to produce a gold precipitate, which is then smelted using a surface with a working temperature of 600-700^{0}C. Meanwhile, the silver precipitation tank contains the clear liquid produced in the dewatering of gold and will be added with reagents to form a silver precipitate.

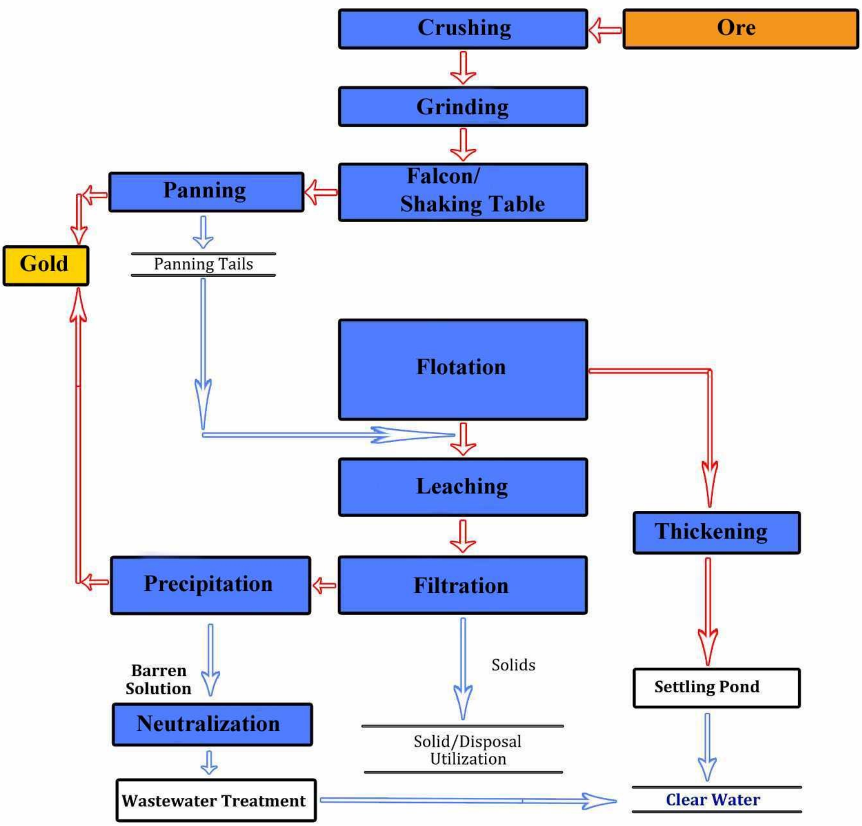
5) Tailings disposal and wastewater treatment facility – The tailings disposal and wastewater treatment, also called tailings storage facility (TSF), is an essential feature of the pilot plant to protect the environment because it is where hazardous components from the tailings are removed before being discharged permanently. The TSF includes wastewater treatment with a tailing settling pond. The wastewater treatment compartment is where heavy metals are removed from wastewater generated in the extractive metallurgy area. The removal of heavy metals is by adsorption using coco peat and zeolite. The wastewater treatment compartment is divided into three sub-compartments to allow

treatment in three stages. The tailings pond allows solids to settle and produce clear water that can be discharged to the nearby river.

6) Analytical (fire assaying) laboratory – The laboratory area contains equipment for analytical tests. The oven, furnace, chipmunk crusher, and disc mill pulverizer are located inside the fire assaying room.

Meanwhile, Figure 3 shows the process flow of CLINN GEM. Fresh ore is loaded into the jaw crusher and roll crusher prior to grinding. The crushed ore is then loaded to the ball mill for grinding via a conveyor belt. The slurry coming from the grinding circuit is then pumped through the Falcon gravity concentrator. The concentrate coming from the Falcon concentrator is collected and concentrated using a shaking table.

Figure 3
CLINN-GEM process flow



At this stage, visible free gold is collected for direct firing. The operations for each section in the crushing-grinding-gravity concentration circuit may run simultaneously. The CLINN-GEM method can process the ore in approximately 12 hours.

The tailings from the gravity concentration are thickened before getting pumped into the flotation circuit in batches of 0.5 MT each. Flotation concentrates coming from the re-cleaner cells are collected and set aside until all flotation batches are completed. A mixture of calcium hypochlorite and sodium chloride is first fed into the oxidation/leaching tank.

The solution is mixed thoroughly to achieve homogeneity before adding it into the final flotation concentrate and shaking table middlings. After 4 hours, calcium hypochlorite replenishments are added and after 3 hours, the oxidation/leaching tank is emptied. The mixture goes to the Filter Press for dewatering. The pregnant solution, which contains the leached gold, is collected in the precipitation container via a launder. Sodium metabisulfite is added in the precipitation container to precipitate the gold. The solution is mixed thoroughly for at least 5 minutes. After this, ascorbic acid is added. The solution is again thoroughly mixed for at least 5 minutes and left for about 2 hours to overnight to precipitate the gold. After that, the solution is filtered using the Pressure Filter to separate the gold precipitates. Zn dust precipitation follows, and the entire process ends with filtration. The gold precipitates undergo purification using a blow torch to produce the final product – gold bead.

