

Systems Approach toward a Greener Eco-efficient Mineral Extraction and Sustainable Land Use Management in the Philippines

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As the world transition towards a low-carbon future through renewable energy, mining of minerals and metals to attain this goal is substantial. The Philippines will play an important role in such global economy as it is the world's fifth most mineral-rich country. However, their exploitation has not been maximized to benefit society. Benefits from the mineral resources sector remain less than 2 % of the country's GDP since 2006, and the mining and mineral processing, including abandoned or legacy mines, are perceived negatively by the public. In low- and middle-income countries with weak implementation of mining and environmental legislation, the mining industry still operates in a linear system which is considered unsustainable. The mining, mineral extraction and processing, and metal extraction are designed to maximize profits with little plan on how to effectively manage mine wastes, protect the environment, transform post-mining land for beneficial use and empower impacted communities. This paper, thus, proposes a systems approach toward greener eco-efficient mineral extraction and sustainable land use management (SAGES). This approach will facilitate a paradigm shift, which is necessary to manage the country's mineral endowments sustainably without compromising future land use of mining areas while at the same time supporting the needs and aspirations of the impacted host communities. It envisions extending the usability of mining areas beyond the life of the mine and integrating circular economy principles in addressing holistically mine waste management problems. The multi-R framework, originally developed in waste management (Reduce, Reuse, Recycle) and extended to circular economy strategies, has potential applications in mine waste management in the Philippines. An illustrative case study is then presented that employs a multi-R framework to address the mine waste in an operating Ni-laterite mining site.

1. Introduction

Mining is an essential sector of the global economy as it extracts raw materials from the Earth's crust to produce metals, industrial minerals, and fuels. In regions with huge mineral endowments, this industry plays an important role in the local and national economies. Metals and mineral commodities are the backbone of our modern society because they are essential in modern conveniences like transportations and telecommunications, clean storage technologies, electronic gadgets and equipment, among others. The mining sector will also play a vital role in our transition toward a low-carbon future because renewable energy and clean storage technologies require more metals and minerals than their fossil fuel-based counterparts (Tabelin et al., 2021). The technologies required for such transition will require significant metal input, as described in Table 1. For example, a 7 % increase in copper (Cu) demand from green technologies by 2050 as a percentage of 2018 annual production would require an additional 1.4 Mt of copper to be mined.

Table 1: Mapping of mineral commodities required for low-carbon energy transition and their projected global demand (Hund et al., 2020)

	C ^a	Li	Co	In	V	Ni	Ag	Nd	Pb	Mo	Al	Cu	Mn	Cr	Fe
Wind						✓		✓	✓	✓	✓	✓	✓	✓	✓
Solar photovoltaic				✓		✓	✓		✓	✓	✓	✓			
Conc. Solar power							✓					✓			
Hydro						✓			✓	✓		✓	✓	✓	
Geothermal						✓			✓	✓		✓	✓	✓	
Energy storage	✓	✓	✓		✓	✓					✓	✓	✓	✓	✓
Nuclear				✓	✓	✓	✓			✓	✓	✓		✓	
Carbon Capture storage			✓			✓				✓		✓	✓	✓	
2050 projected demand ^b	4.6	0.4	0.6	.002	0.1	2.3	.02	.008	0.8	.03	5.6	1.4	0.7	0.4	7.6
% Increase in demand ^c	494	488	460	231	189	99	56	37	18	11	9	7	4	1	1

Note: ^a Graphite, ^b2050 projected annual demand from energy technologies round up in Mt

^c2050 projected demand from energy technologies as percent of 2018 annual production

However, the extraction and processing of these metals for energy transition could intensify a variety of environmental problems, including global warming potential, biodiversity loss, and social and health impact. These impacts include the displacement of communities, contamination of rivers and groundwater from tailings, damage to communities from tailings, land rights violation, and community repression, among others (Lebre et al., 2020). How these mineral commodities are sourced will determine whether our energy transition will promote economic growth and sustainable development in regions or countries where these minerals are mined. This transition could, nevertheless, reinforce weak governance that in turn would amplify the local conflicts and social injustices in these areas. For example, the Philippines is identified as one of the top 15 countries with the highest environmental, social, and governance risk factors, given the assumption that the increased extraction rates will amplify the stress placed on people and the environment in those extractive locations (Lebre et al., 2020). This is exacerbated by the fact that mining industries across the country still operate in a linear system to maximize profits with little plan on how to effectively manage mine wastes, protect the environment, transform post-mining land for beneficial use, and empower impacted communities. To support the mining industries to adopt leading practices and to optimize positive social and environmental impacts, this paper proposes a novel conceptual framework built on greener eco-efficiency to address the key challenges to the sustainability of the mining sector in the Philippines. An illustrative case study is then presented to demonstrate the potential of introducing eco-efficiency in a Ni-laterite mining company through resource recovery from mining waste.

