# A SIMPLIFIED SUSTAINABLE MANUFACTURING PARADIGM FOR SMALL SCALE GOLD PRODUCTION SYSTEMS

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## Abstract

The Philippine gold industry has contributed largely to the country's economy by generating and supporting thousands of small scale industries in mining, processing and jewelry manufacturing. However, small-scale gold production in the country is described as an informal industry with minimal standards, thus affecting their competitiveness and sustainability. This study aims at using a simplified paradigm that integrates the economic, environment, technology, legal and social aspects for sustainability in gold manufacturing. The study used life cycle thinking and systems approach to assess the impact of current practices on the said aspects of the small scale gold production activities. The assessment results showed the important sources of environmental burden, inefficiency, technological and social impacts. Further, through literature review and interviews of industry stakeholders, the identified issues and concerns include the availability of channels to access miner's information, trainings, technology and programs for cleaner and more efficient production, as well as clear and specific environmental legislation and regulations. Finally, the study identified opportunities that could potentially improve and balance sustainability goals of the small scale gold manufacturing industries.

**Keywords**: Life cycle, Small scale gold production, Sustainability

## Introduction

The small scale mining industry has contributed largely to the Philippine economy by supporting more than one million people and generating and supporting at least 20,000 small enterprises and businesses, i.e. jewelry manufacturers [1]. Most of the small scale mining and extraction operators are unregulated. Small-scale gold mining in the Philippines has started in the 3$^{rd}$ century and with the continuous increase in the price of gold, the number of small scale gold miners has also dramatically increased especially in the 1980's [2] and [3]. According to the National Statistical Coordination Board (NSCB), from 1988 to 1996, out of the 164.42 MT of gold produced, 89.42 MT came from the small scale miners which only includes the documented purchase by the Central Bank of the Philippines (Bangko Sentral ng Pilipinas). Globally, it is said that in the 20$^{th}$ century alone, 80% of the gold reserves was mined. Thus sustainability of the activity is in peril.

### Objectives of the Study

This study aims at using a simplified paradigm that integrates the economical, environmental, technological, legal and social aspects for sustainability in gold manufacturing. The study used 2 life cycle thinking and systems approach to establish a situationer of the Philippine gold production and to assess the impact of the current practices on the various aspects of the small scale gold production activities such as productivity, efficiency and environmental effectiveness.

### Methodology

The term "life cycle" refers to the major activities over the product's life-span from raw material acquisition, materials processing, product manufacture, distribution, use and maintenance, to its final disposal [4]. The life cycle phases of gold production included in this ongoing research study are mining, extraction and jewelry-making, as shown in Figure 1. However, for this paper, jewelry-making is not included in the discussion as data gathering and analysis is still ongoing.

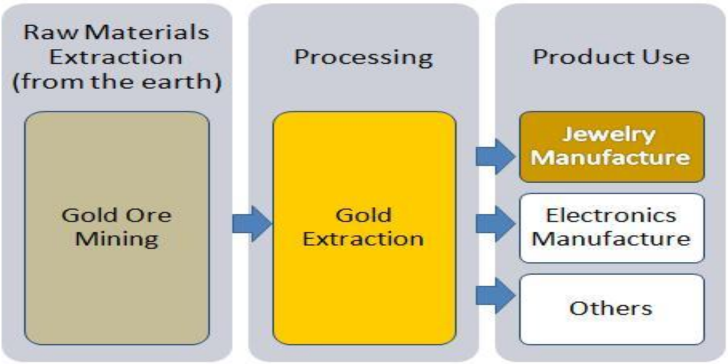


Figure 1. Life cycle phases of gold production

The documentation and analysis of flows of materials and resources were done in order to characterize the various activities and the physical flows of materials and resources for gold mining and extraction. Material and energy inputs and outputs were identified and measured in each operation in the mining and extraction processes.

To evaluate the economic aspects of the processes, measurement of the relevant inputs (such as cost, processing time) were determined. For the environmental aspects, the environmental burden was measured using a life cycle assessment (LCA) tool. For the technology, social, legal and regulatory aspects, the conduct of literature review, interviews and surveys were done for the various industry stakeholders such as the miners, local government units, regulatory agencies, academe and suppliers. Through literature review, benchmarking analysis was done to compare best practices in the Philippines and in other countries.

