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THE FRAMEWORK OF WASTE MANAGEMENT IN GOLD MINING TOWARDS BUILDING SUSTAINABLE COMMUNITIES IN CARAGA REGION, PHILIPPINES

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Abstract

This paper highlights the ecological approaches in the development of a sustainable waste management (SWM) for gold mining by picking up insights from previous works. Key concepts from industrial ecology have been adopted as basis for the approaches in configuring the waste management framework for gold mining. The relevance of industrial symbiosis and systems thinking in the framework for gold mining are emphasized, specifically on the objective of addressing the three pillars of sustainable development – people, planet and prosperity. The application of the key concepts of industrial symbiosis and systems thinking in forming the science for SWM in gold mining and developing the SWM framework are envisioned to provide sustainability in reducing wastes and mitigating environmental impacts.

Keywords: *Industrial symbiosis; Environmental impacts; Mitigation; Gold mining; Mining wastes; Sustainable communities*

Introduction

Waste management is a major environmental issue in the mining industry. Mine wastes can contaminate the soil, air and water that eventually threaten the natural ecosystem dynamics. In Caraga Region, Philippines, the impact of gold mining wastes to the environment has created a social pressure as wastes affect the health and safety of people. Gold mining is regarded to be hazardous due to the use of mercury and cyanide during ore processing, which are toxic to humans and other life forms. The mine tailings and wastewater are the major wastes in gold mining that are generally left unutilized for years. Hazards to the environment can be magnified as a consequence of the heavy metals in tailings that travel to adjoining areas especially when the tailings pond breaks down because of heavy rains and overcapacity. Lead, cadmium and arsenic are among the most prevalent heavy metals in mine tailings which can be toxic at high concentrations. In China, a study conducted a review of heavy metals derived from mining and found that the results demonstrate not only the severity of heavy metal pollution, but also the high carcinogenic and non-carcinogenic risks that heavy metal pollution poses to the public, especially to children living in the vicinity of heavily polluted mining areas [1]. In the study on the occurrence and partitioning of heavy metals in mine impacted paddy rice in South China, a number of highly significant correlations between shoot, husk, bran, and

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endosperm rice tissue fractions and that rice from mining areas was enriched in Cd, As, and Pb [2]. Gases can also be emitted during gold processing [3, 4]. In the urban centres of Segovia, Colombia, and Andacollo, Chile, the average concentrations of mercury vapor measured by mobile analyzer transects taken repeatedly over several weeks were 1.26 and $0.338\mu g \cdot m^{-3}$, respectively from shops located in the urban core, where the mercury–gold amalgam is burned to evaporate the mercury added during ore processing. In Antoquia, Colombia, the levels of atmospheric mercury pollution in populated areas are at least 10 times above the WHO guidelines [5].

The entire industrial system can be grasped by looking at the supply chain, especially the flow of materials and energy and the associated costs. In doing this, new systems-based tools to capture the emergent behaviors and dynamic relationships that characterize complex, adaptive systems have to be developed to assess the interactions among the interdependent systems. The concepts on clean technology, systems thinking, and industrial symbiosis are valuable concepts and frameworks to explore for insights in developing a sustainable integrated waste management in gold mining. Thus in this paper, a comprehensive systems approach in waste management is viewed to reduce the environmental footprints of gold mining while generating useful products for humankind. This is viewed to be possible by identifying the potential uses of waste elements as material inputs to generate new and useful products and the eventual creation of industry as source of livelihood for the people while ensuring the reduction of final wastes.

Methodology

This work presents the conceptual framework of a systematic and sustainable waste management for the gold mining industry in Caraga Region, Philippines. The framework highlights industrial symbiosis and systems thinking as the fundamental guides for the mitigation of the environmental impacts without substantial compromise in the gold mining industry. Review of previous research works is undertaken to design the framework for integrated waste management in gold mining. The framework is configured to define the possible uses of the gold mining wastes in relation with the potential enterprises that will be developed utilizing the mining wastes for sustainable integrated waste management.