2. Key opportunities and challenges to the sustainability in the Philippine mining industry

The Philippines is the world's fifth most mineral-rich country, with resource assets estimated at US\$1 trillion (US\$ 10¹²) in untapped reserves of copper, gold, nickel, zinc, and silver (Nem Singh and Camba, 2020). Despite these large deposits of metals critical to the energy transition, the Philippine mining industry remains small. From the Department of Environment and Natural Resources - Mines and Geoscience Bureau (DENR MGB) report (2020), the Philippines has 9 Mha of land with high mineral potentials (30 %) out of the 30 Mha of land area. However, only 2.42 % or around 727,000 kha are covered by mining tenements. From 2006 to 2017, mining and quarrying accounted for a miniscule 0.8–1.4 % of GDP (Philippine Statistics Authority, 2020). In terms of metallic minerals, it was estimated that the country's production value is around PHP 130 billion (US\$

2.6×10^9) in 2019, primarily on gold, nickel, and copper, surpassing the annual production in 2017 and 2018 at around PhP 109 billion (\sim US\$ 2.2×10^9) and PhP 122 billion (\sim US\$ 2.3×10^9).

One of the main challenges faced by the mining industries is the negative perception of the people to mining. This negative perception will continue to pose resistance to new mine development projects across the country. For example, the development of the Tampakan porphyry copper deposit in South Cotabato has been delayed for 15 years due to local government oppositions, environmental hurdles, and indigenous people rights issues (Hostettler, 2015). These underlying reasons for opposition are complex, and these are amplified by historic mining operations that left hazardous wastes and legacy mines which are sites abandoned without proper rehabilitation. In addition, mining accidents such as the 1996 Marcopper disaster in Marinduque destroyed the ecosystem and caused loss of livelihood and long-lasting health problems to affected communities (Lindon et al., 2014). Legacy mines also caused extensive soil and land pollution due to uncontrolled waste dumping from small-scale activities or indirectly due to tailing storage facility (TSF) failure or acid mine drainage (AMD) formation. Evidently, the people's negative perception has been caused by inferior mining practices and the lack of sustainable rehabilitative practices. This negative perception can be addressed if mining industries adopt more sustainable practices and address the information needs and even support the aspirations of the community including the indigenous people. This may also reveal the weak governance in the country considering that free, prior, informed consent (FPIC) is a widely accepted mechanism to grant the social license to operate; but this was hardly observed in some cases (Church and Crawford, 2018).

3. Systems approach toward a sustainability pathway for the Philippine mining sector

To address the issues explored above, sustainable management of mineral resources and land use beyond the life of the mine will require a nexus of economic development and responsible governance, community benefits and empowerment, and environmental protection. This strategy will address these problems based on the idea of transforming legacy mines into future mines and mine wastes into secondary resources. With such a holistic concept and long-term thinking in mind, a systems approach for greener eco-efficient mineral resource extraction and sustainable land use management (SAGES) is proposed as shown in Figure 1. The SAGES framework incorporates multiple actors' perspectives along the value chain, ensuring the activities are interdisciplinary and participatory by design to provide innovative and sustainable solutions to the mining sector. It provides a unifying framework that will support Philippine mining in its transition into an economically sustainable, socially responsible, and environmentally sensitive industry. This approach can simultaneously reduce waste generation, provide additional economic benefits to stakeholders, empower host communities, and improve rehabilitation programs.