Lastly, one of the most important contributions of CLINN-GEM Technology, which is absent in traditional technologies, is the neutralization of wastewater. The solid residue is washed with water before discharging to the tailings settling pond. The washings and barren solution are placed in the neutralization tank to neutralize the pH before getting discharged to the wastewater treatment compartment. The solution flows through the coco peat-zeolite layer. The treated water at the bottom goes to a holding area (empty compartment). When this compartment is full, it overflows to the second compartment for the second stage of treatment. The treated water from the second stage proceeds to the third compartment and the final stage of treatment. The treated water from the third stage, together with the clear water, is discharged to the river.

Traditional and CLINN-GEM processes compared. The research participants agree that, in principle, CLINN-GEM has a semblance of traditional technologies, but has been modified to be more efficient and sustainable. Informant Gigi[2] (33 years old; Poblacion, Nabunturan) recalls,

> *"Although, in principle, they are almost the same, it [CLINN-GEM] offers something new."*

In a parallel testing conducted by UP Diliman and other stakeholders on August 6-14, 2018, the traditional mineral processing technologies and CLINN-GEM were evaluated based on the following criteria: operating cost; operating time; environmental/detoxification cost; and overall gold recovery (Table 1).

Table 1
Comparative results summary

Traditional Method	Parameters		CLINN-GEM
4.65	Total Ore Feed (dry metric ton or DMT)		4.65
11.44	Calculated Head Assay (gpt)		10.05
144.68	Operating Time (hours)		36
8,282.49	Operating Cost (PhP/DMT)		3,485.68
1,307.26	Environmental Cost		12.80
	Gold Recovered (grams)		
1.144	Amalgamation	Gravity Concentration	13.62
48	Cyanidation	Flotation	21.64

The results of the parallel testing showed that the traditional method takes about 1 week for the process to be completed while CLINN GEM can finish gold processing in just 2-3 days. The operating cost of the traditional method pegged at PhP 8,282.49 (USD 148.69) per metric ton of processed ore while the CLINN GEM costs only PhP 3,485.68 (USD 62.57) per metric ton. Although this costing for CLINN GEM is partial and only up to the flotation process, the significant difference in operating costs cannot be ignored. In terms of environmental cost, the neutralization of the barren solution after leaching and before discharge would only entail an additional cost of PhP 12.80 (USD 0.23) while implementation of the INCO process for the detoxification of cyanidation tailings used in the traditional method costs PhP 1,307.26 (USD 23.72) because of the reagents used during the process. This cost is on top of the additional detoxification tank equipped with agitators and air spargers needed for the process.

Lastly, the costs were determined during the pilot-testing phase where all machines and equipment were in good condition, therefore no maintenance cost was recorded.

With regards to gold recovery, using amalgamation, 1.144 g of gold was recovered while gravity concentration process recovered 13.62 g. Meanwhile, using cyanidation, 48 g of gold was recovered while flotation process recovered 21.64 g. It was calculated that the traditional method obtained 92.38% overall recovery of gold as compared to only 75.46% obtained by CLINN GEM. This was attributed to problems in ore variability, the higher consumption of cyanide, which is 10 times the normal consumption used in leaching and presence of lead (Pb) in the ore that acts as catalyst to the cyanidation process. This occurrence has brought about difficulties for the CLINN GEM that led to the suspension of the leaching process for further analysis.

Moreover, the research participants easily identified several similarities and differences of the technologies. Informant Jessie[2] (26 years old; Poblacion, Nabunturan) listed the following:

1) Free gold recovery

"They obtain similar results, for instance in amalgamation, they focus more on extracting free gold. In our gravity concentration process, we primarily extract free gold, this is like their equivalent process. With our CLINN-GEM Technology in gravity concentration, we extract free gold using a gravity concentrator and shaking table."

2) Equipment

"We have a similar mill to that, which is a ball mill, so instead of using a rod, we use steel balls."

"We also have tanks; although, in amalgamation, there are no tanks, the tanks used for leaching are the same. Basically, cyanidation is also known as leaching, but with the use of cyanide. In our case, leaching is done using chlorine and hypochlorite."

"Firstly, we have new machines, and they're ease of time (time-efficient) machines: gravity concentrators and shaking tables."

3) New processes

"So, what seems new is what we initially refer to as monitoring, where we observe the parameters because in the existing operations, they don't seem to have established technical parameters. For instance, when it comes to grinding, we monitor the percentage passing or the particle size. In amalgamation, they don't really measure the size. It's more about the time element only. So, what's different is that they have a pre-conceived knowledge, notion, or assumption that they should grind the ore for a specific amount of time. But for us, we base it on the actual product itself, if it doesn't meet the desired conditions/parameters, we don't move or receive it to the next level."

"Next, what seems new in CLINN-GEM Technology is the flotation process. That's something that wasn't present here in ComVal or wasn't practiced by small-scale miners before. So, that's the new knowledge that they will acquire, that is the flotation technology."

Other participants shared the following:

"The main difference is the chemicals being used here, which are different from theirs." (Jessie[2], 26 years old; Poblacion, Nabunturan)

"The [mineral process] plant has an available assay laboratory, in which those who are familiar with the process are only those who own assay lab here in ComVal. But now, this [technology] has been introduced, they've realized, especially the trainees, that this is the principle, this is how assaying process works." (Jessie[2], 26 years old; Poblacion, Nabunturan)

The research participants relate easily with the basic principles of the technology and identify some of the equipment. However, they are still trying to familiarize themselves with the new equipment and processes. Thus, new knowledge and skills are taught during capability building activities, observed, and practiced in the mineral processing plant to ensure that all project staff, employees, and members of the operations group acquire the same understanding of the CLINN-GEM technology.