The gold ecological and integrated waste management system is proposed for piloting in the Caraga Region where the large-scale gold mine and the interconnected small-scale gold mine in the vicinity are located. Analysis and characterization of the wastes are crucial to identify the materials that have potential for product development to considerably reduce the amount of final wastes. An assessment of the social and economic environment of the gold mining host communities is also considered to provide the links between the social, economic and ecological sub-systems.

Results and discussion

Industrial symbiosis in the integrated waste management in gold mining

Systems approach adopting industrial symbiosis, circular economy and its various synonyms are currently broadly recognized to include the reuse of previously disposed by-products from one facility by another, as well as supply, utility and even facility sharing among collocated firms [6]. Industrial symbiosis is taken from the ecological relationship in a community where there is mutual, synergistic relation between two organisms. This mutual relationship is manifested in a system where various processes can be linked into a close loop to minimize waste of material and energy. In industrial symbiosis, typically isolated industries are gathered in a collective approach to have a competitive advantage which involved the physical exchanges of materials, energy, water and/or by-products [7-9]. The ecological systems and industrial systems may have much in common as both are characterized by flows of material and energy between components, have components that use energy to transform materials, and involve interactions that regulate energy and material flows such as competition and mutualism [10]. Industrial symbiosis in relation to waste management nurtures synergies among industries to transform wastes into resource inputs in the production of outputs [11]. With the recycling of wastes adopting the principle of industrial symbiosis, the waste to wealth concept is promoted. Evidence is increasing in the stimulation of industrial symbiosis across the world [12]. Technically, industrial symbiosis is in consonance with circular economy in the sense that both are pursued with sustainability and/or sustainable development in mind [13-15].

Industrial symbiosis has been practiced in the Philippines in relation to clean technology even in the ‘90s. The application of the 3Rs (reuses, reduce and recycle) in solid waste management at the industry scale can be linked to sustainable production. In integrated rice-based farming, for instance, the crop residues (rice straw, leaf litter) are used as substrate for organic fertilizer production [16]. The compost (organic fertilizer) is used to supply nutrients to rice and other crops which in turn are generating feeds for swine in the adjoining piggery project. The piggery wastes are used for power generation through biogas production while the solid part is also integrated in the composting process. This picture of an integrated rice-based farming is a simple illustration of industrial symbiosis at the local scale under Philippine setting. What is not considered in adopting this concept in the country specifically in small-scale enterprises is the valuation of the various materials used, reused and recycled to close the loop while continuing the operation. In addition, the cost-effectiveness and efficiency of the system is likewise not given attention.

Developing a circular economy framework for gold mining is stimulated by the environmental impacts brought about by the mining operations at various phases. Circular economy is thought to have self-sustaining working elements in “closing the loop,” which is basically finding strategies and arrangements to foster designing out wastes sustainably. This lays down the conceptual framework which tries to complete the circular economy for gold mining by devising the arrangements and strategies to enable the mining industry to continue operation. In this context, the Chinese model of circular economy can be adopted since the evolution of circular economy is relatively perceptible with the tiers of circular economy development being provided at the enterprise, industrial park, and city/regional levels. A gradual evolution can be gleaned from the micro to macro level of circular economy, starting at the enterprise to the eco-industrial parks and to the regions [17].

Systems thinking and circular economy in relation to waste management in gold mining