### Observation Sites

The provinces of Benguet and Camarines Norte were chosen as observation sites because of their reputation as regular gold mining areas for many decades. There were a total of eight mining sites and eight extraction sites available for observation in Benguet and Camarines Norte provinces, respectively.

## Results and Discussions

### Key Observations

Different mining and extraction sites in Benguet and Camarines Norte were visited to measure and quantify the inputs (i.e., materials, energy, labor, equipment) and the outputs (i.e., desired product, solid residues, liquid residues, and gaseous residues) for each operation. In mining, different procedures were done. The common practices include the sinking tunnel and underground mining, as shown in Figure 2. In Camarines Norte, also rampant are underwater mining and open mining, as shown in Figures 3 and 4, respectively.

Figure 2. Underground mining in Benguet and Camarines Norte

Figure 3. Seafloor mining in Camarines Norte

Figure 4. Open mining site in Camarines Norte

For both Benguet and Camarines Norte, the extraction phase has two stages: the first stage involves capturing free gold from the ores and the second stage is the further extracting of gold from the tailings from the first phase. The different methods observed for the extraction of gold involve using either cyanide, mercury, or zinc. Figure 5 shows the carbon-in-Leach (CIL) extraction process. In Camarines Norte, the use of mercury in the first phase of extraction poses harm to the stakeholders and to the environment. In Benguet, the use of Mercury is no longer practiced. This may be attributed to the presence of an active small-scale miners' association in Benguet. Although majority of the small-scale miners in both provinces operate illegally, the association serves as an effective monitoring body for the miners. The Mineral and Geosciences Bureau (MGB) coordinates with the association to monitor their practices.

Figure 5. Carbon-in-leach (CIL) process

**Issues and Challenges**

Despite of the differences, there are many common issues and challenges that are experienced in the observed areas. Key issues and challenges were identified based on the existing practices for the mining and extraction processes.

In Benguet, mining areas are usually located in mountainous and sloping topography. Therefore the clearing of the forests adds to the risk of soil erosion [3] and [5]. Underground mining creates a problem regarding water loss in the streams and springs [3]. Acid mine drainage can also occur because of the excavated sulfide minerals in the waste rocks [6]. There is also the risk to the safety of the miners. Usually the tunnels have poor timbering support and poor ventilation [5].

In sinking tunnels and seafloor mining in Camarines Norte, the size of the tunnels are not as big as that of the underground tunnels in Benguet. Therefore, supply of air and ventilation is very limited. Miners' physical movements are also limited for a long period of time. Also, because the tunnels are smaller, there is very limited size for worker that can go in. Likewise movement is restricted.

Mercury is considered to be more harmful than cyanide because it persists longer in the environment while cyanide, though also toxic, degrades or changes to lesser toxic forms [5]. Mercury is released easily to the air from the amalgam at the blowtorching process. The first phase of extraction process in Camarines Norte wherein the use of mercury can be considered as more detrimental and harmful compared to the processes used in Benguet. In Figure 6, the workers were observed to be exposed to the fumes and mercury released from the blowtorching process since no protective gadgets or masks are used. Since the Small-Scale Miners Association of Benguet has forbidden their members from using mercury in extraction, the sites observed in Benguet used the cyanide and zinc instead.

Figure 6. Worker torching the amalgam to recover the gold

Another serious concern that is related to the extraction process is the tailings and the wastewater that are produced. Figure 7 shows a tailings pond in Camarines Norte. According to the NSCB, 33.5 million MT of tailings were produced from 13.3 million MT of gold ore treated from 1988 to 1996 [3]. The solid to liquid ratio component of the tailings is 40:60 where the liquid part is the water being used in the processing thus implying the huge amount of water being used. The problem also with tailings is that not all small scale operators have tailings ponds to contain their wastes [2].

Figure 7. Tailings pond in Camarines Norte

**Environmental Aspects**

Some issues identified are environmental hazards from certain practices in mining such as the use of hazardous materials (e.g. mercury, cyanide, dynamites, etc.) as well as the difficulty in regulating and monitoring all the miners in order to prevent noncompliance to regulations.