CLINN-GEM Technology as Mining Technology Innovation

Innovation factors. Mining is an industry that the world can no longer rid itself of. The world's growing demand for and dependence on such mined metals as gold and copper to create countless objects has made mining indispensable. This, however, has also resulted in the destruction of the environment leading to adverse effects on people's health, economy, food security, personal, community, and political security.

The creation of the CLINN-GEM emanated from the desire to synthesize and systematize local knowledge on mineral processing methods and roll-out an alternative technology, which addresses the economic and environmental risks of hazardous and low-end technologies in mineral processing used by the small-scale miners. Specific considerations in creating the technology address the problems associated with hazardous and low-end technologies such as amalgamation and cyanidation processes to include: 1) low gold recovery; 2) high operating costs; 3) prolonged operating time; 4) environmental cost; and 5) limited and minimal mineral recovery.

Aside from the noble goal of articulating people's experience and giving back through technological innovation, CLINN-GEM was created for a number of innovation-related reasons identified by the International Institute for Sustainable Development (Crawford, 2018). These reasons are the need to improve the productivity of assets; reduce operational risks; strengthen mineral recovery rates; and, recover metals and minerals of higher quality and drive their growth. Meanwhile, the technology's primary considerations corroborate with the findings of Deloitte Africa Energy & Resources Leader (2016) and Echendu et al. (2011) who reveal that enhancing productivity and sustainability such as reducing the cost to operate and develop assets, reducing risks and promoting safety, and ensuring environmental sustainability are the highest impetus for technology innovations.

The nature of CLINN-GEM technology. The CLINN-GEM technology features resonate with several emerging concepts in mining. CLINN-GEM technology can be characterized as follows:

1) Green mining technology – Green mining refers to technologies, best-fit practices, and mine processes that are implemented as means to reduce environmental impacts associated with the extraction and processing of metals and minerals. Green mining technologies and practices offer superior performance in terms of energy efficiency, greenhouse gas emissions, and the use of

chemicals (Garrun, 2014). The field-testing of the integrated gold-copper mineral processing pilot plant showcases both CLINN-GEM technology and best-fit practices in mineral processing. The CLINN-GEM technology uses established methods like flotation and enhanced gravity concentration for gold recovery while pyrometallurgical and/or hydrometallurgical processes were applied to ensure non-hazardous extraction of gold. Likewise, the operation and management of the technology have been compliant with government requirements, occupational safety standards, and gender sensitivity principles in the operations.

2) Clean technology – Clean technology in chemical process industries means that the chemical reactions involved in producing the main product are modified (Yarime, 2003). With CLINN-GEM technology, gold is produced without using mercury and cyanide. CLINN-GEM technology uses non- and less hazardous chemicals such as Caustic Soda (NaOH), Concentrated Hydrochloric Acid (HCl), Sodium Hypochlorite (NaOCl), Calcium Hypochlorite (CaOCl), Sodium metabisulfite (SMBS), and Ascorbic acid (HASc) to prevent human and environmental hazards.

3) End pipe technology – End pipe technologies aim to reduce remaining wastes (Mulder, 2007). CLINN-GEM technology includes wastewater treatment by absorption using cocopeat. This process transforms wastewater with heavy metals back to its normal state.

Despite the technology not being optimized yet, it features copper and other minerals recovery that ensures resource efficiency and increased income. Its management also has plans to develop tailings or solid wastes into new products to achieve zero waste and augment the community's income.

The features of CLINN-GEM show different dimensions in its development. The results of the study reveal that CLINN-GEM technology is geared towards becoming a sustainable technology, which, according to Mulder (2007), has a far broader aim of enabling the needs of the whole of humanity to be fulfilled without exhausting the planet's non-renewable resources, exceeding its ecological recovery capacity, and consolidating or promoting inequity. Its emphasis on safety, community, and resource efficiency is linked to the sustainable mining framework (Australian Centre for Sustainable Mining Practices, 2011). It also adheres to the green mining concept, which promotes materials and energy efficiency, ensures the availability of mineral resources for the future, reduces adverse environmental and social impacts, improves work and organizational practices, and sustains land use (Nurmi, 2017). Lastly, because CLINN-GEM makes environmental, economic, and social considerations, its introduction to the community is tantamount to the introduction of responsible mining, the fundamental tenets of which are economic growth, environmental protection, and social development (Abao, 2019).

The technology shows that it is conscious of integrating the principles of sustainable, responsible, and green mining through mineral processing.

New knowledge in small-scale mineral processing through CLINN-GEM. CLINN-GEM is commonly known as an alternative process of extracting gold from ores using flotation and enhanced gravity concentration techniques. It addresses technology limitations of mineral processing and extraction through the proper application of technology to allow even small-scale operations to conduct recovery activities at the lowest capital and operational expenditure while maximizing profit and minimizing if not eliminating the adverse effects on health and environment. Aside from these innovations, it makes several changes in operating procedures and management, business culture, and stakeholder engagement.