In establishing the science for the development of a circular economy specifically in gold mining’s SWM, trans-disciplinary research is an essential activity. It is important to tackle the technical, socio-political and cultural aspects of waste management especially that circular economy concerns a holistic scheme in the process of setting up mechanisms to catalyze sustainable mitigation of gold mining’s environmental impacts. In this case, the emphasis is on enabling an existing economy where gold mining is operating to close the loop. In the process, this designs out wastes and emissions with the help of the mechanisms that various stakeholders will support to attain the goal of sustainable mitigation of environmental impact. The tiered circular economy of the Chinese model provides important hints that help determine the scope of the scientific inquiry from the enterprise to the regional level. At the enterprise level, the inquiry must look into the operations of gold mining to observe the efficiency of resource utilization (water, energy and other inputs). This will lead to understanding the generation of wastes and emissions from the operations as basis in developing the industrial symbiosis at the regional level. Systems thinking is essential in the aspect of connectedness relative to the development of industrial symbiosis [18]. Thus it is relevant to consider life cycle thinking to help conceptualize environmental problems as a system-level issue along a product's life cycle [19]. This is relevant in examining the gold mining process as it utilizes resources (e.g. energy, water and chemicals) to produce gold and other by-products.

Developing the Integrated Waste Management Framework for Gold Mining

To understand the links between the sub-systems, industrial symbiosis needs to be adopted. The concept of symbiosis is taken from nature, where both species benefit from the short and long term interactions, resulting to a higher chance of survival in the environment. As the sustainable development efforts progress, there is a need to reconsider strategies specifically on addressing the rising waste disposal costs, concerns over environmental degradation accompanied by stricter environmental regulations, and a growing awareness of the potential profits from by-product and waste utilization [20]. In industrial symbiosis, the first step is identification of the various component projects of the industry and their corresponding wastes to be the basis for planning the industrial system using the systems approach. Comprehensive planning for systems approach in waste management in a gold mine is essential to sustainable mine-based economy to reduce environmental impacts and prepare the community for the life-after-mine.

In mining industry, published information on the application of industrial symbiosis is still limited. In mid-1980s at the Russian Kola Science Center, complex utilization, a production model similar to those described by industrial symbiosis, was planned. The model incorporates the waste streams of mining industries in the Kola Peninsula such that waste from one industrial operator becomes raw material for another [21]. In Australia, a mining-based industrial symbiosis is documented at the country's major industrial regions: Kwinana, Western Australia and Gladstone, Queensland. The synergies of the industries in these regions have been documented in 2007 [22]. For Kwinana, synergies are noticeable in by-products and utility aspects. In Gladstone, industrial area exhibits synergies capitalizing on alternative fuels for cement clinker production, water reuse, waste separation and reuse, fly ash reuse, and caustic recovery. These industrial areas demonstrate that synergistic relationships among industries can be tapped to reduce wastes and emissions by finding their further uses in industrial processes. In making the design for industrial symbiosis in gold mining to work, a proactive science-based approach can be undertaken following the steps discussed below.

1. Characterization and analysis of wastes generated from gold processing. The entire process in gold processing needs to be characterized, particularly the main product/s and the by-product/s generated per unit time. The material and energy flows involved in the process are important to be documented. Characterization of the waste products is through chemical analysis of samples to identify the components of the wastes that can be further utilized for industrial purposes. Previous experiences (from local knowledge and literatures) can be the basis for the identification of potential industrial uses of the wastes. A detailed inventory and/or materials flow analysis must be also done for all the wastes and by-products of gold mine processing.

2. Development and testing of products out of mining wastes for industrial use. The various raw materials from mine tailings and wastewater after analysis are the material inputs for the development of products with industrial value. Testing of the clay materials for pottery and bricks production should be conducted to evaluate the strength of material. In addition, effects of the new products to health of animals should be evaluated to ensure that there are no harmful effects to animals and humans before manufacturing is undertaken on an industrial scale. Observations at this point are essential for further analysis on the feasibility of manufacturing the derived products.