Using an LCA tool, the environmental burden or score ( usually in Points or milli Points) is computed based on the inventory of material and energy inputs and outputs identified and measured in each operation in the mining and extraction processes.

The processes with higher scores are more environmentally malign than those with lower scores. In Table 1, the process which uses mercury has the most environmental burden having a score of 45,567 Points and is ranked no. 1. This is followed by leaching with zinc with a score of 63.7 Points. In Table 2, the major impact categories are shown for each type of process used by the observed sites. The top three environmental burdens associated with all of the processes are respiratory illnesses caused by inorganic substances, climate change and mineral resource depletion at varying rankings.

**Table 1. Environmental Burden (in Points)**

| Type of Process | Average Points | Rank |
|---|---|---|
| Extraction of free gold from ore | 0.75 | 4 |
| Carbon in Leach (CIL) | 49.3 | 3 |
| Leaching with Zinc | 63.7 | 2 |
| Use of Mercury | 45,567 | 1 |

**Table 2. Major Environmental Impact Category**

| Type of Process | Sites | Process with the most burden | Major Impact Category |
|---|---|---|---|
| Extraction of free gold from ore | Site 1 | Milling | Respiratory inorganics |
| Carbon in Leach (CIL) | Site 2 | Milling | Respiratory inorgaincs |
| | Site 3 | Leaching | Mineral resource depletion |
| | Site 4 | Leaching | Respiratory inorganics |
| Leaching with Zinc | Site 5 | Pre-leaching/ dissolution | Mineral resource depletion |
| Use of Mercury | Sites 6, 7 and 8 | Milling | Mineral resource depletion |

Respiratory illnesses caused by inorganic substances are usually due to energy consumption such as the use of diesel and LPG in different processes. From a study of the US National Research Council, the (complete or incomplete) combustion of these fuels produces different inorganic oxides such as CO, CO2 and NO2 for LPG and diesel exhausts (composed of different organic and inorganic compounds) are harmful to the respiratory system when they are in excessive amounts [7]. Sodium cyanide also contributes to this impact. Cyanide is known to be a respiratory poison [8]. Climate change is associated to the energy consumption (combustion of fuels) whereas mineral resource depletion is caused by the use of sodium cyanide and mercury.

The damages to landscape due to the mining activities are happening worldwide. In Ghana, mining is also a migratory activity and large pits are left uncovered therefore leaving the land unsuitable for other purposes and when filled with water, serves as a breeding ground for mosquitoes. In Zimbabwe, reports say that 100,000 ha of land are cleared annually for small-scale mining purposes. There is also the release of gaseous mercury that becomes toxic when it becomes stable as a methylmercury although there are already numerous mercury-related projects that are done worldwide.

Acid mine drainage also has detrimental environmental impacts especially when rainwater flushes the tailings which still happens even after mine closure [9].

According to Veiga and Baker, 150 tons of Hg in Indonesia is discharged and affects the Java Sea and other bodies of water [10] and [11]. Mercury vapor from the gold shops also pose as a hazard because the gold shops are in the middle of villages and there is no proper ventilation for mercury fumes. It is estimated that the gold shops release at least 200kg of Hg per year (Brazilian Ministry of Science and Technology). In Ghana, excessive mercury pollution from the refining processes is also a problem with 2g of Hg being used per gram of gold recovered [12]. Forty tons of mercury per year is reported to be discharged into the Amazon Basin in Brazil [13].

**Economic Aspects**

From the interviews with the miners and local government agencies, the key issues on economic aspects include the following:

a) there is a perception that gold recovery efficiency may not be optimum;
b) the miners stick to their traditional process because of additional costs involved in switching processes from use of mercury to cyanide (due to changes in equipment and set-up);
c) the lack of standard assessment of quality and quantity of gold present in the ores due to high costs involved in testing/assaying
d) not all of the gold generated by the small scale miners go to the Central Bank of the Philippines;
e) the miner's income is low and insufficient leaving them in financial difficulties; and,
f) traders pass on to the miners the government imposed 7% taxes.