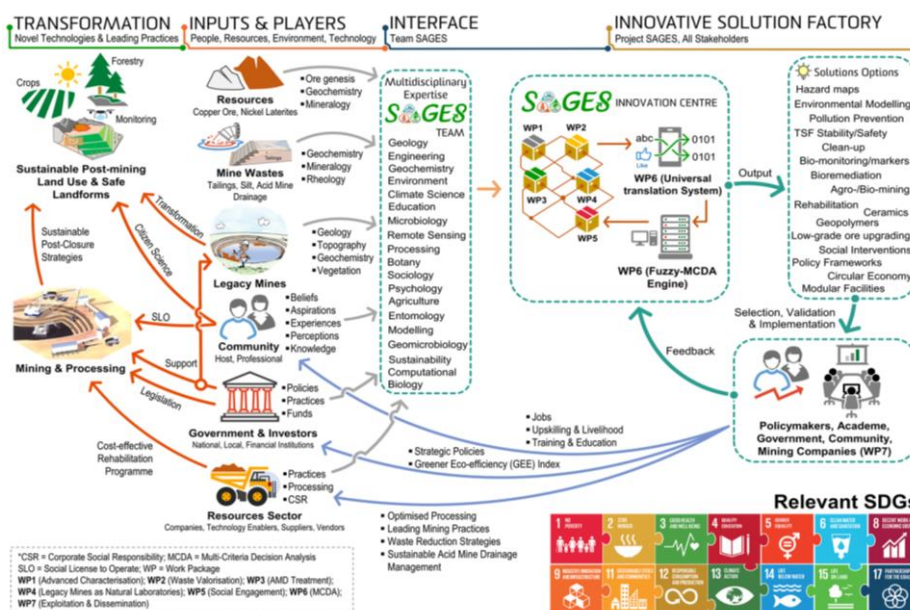


Figure 1: Systems approach for greener eco-efficient mineral resource extraction and sustainable land use management

3.1 A proposal on greener eco-efficiency metric for the mining industry

SAGES introduces a composite metric on greener eco-efficiency to serve as a measure of sustainability in transition for the mining sector. Eco-efficiency as originally conceived in the 1990s by the World Business Council for Sustainable Development is the integration of economic and material efficiency of production with the objective of sustainable development and the notion of social equity or justice. This metric is typically operationalised for business and industry as the ratio of desired output (e.g., economic value) to the environmental burden. Thus, an economy or economic sector is assumed to progress along an eco-efficient path when it produces an improvement to the quality of life or social welfare while not only promoting the efficient use of natural resources and energy, but also reducing the generation of waste and pollution to the environment. However, there is still research gap in the literature on a holistic framework used to assess the eco-efficiency of the mining sector in the Philippines, and to define the economic, environmental and social dimensions in an integrated way. Results from eco-efficiency (EE) metric with fuzzy multi-criteria decision analysis (MCDA) can be used as an effective communication tool that can measure the impacts on a system level and include a comprehensive, science-based approach to sustainability assessment. This approach can protect against potential unsustainable solutions that can result from considering only single metrics.

Greener eco-efficiency (GEE) can be disaggregated to techno-economic viability and socio-ecological inclusivity. Techno-economic viability will not only measure the desired output of techno-economic value but also the eco-environmental burden such as the resource intensity and carbon footprint. Socio-ecological inclusivity ensures the notion of social justice is included in the metric by measuring both the socio-cultural values and socio-ecological burden like displacements of indigenous people (IP). Increasing eco-efficiency can be achieved by increasing the techno-economic and socio-cultural value and/or reducing the environmental burden. As shown in Figure 2, consider for example, somewhere near the origin is the current situation of the mining site or the study area of concern. A movement toward Quadrant 1 to the upper right suggest an improved GEE score, i.e., a strong ecologically sustainable development. On the other hand, the path toward the lower left of the Quadrant 3 is the possible future of the mining area resulting from an ineffective governance and lack of proper post-mining land use management. Such scenario or possible futures are the current situation of most legacy mines in the Philippines. The movement towards the region in Quadrants 2 and 4, i.e., above the diagonal suggests weak sustainable improvement in eco-efficiency. GEE score of management options can thus be used as a composite index and can be plotted to visualize and compare the performance among options.

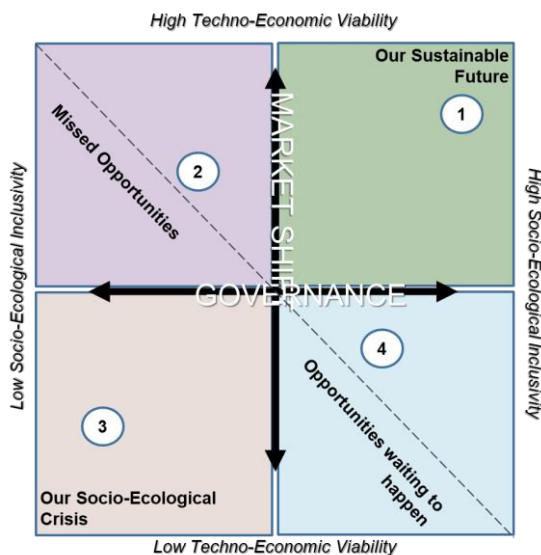


Figure 2: Visualization of the scenarios and pathway toward sustainability in the mining sector