3. Evaluation on the IWM in gold mining for sustainability. The points at which industrial symbiosis in large scale gold mine and even in small scale can be made and why such industrial symbiosis can help the mining industry mitigate its environmental impacts is shown in Figure 1. A causal loop diagram is used to demonstrate the benefit from such symbiosis. The ultimate scenario is to create a network of industries arising from the different by-products of gold processing considering the flows of materials and energy within the system. With the various industries developed, the economic benefits are assessed to determine the cost-effectiveness of the system. Aside from the economic benefits, the cost of turning wastes into beneficial, value-added products can be calculated such that the system-wide benefits are accounted for. The input-output model (IO) may provide the basis in the analysis of the material and energy flows from the upstream to the downstream [23, 24]. The life cycle assessment methods are important in understanding the environmental, economic and social hotspots of the gold mining process with respect to the environmental LCA, life cycle costing and social LCA considerations [25-27].

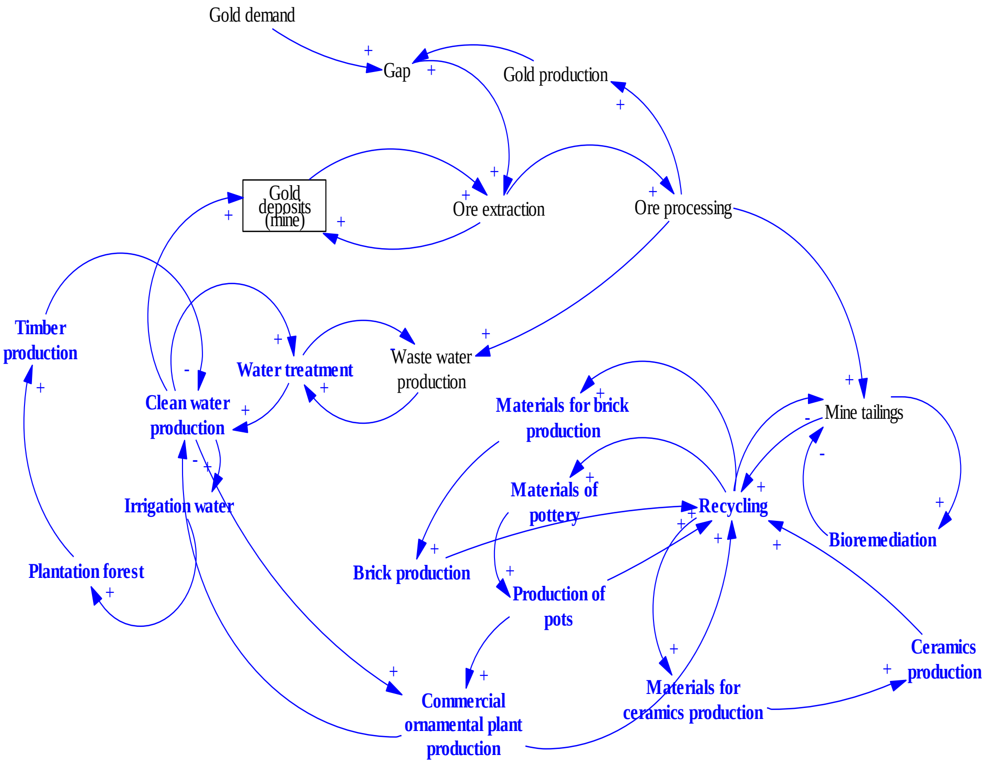

Fig. 1. Model of the industrial symbiosis and circular economy on waste utilization in gold processing

The flowchart of the various processes and steps in the entire industrial symbiosis modelling is presented in figure 2. The process starts from the identification of the major by-products of gold mining and processing to the analysis and characterization of wastes in detail up to the chemical composition. This is an important basis in determining the treatment to apply prior to product development out of the inputs from the wastes. From this, products from the wastes of gold mining are planned to be developed through green chemistry technologies.

When products have been developed, testing follows to see the matters on safety, effectiveness, efficiency of product development, and product packaging. After the products have been tested to have market potentials, a feasibility study is important to be conducted for wholesale production in mind. In the feasibility study, material and energy flow analysis needs to look into the interconnectivity and interdependence of the various potential industries established from utilization and recycling of gold mining wastes. However, in the context of sustainability and in view of mitigation and consequences associated with spending benefits from increased efficiency (rebound effects), circular economy can be developed around the planned industrial symbiosis. The tiered Chinese model of circular economy makes great sense in such undertaking where the case of gold mining has to be examined with life cycle and systems approaches for holistic analysis.