The technological innovations introduced by CLINN-GEM technology are the use of flotation and enhanced gravity concentration techniques and introducing mechanized, automated, and digital equipment. CLINN-GEM uses such equipment as flotation cells, gravity concentrator, shaking table, leaching circuit, pressure filter, conveyors, and pumps to mechanize and automate the mineral extraction processes. Mechanization and automation significantly contribute to efficiency while increasing women's access to the technology. It also uses digital equipment such as oven, furnace, chipmunk crusher, and disc mill pulverizer, fumehood, and microbalance to provide on-time and accurate laboratory results. Release of timely and accurate results contribute to optimizing time and money.

Moreover, CLINN-GEM is innovative in the sense that it has improved operating procedures and management. It ensures compliance with government requirements and observance of health and occupational safety standards. Additionally, CLINN-GEM promotes gender equality and inclusion by allowing women and other marginalized sectors to access the technology. These developments promote the importance of rule of law, gender equality, and inclusion as fundamental tenets in business culture.

The physical tools, cognitive learnings, and new operating standards bring new knowledge to the physical, cognitive, and social realms of the mineral extraction process. This result concurs with Freeman's (1997) definition of technological innovation as the successful introduction of a new product, process, or service to the market. It also supports his idea that technological innovation goes beyond invention but depicts the elaboration and prototyping of a new technological principle. Moreover, the results agree with the position of Deloitte Africa Energy & Resources Leader (2016) that innovation is not just continuous improvement, neither is it restricted to technology and changes in the way that companies mine. Rather, it is applicable to the company's operating structure, management, communications strategies, stakeholder engagements, and several areas central to the business.

Freeman (1997) argues that new products, processes, or services are sold for profit. However, this is not the case with CLINN-GEM. While UP Diliman has the CLINN-GEM patent, it has granted a royalty-free, non-commercial license to DOST Region XI and PLGU-ComVal for 20 years. This allows the small-scale miners to use and eventually adopt the technology. This initiative answers Anadon et al.'s (2015) concern about the difficulty of the poor, marginalized, and unborn populations to implement sustainable technologies for they lack the economic or political power to shape innovation processes to meet their needs. Thus, by providing them with proper technology, skills, and attitudes, small-scale miners can control resources and become autonomous and self-sustaining. This result means that technology innovators and funders play a major role in addressing technological gaps between large and small-scale industries. Also, it implies that the provision of appropriate technology that could develop local assets and maximize resources and inculcating skills and attitudes could empower marginalized sectors of society.

Towards Achieving Sustainable Development in Small-scale Mining Communities

Addressing the risks of small-scale mining through the CLINN-GEM Technology. CLINN-GEM Technology addresses several risks and problems that confront the small-scale mining industry, such as risks to health, environment, food security, and community security. Small-scale mining technologies such as amalgamation and cyanidation are labor-intensive technologies, which results in high losses of values and time (Hentschel, 2003). High losses result in economic risks, a cycle of subsistence, debt bondage, and poverty trap (Hilson, 2012).

Based on the parallel testing results, the CLINN-GEM technology has been proven to be way more efficient than traditional technologies because of its higher recovery rate (except for the ore variability problem encountered during the testing, which affected flotation process recovery and needs further studies), cheaper operating cost and shorter processing time. Using gravity concentration, CLINN-GEM can recover 13.62 g of gold while amalgamation can only recover 1.144 g. With the flotation process, recovery of the CLINN-GEM is at 21.64 g, while cyanidation is at 48 g. In terms of the processing cost, CLINN GEM costs only PhP 3,485.68 per metric ton while the traditional method is at PhP 8,282.49 per metric ton (Table 1). The costing for CLINN GEM is partial and only up to the flotation process, but the significant difference in operating costs cannot be ignored. Lastly, processing time for traditional methods takes approximately 1 week, while the CLINN GEM is able to complete processing in 2 to 3 days.

The second problem that CLINN-GEM technology has addressed relates to the health risks experienced by the small-scale miners and their families that emanate from 1) exposure to hazardous chemicals such as mercury and cyanide; 2) occupational, safety, and pollution hazards; and 3) exploitation in the working and living conditions of the miners (Colina, 2008). CLINN-Gem technology recovers gold without the use of mercury and cyanide. The operations group describes their working conditions as convenient and safe as strict observance of occupational health and safety standards is a management policy in the mineral processing plant. These policies are intended to prevent accidents and diseases common to small-scale miners such as pulmonary diseases, suffocation, mercury, Minamata and chemical poisoning (ILO, 1999; Lu & Lu, 2022; Verbrugge, 2015).

Third, CLINN-GEM Technology prevents the continued destruction of the environment. Israel (2011) also recognizes mercury pollution in small-scale mining as a serious menace. Environment-friendly features are innate in CLINN-GEM as seen in its use of such non-hazardous extraction methods as gravity concentration, flotation, and wastewater treatment. It also disposes of its wastewater properly by cleaning it prior to its release. Computation of the environmental cost of the new technology was made during the parallel testing. Results reveal that the cost of neutralization of the barren solution after leaching in CLINN-GEM is comparatively lower at Php 12.80 than implementing the INCO process for the detoxification of cyanidation tailings used in the traditional methods that costs an additional PhP 1,307.26 for the reagents consumed in the process. This cost is on top of the additional detoxification tank that is equipped with agitators and air spargers needed for the process.