Note that mining and mineral processing industries are traditionally resource and energy intensive (Adiansyah, 2019). Irrespective of mining and extractive techniques, mine waste and emissions will always be present in one form or another, such as waste rock, overburdens, spoils, and mine drainage. Resource recovery from such waste could be “opportunities waiting to happen” or “missed opportunity” for the mining industry to be integrated with other sectors in a circular economic system. Assuming circular economy will be achieved by 2050, the

government, during this transition will provide the right infrastructure while the private sectors will drive the innovation ecosystem to ensure products are designed for disassembly, recycling, and resource recovery. New technologies (e.g., waterless mining, biomining, etc.) can also be developed to transform mining and mineral processing into a carbon-neutral and resource-efficient extractive industry to improve its eco-efficiency.

3.2 An illustrative case study: multi-R approach to nickel laterite mine waste management

To operationalize the SAGES framework, the multi-R approach analogous to “Reduce, Reuse, Recycle” paradigm in waste management is applied for the Ni-laterite mining sector. This approach seeks opportunities to implement circular flows at the mine site level, which enhance mineral extraction, reduce mineral losses to mining waste and mitigate the environmental impacts of mine waste disposal. It also requires reimagining post-mining land use that is climate- and culture-sensitive and rethinking the value derived from the site rehabilitation for the environment and the impacted community. Note that the siltation and excessive soil erosion could pose severe problems for operations that employ surface mining such as that of Ni-laterite mining company. For example, the siltation ponds are typically monitored not to go beyond its holding capacity to avoid overflowing of silt or spillage of silt to nearby aquatic bodies. Otherwise, siltation of aquatic bodies requires at least more exhaustive and expensive remediation approaches and more delicate negotiation engagements with affected communities. The valorization of these silts from the pond to produce high-value products while reducing the environmental burden could increase the eco-efficiency of the mining company.

The research program lead by the first author of this paper was recently funded by the Philippine government to valorize the Ni laterite mine wastes, specifically silt and low-grade ore, through reuse, recycling, and reprocessing. Figure 3 describes the output from such project. For example, nickel mine waste is reprocessed and recycled as raw material to produce geopolymer as construction materials as shown in Figure 3a (Longos et al., 2020). Moreover, Turingan et al. (2020) reuse low-grade nickel ore for AMD treatment as shown in Figure 3b. Furthermore, silts from the siltation ponds of the Philippine nickel laterite mine containing various oxides such as silica, alumina, and of iron that can be repurposed or reprocessed to produce various ceramic wares for household and industrial applications (see Figure 3c), as well as to synthesize magnetite nanoparticle to adsorb arsenic from aqueous solution (see Figure 3d).



Figure 3: Multi-R approach to nickel-laterite waste management

4. Conclusion and prospects

Green technologies and infrastructure of low-carbon future demand intense mining and sourcing of critical metals. The Philippines could be part of the global supply chain during the clean energy transition as the country is endowed with large untapped deposits of critical metals such as Cu and Ni. However, there is a need to balance the economic growth brought by the extractive industry with the need to address environmental, socio-cultural, and governance issues to ensure mining is beneficial for both our people and the planet. Thus, this study proposes a systems approach toward greener eco-efficient mineral extraction and sustainable land use management in the Philippines. This approach will facilitate a business culture change in the mining sector, which is necessary to manage the country’s mineral endowments sustainably without compromising future land use of mining areas while reducing its environmental burden. The recent research project in a Ni-laterite mining

area demonstrates the potential of resource recovery from mine spoils such as silt. Discussion with the said mining company is on-going to consider the developed technologies as part of their program for corporate social responsibility. Future work will also further develop the greener eco-efficiency as a metric by promoting resource efficiency and cleaner production and socio-cultural values as integrated into the ecosystem services approach. A holistic approach will thus be achieved by systematically accounting for multiple criteria such as the economic, technical, environmental, and social dimensions of sustainability. Techno-economic assessment must then be harmonized by a life-cycle approach to provide us guide in identifying technological options for cleaner mineral production that are more eco-efficient. Combining concepts in futures and design thinking that focus on human-centered values will promote socio-ecological inclusivity for post-mining land use planning which accounts for socio-cultural values embedded in the ecosystem services of the mining area. Thus, research projects and programs are currently being planned with these tools and perspectives from futures thinking, life cycle thinking, and design thinking. This markedly differs from the 'silos' approach prevalent in approaching the wicked problem of sustainability in the mining sector.

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