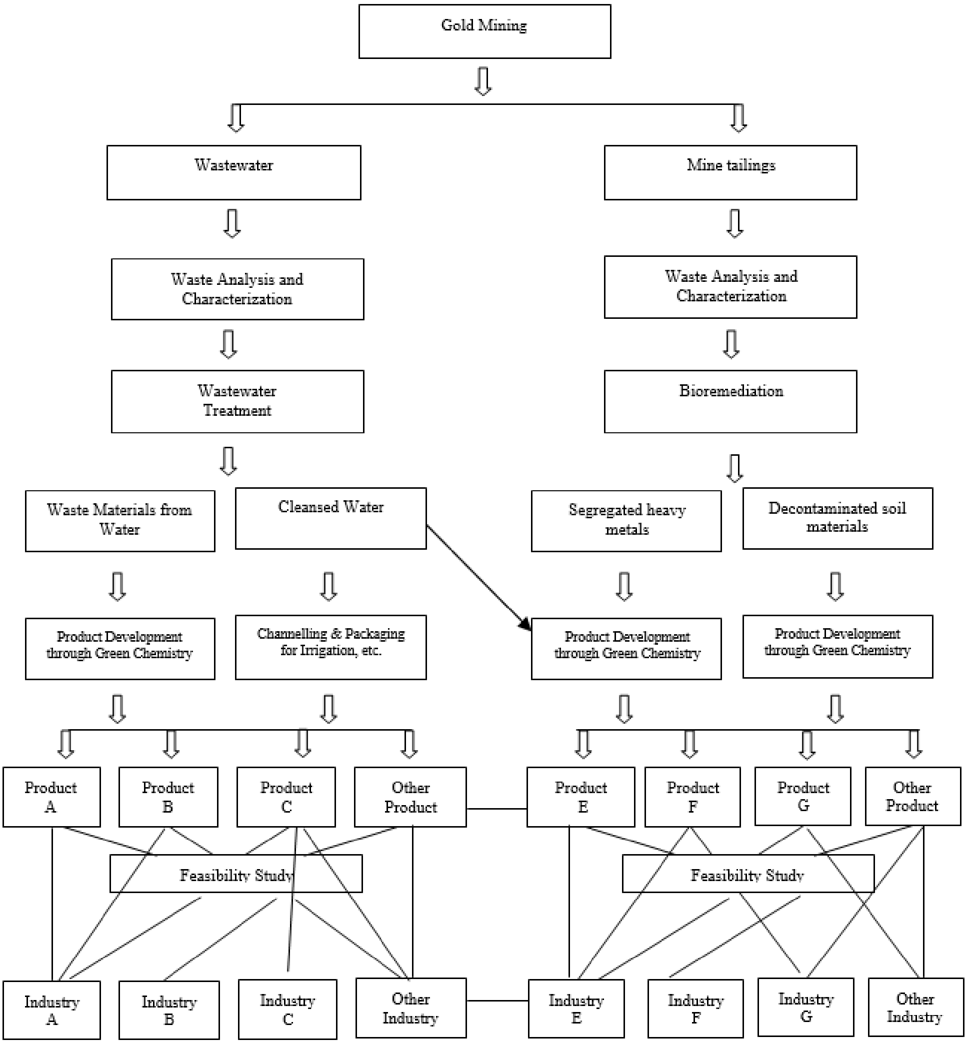

Fig. 2. Flowchart of the processes involved in the industrial symbiosis in gold processing

Figure 3 shows industrial symbiosis as essential in circular economy development to close the loop for gold mining, enabling the gold mining industry to have an active role in minimizing wastes that can potentially harm the three pillars of sustainability. The model shows that the control for the gold mining wastes starts at the enterprise level where the gold mining enterprises have to adopt some options available to minimize the said wastes. These can be apparently done by technology improvement. At this stage, the life cycle assessment is relevant to point out the major environmental hotspots to guide consequent improvement in technologies.