Fourth, CLINN-GEM technology addresses the cause of food insecurity in the community. Causes of food insecurity in mining areas are related to agriculture and mineral extraction, and pollution and mineral processing. Agriculture and mineral extraction problems include clearing of sizable tracts of vegetation and removing fertile topsoil (Moretti & Lorenzen, 2007). Drying up of water supplies is due to heavy pumping to facilitate mineral extraction (Ingelson et al., 2009), which leads to reduced soil quality for agriculture. Meanwhile, problems related to mineral processing include the pollution of agriculture and marine sources of food and livelihood. As CLINN-GEM technology is a mineral processing technology, its primary aim is to address land and water pollution caused by the use of hazardous chemical during mineral processing. CLINN-GEM ensures that wastewater with heavy metals returns to its normal state before getting released to bodies of water, thus preventing water pollution. Considering that processing does not use chemical pollutants such as mercury and cyanide, mercury contamination in agricultural land and plant-based food products is prevented.

While not considered a risk, the informality of small-scale mining is a serious concern. A research participant says that majority of small-scale miners are hybrid in the sense that they comply with some government requirements, but do not completely accomplish the requisites for legal operations. During the field-testing, the implementing team ensured compliance with all documentary requirements before the establishment and operation of the mineral processing plant. This does not only exemplify compliance to government regulations but also urges small -scale miners to do the same.

The features of the CLINN-GEM technology that promise high recovery, less operating costs, improved health, occupational and environmental protection, and stable food supply makes the technology a good answer to economic, health, environment, and food security in small -scale mining communities.

Assessing sustainability and building a sustainable mining community. In hopes of empowering small-scale miners to pursue sustainability, they were given various training programs on mineral extraction, basic mining, metallurgical engineering, legal and paralegal principles, and livelihood. These are intended to equip them with skills so that they can properly manage their resources and eventually become autonomous and self-sustaining. To determine whether the CLINN-GEM is headed towards sustainability, Gibson (2006, pp. 170-186) suggests a sustainability assessment that utilizes the following criteria:

1. Socio-ecological system integrity – The requirement is to build socio-ecological relations to establish the long-term integrity of socio-biophysical systems and protect irreplaceable life support functions upon which human and ecological well-being depends. The CLINN-GEM technology does not entirely change the small-scale mining cycle, but contributes to addressing the issue of low and inferior technology and its adverse impacts on the environment. Its introduction has brought in new infrastructure and innovations that contribute to economic development and environmental sustainability. For now, these impacts, however, do not guarantee long-term integrity; thus, there is a need to optimize the use of the technology and reduce its potential issues.

2. Livelihood sufficiency and opportunity – The requirement is to ensure that everyone in the community has enough resources and opportunities for a decent life. These, however, also need to include future generations who will also need the land and the environment for survival. The training programs given to the members of the community are expected to help them manage their resources and ensure that future generations still have enough resources to survive. The impacts of these initiatives, however, are currently not yet evident. An extended period of time is needed to allow these impacts to surface. Continued monitoring is needed to ensure the area's sufficiency both for the current and future stakeholders.

3. Intragenerational equity – The requirement is to ensure sufficiency and practical choices for all. The CLINN-GEM technology is offered to small-scale miners to level the playing field against large-scale mining companies in terms of access to technology and innovation. Small-scale miners need technological opportunities more than large-scale miners do because of the nature of small-scale mining, which utilizes cruder and more traditional operating processes. It provides an opportunity for small scale miners to improve their socio-economic conditions, reduce their vulnerabilities, and achieve sustainable human development.

4. Intergenerational equity – The requirement is to favor present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably. While CLINN-GEM is a welcome development for miners, some of them consider mining as unsustainable because

gold as a resource is non-renewable; once gold deposits are exhausted, mining stops. This led a number of them to explore the conversion of assets into other sources of income, such as the establishment of a new enterprise, the acquisition of properties, and the investment on human capital, i.e., education of their children. These strategies help preserve and enhance the livelihood opportunities of future generations.

5. Resource maintenance and efficiency – The requirement is to provide a broader base for ensuring sustainable livelihoods for all while reducing threats to the long-term integrity of socio-ecological systems by reducing extractive damage, avoiding waste, and cutting over-all material and energy use per unit of benefit. The CLINN-GEM technology was developed to manage resources efficiently. It can recover several mineral deposits at a lesser operational cost and at a shorter operational time. It also has higher recovery and reduces if not eliminates mineral processing wastes. These features guarantee resource efficiency; however, for now, there is still a need to optimize the technology and develop new technologies for solid wastes to optimize production.

6. Socio-ecological civility and democratic governance – The requirement is to build the capacity, motivation and habitual inclination of individuals, communities and other collective decision-making bodies to apply sustainability requirements through more open and better-informed deliberations, more considerable attention to fostering reciprocal awareness and collective responsibility, and more integrated use of administrative, market, customary and personal decision-making practices. The name of the technology, CLINN-GEM, which stands for Community-Led Non-Mercury, Non-Cyanide Gold Extraction Method, is already indicative of its commitment to sustainable mining. The training programs that it provides are all geared at creating sustainable mining communities.

7. Precaution and adaptation – The requirement is to respect uncertainty, avoid poorly understood risks of severe or irreversible damage to the foundations for sustainability, plan to learn, design for surprise, and manage for adaptation. Since mineral processing is not fully operational, the actual risks are not yet identified. However, the possible risks are already observable to stakeholders who are expected to design possible actions to prevent and manage these risks.