The common extraction practices include amalgamation and cyanidation. From the miners' experience, roughly 30% of gold is easily captured through amalgamation which takes an average of 5 hours to less than a day. Cyanidation usually takes 72 hours and requires high capital whereas amalgamation requires low capital but has a high operating cost of about P15000/5kg of Hg. One observed site contains the cyanide processing plant with a capacity of 200 tons of ore per day.

Table 3 shows a sample of raw materials costs from 2 sites for extracting 100 g of gold from 8,000 – 9,000 kgs of mined ores with the use of mercury. As shown, bulk of the cost of processing comes from the use of mercury.

**Table 3. Example of Raw Materials Cost Contribution**

| **Raw Material** | **SITE 1 (in Pesos)** | **SITE 2 (in Pesos)** |
|---|---|---|
| Borax (kg) | 0.15 | 0.15 |
| Calamansi (kg) | 17.50 | 26.25 |
| Cracked Ice (kg) | 1.00 | - |
| Mercury (kg) | 9,315.63 | 9,739.06 |
| Nitric Acid (L) | 0.44 | 1.09 |
| Water (L) | 0.77 | 1.16 |
| Total | 9,335.48 | 9,767.71 |

The processing of the ores includes grinding with the use of rod and ball mills that produce 30-60 mils of dust whereas a minimum of 105 mils has to be produced for maximum extraction. The current milling system of the observed processing sites is a single drive. The main motor with a specification of 10 HP (7.5 kW) or 18HP (13.5 kW) is connected and driving at most 20 ball/rod mills. With this set-up, there is a high in-rush current of 34 A (amperes) with a starting current of 51 A. In this case, the local government requires the processing site to have its own transformer. Consequently larger-sized wires are needed. The set-up also involves frictional losses between belt and pulley, slippage when belt is loose and rolling friction in the bearing. High force is needed due to additional load weight of the shafting and pulley. Since it is a single drive, the breakdown of one part of the system means the processing is discontinued. Since the current system requires a fixed installation, it is difficult to improve the layout of the plant for efficient flow of materials

Assaying costs P1000 per test. This amount places a heavy burden on the miners. Thus they resort to makeshift testing processes. The lack of standard assessment of quality and quantity of gold present in the ores leads to waste in capital due to trial and error effort in mining the ores. Another source of waste and loss of opportunity is seen in the disposal of tailings in lakes and ponds where other minerals present in the ores are also part of the tailings. These other minerals could have been extracted and put to good use instead of being dumped or thrown away.

Most of the observed mining areas are organized like a cooperative where 60% of the income goes to the miners and 40% to the processing plant owners. Interviews with the small scale miners reveal that they lack a formal source of credit. Thus, many of the miners resort to informal financers where they are indebted. As a result, most of their products go to, or are being purchased by these financers. The traders also pass on to the miners the government imposed 7% taxes.

Figure 6 shows a mother and daughter team working on the washing of mined ores in Benguet, Philippines. There are approximately 10-15 million small-scale gold miners where 4.5 million are women and 300,000 are children [10] and [11]. In Ghana, the miners experience lack of working capital and credit facilities, inappropriate wages and inappropriate prices for their products [12]. In Suriname, miners choose working in the mines as wage laborers because wage labor provides less economic security where they have to live in a city where living expenses are high [14]. In Benguet and Camarines Norte, there is a lack of alternative livelihood for the miners which they can turn to at times when no more ore can be processed. This may also be the reason why miners stick to their jobs despite the risks that they are facing

Figure 6. Mother and daughter team up in washing mined ores

## Technology Aspects

From a survey conducted to identify the perceived areas for improvement and intervention, the Benguet miners included the following: availability of channels for access to technology, programs for promotion of cleaner and more efficient technology, specialized training institutions, miners' access to information as well as adequate human and financial resources.

There are district centers in Ghana where clean technologies are available but there is a problem with dissemination because government does not subsidize these sufficiently [12]. Such centers are also available in Zimbabwe, Colombia and Venezuela [15]. These centers though are not enough to provide all the miners with sufficient support, aside from the shortage of technical expertise, and the problem of dissemination [15].

## Social and Health Aspects

Some social and health issues identified from the survey conducted included the peace and order concerns in the community that affect operations, taxation issues, siltation of nearby rivers and problems regarding disposal of tailings.