Furthermore, the wastes that cannot be contained at the enterprise level become the subject for further scrutiny to draw industrial symbiosis implications as presented earlier. The systems approach (i.e. systems dynamic analysis) is helpful to understand the possibility of the whole structure to work for gold mining waste management, considering the policies, people and economy that are likely affected by the new development.

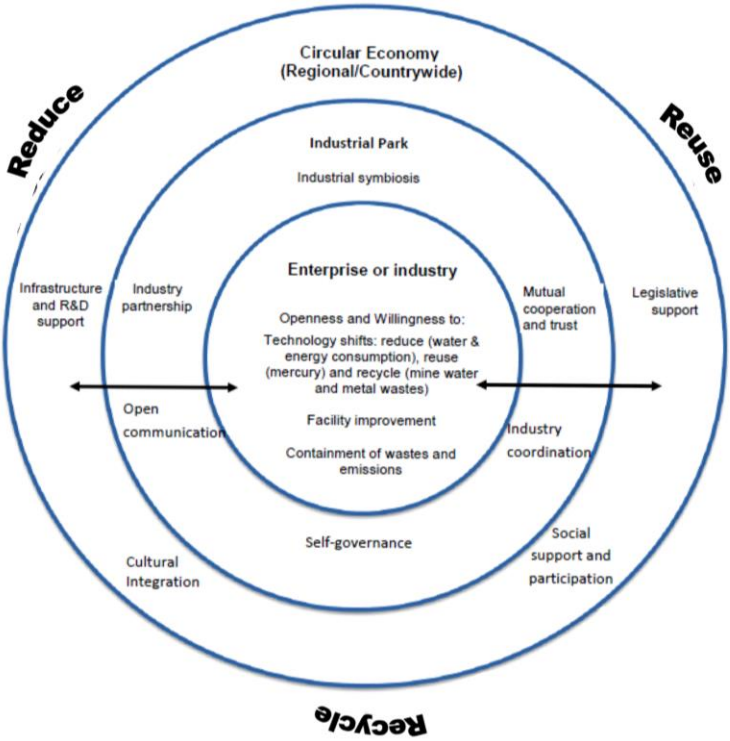

Fig. 3. The circular economy model for the sustainable mitigation of the gold mining wastes

These aspects are among the concerns of sustainability, which can help prepare for propensities toward rebound effects. Nonetheless, given the holistic nature of circular economy which involves multiple sectors and aspects, it remains a tall order that has to be carried out with the right aptitude and caution.

Conclusions

Gold mining has been producing wastes that can potentially harm people and other life forms. Some heavy metals are contained in these wastes that are toxic at high concentration and can put people and livelihood at risk when the wastes flow to adjoining communities and ecosystems. In view of developing the framework for integrated waste management towards sustainable mitigation of environmental impacts in gold mining, the concepts of industrial symbiosis and systems thinking are very important. Industrial symbiosis, systems thinking and circular economy are key concepts which, when applied intelligently, will help provide security to the three pillars of sustainability. Industrial symbiosis can stimulate ingenuity in the reuse of wastes from gold mining through mutual coordination and partnership among industries and the local communities. Life cycle and systems thinking lend backbones to life cycle assessment methods and systems analysis, which are the key to determining the environmental, social and economic hotspots of the life cycle of gold mining and to analyzing holistically gold mining for sensible policy actions in the mitigation of environmental impacts. The integration of the major concepts in the proposed framework for integrated waste management in gold mining provides a holistic approach in mitigating gold mining's environmental impacts. The framework covers a wider perspective that may lead to policy action in terms of responsiveness. The experiences in employing industrial symbiosis in other countries are grounds to draw insights from for a sustained systematic waste management for gold mining to reduce wastes and control environmental impacts.

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