8. Immediate and long-term integration – The requirement is to apply all principles of sustainability at once, seeking mutually supportive benefits and multiple gains. A number of gains and opportunities have been identified since the development and testing of the CLINN-GEM. These include the following: a) providing a more efficient and sustainable alternative technology to amalgamation and cyanidation; b) building capacities of people and communities; c) providing livelihood opportunities; d) providing infrastructure for economic development; and e) promising improved socio-economic conditions. However, because the mineral processing plant is not yet operational and the technology is not yet optimized, it is not yet safe to assume sustainability; instead, there is a need to take positive actions such as continuous research and development and strengthened collaboration and partnership among stakeholders to achieve greater efficiency, equity, and ecological integrity and civility.

The results show that CLINN-GEM has achieved a number of requisites for sustainability, but with its current performance, it still has rooms for development. Currently, the impacts are insufficient to conclude that with the CLINN-GEM, Barangay Katipunan is sustainable. The findings, however, suggest that while efforts from its development to the field-testing are geared towards sustainability, research and development for CLINN-GEM must not stop until its desired goals are achieved. This result supports Goodland's (2012) weak sustainability premise that says mining can contribute to sustainable development, but only if it gives rise to long-term net benefits (environmental, social, or economic) that equal or exceed the values that existed before its exploitation.

The lessons learned from the different transition phases and the future decisions for CLINN-GEM will further define its transition path. The PLGU, stakeholders, and the community must consider achieving long-term goals because, as Cooney and Lansbury (2018) suggest, technological change alone does not create disruption; instead, the choice of pathway is deeply embedded in institutions, social values, and social choices about social development. Thus, the role of the community and the exercise of power are vital to a successful transition (Avelino & Rotmans, 2011; Rossi, 1957).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The CLINN-GEM technology is a synthesized and systematized articulation of local knowledge on mineral processing, which aims to address the adverse impacts of mineral processing using traditional hazardous and low-end technologies in small-scale mining. CLINN-GEM proved to be cost-efficient with less environment cost, and non-hazardous. As a technological innovation, the features of CLINN-GEM subscribe to the principles of responsible and sustainable mining, green mining, clean technology, and end-pipe technology.

Introduction of the CLINN -GEM resulted in restructuring of organizations. Physical, cognitive, and social systems were made to effect change in knowledge realms and the social conditions of the community. The changes were intended to address the risks of small-scale miners by allowing them to tap on their potentials, which hopefully could serve as springboards to more initiatives towards sustainability. Further, the introduction of CLINN-GEM brought about several changes in the physical, knowledge, and social realms of small-scale mineral processing. Also, it resulted in several changes in the economic, social and environmental conditions of the community.

For physical changes, manual and expensive mineral extraction processes shifted towards cheaper and more efficient processes. This resulted from digitalization and mechanization brought about by new machines and equipment. For new knowledge, CLINN-GEM brought in gravity concentration and flotation methods as new knowledge in mineral processing. Also, it introduced new knowledge in proper waste disposal, more efficient wastewater treatment process, and use of none and less hazardous chemicals in mineral processing. And for changes in the social realms, the compliance to government regulations and observance of health and occupational safety standards were new practices observed in the mineral processing plant.

Meanwhile the community experienced economic, social, and environmental changes. Economic changes include road restoration and improvement, installation of a three-phase electrification system, and additional livelihood sources such as employment in the mineral processing plant, food processing, and cosmetology. Moreover, social changes include the increased visibility of government officials in the community, inclusivity, women's use and access to the mineral processing plant. Lastly, environmental changes refer to physical changes

Vol. 10 No. 1: 79–107 (2023), ISSN 2718-9228

in the natural surroundings such as the newly planted lumber and fruit-bearing trees and release of clean water (instead of dirty wastewater) to bodies of water after treatment in the plant.

Recommendations

The results of this study provide insights on technological innovations based on the experiences in CLINN-GEM. Thus, the following are recommended to help address the issues and challenges of the CLINN - GEM technology and ensure its sustainability.

For the Stakeholders

1. Continued research and development efforts must be made to address recovery issues to optimize the technology specifically on ore characterization, leaching and precipitation processes, and recovery of other valuable minerals such as copper, lead, and zinc.

2. The PLGU and DOST Region XI shall be allowed to make necessary alterations and modifications in the mineral processing plant to speed-up optimization process.

3. The PLGU and DOST Region XI must continue to provide human and financial support for the project's research and development. The operations of the mineral processing plant must ensure its viability and the environment's sustainability.

4. The stakeholders and the community should strengthen partnership to encourage the utmost adoption of the technology.

5. Strict compliance, monitoring and enforcement of environmental laws are necessary to hasten the retirement of traditional technologies and the adoption of the CLINN-GEM.

6. More feasibility studies can be conducted on how small-scale miners can adopt and replicate the mineral processing plant. Replication of the mineral processing plant in other small-scale mining communities can be done to increase accessibility of the technology.

For Further Studies

While the study explored several variables regarding technological innovation and transition, its scope and complexity necessitate further study. It is recommended that further research be undertaken in the following areas:

1. Impacts assessment – Given the importance of the element of time in transition, an impact assessment or a longitudinal study can be done after some time (a decade perhaps) to trace the subsequent changes and impact of the CLINN-GEM. This study has already provided initial data that can be used for future studies on long-term impacts of the technological transition.

2. Re-examination of the transition outcomes – This research is exploratory and descriptive. It employs qualitative research methods, but once the technology is optimized and adopted, transition outcomes can be re-examined using both qualitative and quantitative indicators.