Due to lack of budget, small-scale miners often discount health and safety practices and do not use appropriate environmental technology even when it is available [9]. In Africa, bacterial and viral diseases are common. Lung cancer, tuberculosis and pneumonia are also common due to exposure to silica dust from ore mining and crushing [9] and [16]. Carbon monoxide poisoning from a faulty water pump is also reported in Kenya causing death undergrounds [16].

In Indonesia, the practice of manual amalgamation has serious health impacts to the miners. Approximately 2-5 lethal accidents happen each year because of the collapsing of tunnels. Infectious diseases such as malaria, tuberculosis and sexually transmitted diseases, diarrhea, skin diseases, parasitism and upper respiratory tract diseases are also widespread due to poor sanitary conditions [17]. In South America, the prevalence of malaria and other mosquito-related diseases increased (in Brazil and Suriname). Vampire bats are also reported to attack the miners in Venezuela that is attributed to the loss of the habitat of their normal prey from deforestation. Deaths from mining accidents are also recorded [9].

## Regulatory and Legal Aspects

From the point of view of the government agencies in Philippines, there is a need to establish incentives to encourage value adding and standard practices for mining and the specific environmental legislation and regulations to support these. Moreover, legalization issues arise due to the difficulty in obtaining and completing requirements for registration as small scale mining operators. There are several procedures and papers required to be filed in order to be legitimate small-scale mining operator in the Philippines. There are at least 21 agency requirements for the miners that are needed by the agencies governing the industry. There are 49 requirements for the operations itself. The registration fees for operations include a minimum of PhP 24,000 (or roughly USD 600) for mining operations and processing fees for other requirements. However, legalization does not mean better or increased income since the industry is a hit-and-miss industry. From interviews, non-legal operators would rather dedicate their time and money to make sure that they would have some gold mined than use those resources to become legal. The operators become discouraged and do not see the use of doing all of the legwork in becoming a legal operator.

Likewise, from the interviews made during the study, it was found out that there is confusion regarding which government agency is authorized to give out the permits and the mining contracts. One issue that was brought up regards to a mining permit that was forfeited after it was found out that the one issuing the permit was the governor when it should have been the Provincial Mining Regulatory Board (PMRB). Transparency of records was also an issue raised in one of the workshops conducted. The respondents indicated that they have complied with all of the requirements to be submitted for legalization of mining operations. However, after submitting the complete set of required papers, their application was rejected. They were not informed regarding the reasons for rejection.

This incident shows that there might have been lapses in the government's information dissemination and unclear roles and assignment of duties. Further, since there is no government agency to manage the community mining and with the abundance of illegal operators in the area, controlling and monitoring issues arise. This is due to lack of profiling of miners, e.g. how many and where they are.

The Central Bank of the Philippines Circular No. 1389 states that, "there is no need for BSP approval for the purchase and sale of gold … except for small-scale miners who have to sell gold to the BSP." Therefore it is necessary for the small-scale miners to sell their gold to BSP buying stations, and these will be forwarded to the mint and refinery operations department. After which the gold will be sold to the manufacturers or be stored into the bullion vault where it becomes a part of the country's gross international reserve [18]. But this is not necessarily the case. Small scale miners sell their gold to the tunnel owners, processors, financers and some to the BSP. However, some are being smuggled out of the country. This results to their own poor economic condition where their products are usually underpriced and more importantly, the government loses huge amounts of gold which is not good for the economy [5]. Moreover, traders pass on to the miners the government imposed 7% taxes leaving them with lower income from the gold.

## Recommendations

Some alternatives and recommendations were generated to address the issues that concern the wellbeing of small scale mining industry. These shall be subject to evaluation according to their readiness, acceptability, ease of implementation and use, and cost efficiency as part of the continuing study phases. The recommendations generated in this study include the following:

a) Develop clear mining legislation and associated regulations. Streamlining of the procedures should be done as well as justification of the requirements. The study included surveys and interviews of agencies regarding the justification for each requirement. Currently, none of the requirements could be disregarded for legalization. It was noted that the Mines and Geosciences Bureau are conducting their own streamlining efforts to simplify the procedures in order to facilitate legalization among the stakeholders.