3. Context as a crucial element in transition studies – Since CLINN-GEM is implemented in four regions in the country, the same study can be conducted in each site, or a multiple case study can be conducted to find out similarities and differences in their transition processes and outcomes.

For Policy Review and Reforms

The development of CLINN-GEM is a concrete manifestation of government's efforts to address mineral processing concerns of small-scale miners. Therefore, once the CLINN-GEM is optimized, policy reviews and reforms are needed to examine the applicability and replace irrelevant laws. The policy review and amendment may consider the following:

1) Review and amend Sec 3 paragraph (a) of *RA 7076* also known as the *People Small-Scale mining Act of 1991* on the definition of mineralized areas and Sec. 11 (d) of *EO 79, s. 2012, Institutionalizing and Implementing Reforms in the Philippine Mining Sector Providing Policies and Guidelines to Ensure Environmental Protection and Responsible Mining in the Utilization of Mineral Resources* on the limitation and applicability of metallic minerals to include copper and other minerals as a resource. Aside from gold and silver, CLINN-GEM is versatile in the recovery of other minerals such as copper, zinc, lead, and others. Therefore, small-scale miners must be allowed to recover these minerals to optimize mineral recovery.

Vol. 10 No. 1: 79–107 (2023), ISSN 2718-9228

2) Development and formulation of a national policy towards the use of CLINN-GEM as a clean and sustainable technology for the small-scale mining communities in the entire country.

3) The field testing and the technical -social initiatives taken by the stakeholders of Compostela CLINN-GEM Team can serve as a model for other CLINN-GEM facilities in Itogon, Benguet (CAR), Jose Panganiban, Camarines Norte (Bicol), and Del Pilar, Agusan Del Norte (Caraga).

To put forward these policy reforms the following are recommended: 1) local policymakers, small-scale miners and small-scale mining advocates shall organize and spearhead policy advocacy initiatives for the review, repeal, and amendments of existing environmental and mining laws; and 2) aside from organization, small-scale miners' resources and capacities must be strengthened for them to effectively lobby policies favorable to them.

ENDNOTE

[2] The respondents' name were replaced to respect their privacy.

REFERENCES

Abao, C. (2019, April 8). Responsible mining: Planet, people, profit, policy. *Business World*. https://www.bworldonline.com/editors-picks/2019/04/08/224909/responsible-mining-planet-people-profit-policy/

Alexopoulos, A. (2014). *Small scale mining in the Philippines.* Philippine National Volunteer Service Coordinating Agency. https://www.pnvsca.gov.ph/old/pnvsca/news/page.php?article=features/2014/2014-03-21c

Anadon, L. D., Chan, G., Harley, A., Matus, K., Moon, S., Murthy, S., & Clark , W. (2015). Making technological innovation work for sustainable development. *Proceedings of the National Academy of Sciences*, *113*(35), 9682–9690. https://doi.org/10.1073/pnas.1525004113

Asirot, D. C. (2000). *Mercury pollution due to small-scale gold mining: A serious menace* [Policy Notes 2000-03]. Philippine Institute for Development Studies. https://www.pids.gov.ph/publication/policy-notes/mercury-pollution-due-to-small-scale-gold-mining-a-serious-menace

Australian Centre for Sustainable Mining Practices. (2011). *A guide to leading practice sustainable development in mining.* Department of Industry, Innovation and Science, Australia. https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-a-guide-to-leading-practice-sustainable-development-in-mining-handbook-english.pdf

Avelino, F., & Rotmans, J. (2011). Power in transition: An interdisciplinary framework to study power in relation to structural change. *European Journal of Social Theory, 12*(4). https://doi.org/10.1177/1368431009349830

Baggo, J. (2015, March 3). *Philippine Mining Act of 1995: A curse to the environment and communities*. Cordillera Peoples Alliance Philippines. https://cpaphils.wordpress.com/2015/03/06/philippine-mining-act-of-1995-a-curse-to-the-environment-and-communities/

Colina, N. (2008, January 22). *Impact of mining: Beyond the occupational health and safety orbit*.

Cooney, R., & Lansbury, R. (2018, June 23-25). *Socio-technical transition in mining, Sweden and Australia compared.* 30th Society for the Advancement of Socio-Economics (SASE) Annual Conference. Doshida University. Kyoto, Japan.

Crawford, A. (2018). *Innovation in mining: Report to the 2018 International Mines Ministers Summit.* International Institute for Sustainable Development. https://www.iisd.org/system/files/publications/innovation-in-mining-imms-report.pdf

Decena, R. J., Callano, K. J., Mahinay, K., Colomer, G., & Forro, J. (2016). *Ani Bina: Production practices of small-scale miners in Compostela Valley* [Unpublished terminal report]. Research and Development Office, Compostela Valley State College.

Deloitte Africa Energy & Resources Leader. (2016). *Innovation in mining Africa*. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-za-en-innovation-in-mining.pdf

Doyle, C., Wicks , C., & Nally, F. (2007). *Mining in the Philippines concerns and conflicts: Report of a fact-finding trip to the Philippines.* Society of St. Columban. https://www.upr-info.org/sites/default/files/documents/2013-10/cafodphladd1.pdf

Dubinski, J. (2013). Sustainable Development of Mining Mineral Resources. *Journal of Sustainable Mining, 12*(1), 1–6. https://doi.org/10.46873/2300-3960.1312

Echendu, J. A., Lephauphau, O., Maswanganyi, M., & Mkhize, M. (2011). Case Studies of Technology Roadmapping in Mining. *Journal of Engineering and Technology Management, 28*(1-2), 23–32. https://doi.org/10.1016/j.jengtecman.2010.12.002

Ellet, W. (2007). *The case study handbook.* Harvard Business School Press.

Freeman, C. (1997). *The economics of industrial innovation.* MIT Press.

Gamba, B. C. (2019, June 28). UPD grants royalty-free license to 4 localities. *UPdate Online.* UP Diliman Information Office. https://upd.edu.ph/upd-grants-royalty-free-license-to-4-localities/

Garrun, D. (2014, January 29). *Eco friendly mining trends for 2014.* Mining Technology. https://www.mining-technology.com/features/featureenvironment-friendly-mining-trends-for-2014-4168903/

Gibson, R. (2006). Sustainability assessment: Basic components of a practical approach. *Impact Assessment and Project Appraisal, 24*(3), 170–186. https://www.tandfonline.com/doi/abs/10.3152/147154606781765147

Goodland, R. (2012). Responsible mining: The key to profitable resource development. *Sustainability, 4*(9), 2099–2196. https://doi.org/10.3390/su4092099

Hentschel, T., Hruschka, F., & Priester, M. (2003). *Artisanal and small-scale mining: Challenges and opportunities.* World Business Council for Sustainable Development. https://www.iied.org/sites/default/files/pdfs/migrate/9268IIED.pdf

Hilson, G. (2012). Poverty traps in small-scale mining communities: The case of sub-Saharan Africa. *Canadian Journal of Development Studies, 33*(2), 180–197. https://doi.org/10.1080/02255189.2012.687352

Hilson, G., & Pardie, S. (2006). Mercury: An agent of poverty in Ghana small-scale mining sector. *Resources Policy, 31*(2), 106–116. https://doi.org/10.1016/j.resourpol.2006.09.001

Ingelson, A., Holden, W., & Bravante, M. (2009). Philippine environmental impact assessment, mining and genuine development. *Law Environment and Development Journal, 5*(1), 1–21. https://lead-journal.org/content/09001.pdf

International Labour Organization. (1999, May 17). *Small-scale mining on the increase in developing countries.* http://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_007929/lang--en/index.htm

Israel, D. C. (2011). *Value addition: The way of the future for Philippine mining* [Policy Notes 2011-18]. Philippine Institute for Development Studies. https://www.pids.gov.ph/publication/policy-notes/value-addition-the-way-of-the-future-for-philippine-mining

Lu, J. L., & Lu, S. F. (2022). Occupational safety, best practices, and legislative review on small-scale mining in the Philippines. *Acta Medica Philippina, 56*(1), 12–23. https://doi.org/10.47895/amp.v56i1.3886

Mesquita, R. F., Xavier, A., Klein, B., & Matos, F. R. (2017). *Mining and the sustainable development goals: A systematic literature review* [Paper presentation]. Proceedings of the 8th International Conference on Sustainable Development in the Minerals Industry. Canamaple Academia Services. https://doi.org/10.15273/GREE.2017.02.006

Mines and Geosciences Bureau. (2019). *Mining industry statistics.* http://mgb.gov.ph/attachments/article/162/MIS(2018)%20Annual%203Yr-2016%20to%201st%20to%203rd%20Qtr%202019%20for%20UPload%204Dec2019.pdf

Moretti, D., & Lorenzen, R. (2007). *Research report on the Japan social development fund project on artisanal and small-scale mining in Papua New Guinea*. ASM Asia Pacific. http://asmasiapacific.com/wp-content/uploads/2014/07/ASMAP-CS13_PNG.pdf

Mulder, K. F. (2007). Innovation for sustainable development: From environmental design to transition management. *Sustainability Science, 2*, 253–263. https://doi.org/10.1007/s11625-007-0036-7

Nurmi, P. A. (2017). Green mining - A holistic concept for sustainable and acceptable mineral production. *Annals of Geophysics, 60*, 1–7. *https://doi.org/10.4401/ag-7420*

Official Gazette. (2012, July 6). *Executive order no. 79, s. 2012.* Presidential Communications Office. https://www.officialgazette.gov.ph/2012/07/06/executive-order-no-79-s-2012/

Rossi, P. H. (1957). Community decision making. *Administrative Science Quarterly, 1*(4), 415–443. https://doi.org/10.2307/2390867

Senate Economic Planning Office. (2013, December). Realizing the Philippines' Mineral Potential. *Senate Economic Planning Office Policy Brief,* p. 2. Retrieved from https://www.senate.gov.ph/publications/PB%202013-12%20-%20Mining_Policy%20Brief_final_revised_010614.pdf

Sonesson, C., Davidson, G., & Sacs, L. (2016). *Mapping mining to the SDGs: An atlas.* World Economic Forum. https://www.undp.org/sites/g/files/zskgke326/files/publications/Mapping_Mining_SDGs_An_Atlas_Executive_Summary_FINAL.pdf

The Alternate Forum for Research in Mindanao. (2012). *A background study on small scale gold mining operations in Benguet and South Cotabato and their impact on the economy, The Environment and The Community* [Occasional Paper No. 2012-02]. BANTAY KITA. https://www.bantaykita.ph/for-publications/small-scale-gold-mining-