b) Provide proper and clear criteria for approval / disapproval for those who are applying for permits. This will aid the applicants in addressing whatever they might be lacking. Procedures and forms should also be clear and properly documented so that missing forms will not be an issue for applications. In the end, proper information dissemination should be done so that every stakeholder is informed of what are the rules, regulations and procedures that should be followed. This will also help the applicants to be aware of the repercussions, benefits, and responsibilities for applying and going into the small scale gold mining industry.

c) Develop specific regulations for small-scale mining in order to address environmental protection, health and safety requirements that are practical, implementable and within the technical and financial capacities of the miners.

d) Establish a specialized small-scale mining unit/department within the government responsible for mining that will promote and provide support services to the sector.

e) Encourage the formation of small-scale miners' organization or cooperative that will serve as an effective monitoring body for the miners. Although small-scale miners in both provinces operate illegally, since according to the Mines and Geosciences Bureau (MGB), only a few medium to large organizations are registered, the existing Benguet miners' association has been an effective monitoring body for the miners. The MGB coordinates with the association to monitor their practices. The association also helped in the elimination of the use of mercury in gold extraction processes in Benguet.

f) Consider alternative technologies or processes that do not require the use of toxic or hazardous substances. One of the alternatives that can be considered is the application of an existing technology, flotation, to replace the use of mercury and cyanide in small-scale mining operations. Flotation is effective in selectively and serially recovering gold, copper and other mineral components in the ores. This leads to maximized utilization of ores mined and processed.

g) To improve efficiency and reduce costs, change the milling set-up of the processing sites from being single drive type (where the main motor is used to power multiple mills) to a modular type (where one motor powers one mill). A single ball/rod mill will be powered by a 1.5 HP (1.1 kW) motor. The drive set up is maintained wherein the pulley or sprocket is almost the same diameter to the drum. This set up requires minimal force to rotate the drum in comparison when applying force from the center of the shaft (direct drive) which needs greater force to rotate. With this set-up, power requirement is low because a current of only 5 A and starting current of 7.5 A is needed. Consequently, smaller size of wire is needed, thus there is no need to install a transformer. The units will be independent, mobile and portable. The ball/rod mills can run separately so the processing is continuous even if there is a breakage of a unit. Fewer parts will be maintained and there is less mechanical losses (frictional, slippage, rolling friction) since it is a direct coupling and there is no exposure of parts. Although high initial cost is needed in setting up the modular system, it is compensated by the lower operating cost in the long run.

h) Conduct of a feasibility analysis in setting up Assay Testing Centers in optimal number of sites to provide service to miners. Miners perform assay testing through traditional manual sampling and testing. There are only two publicly listed assay testing center in the Philippines and the MGB also provides assay testing centers in the regions. The type of process to use, the duration of the processes and the amount of water and chemicals depend on the type of gold ore. The most essential task in the laboratory is the assay testing. Assay Testing Centers perform assaying procedures in order to obtain unbiased and reasonably accurate Au grade estimates in drill samples from a coarse gold deposit [19].

i) Organize activities aimed at imparting information and/or instructions to improve the small scale miners' performance and know-how. A small-scale mining training center can be designed to offer courses on geology, occupational health and safety, other methods of mining and extraction that are economically and environmentally sound, management skills, environmental management, etc. The United Nations Industrial Development Organization released a manual for training small-scale gold miners under the Global Mercury Project [20].

## Conclusions

There are different procedures and technologies used in the mining of ores and extraction of gold in the Philippines. This is also true in other countries where small scale gold mining exists. The common practice is underground mining. Other practices include open pit, sinking tunnel and seafloor / underwater mining. The extraction phase has two stages: the first stage involves capturing free gold from the ores and the second stage is the extraction of gold from the tailings of the first stage.

Despite the differences, there are many common issues and challenges that are experienced in the various observed areas. From the review of literature, most of the identified issues and problems are also common to small scale miners in other countries. Productivity levels of the small scale mining and extraction operations could be raised through interventions addressing the factors that have been identified in this study. Likewise, environmental performance could be improved through the exploration of alternative methods for extraction of gold and other minerals from the same ores being processed in order to minimize resource depletion. Proper organization and structure could also be used to the advantage of the small scale miners in marketing their gold and increase profitability and competitive growth.

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