

Review

Charting Policy Directions for Mining's Sustainability with Circular Economy

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Academic Editors: Michele Rosano and Julie Hill

Received: 26 April 2016; Accepted: 21 June 2016; Published: 30 June 2016

Abstract: This paper discusses circular economy (CE) as an option to mitigate the environmental impacts of mining operations, and a framework based on the three dimensions of sustainability, the possible uses of mining wastes, the life cycle, and the systems approaches to determine the policies that will induce initiatives towards designing out wastes for a mining-based circular economy. Previous research has been reviewed to determine CE configuration and the basis for the framework to guide in the development of CE-related mining policies. The Chinese model of circular economy, noted for the introduction of industrial symbiosis through eco-industrial parks at the meso level, and public participation at the macro level, forms the basic structure of the framework aimed at curbing mining waste, and closing the loop in mining. Holistic research is important in taking proactive CE technology actions, strategic measures, and policies, which can use life cycle assessment (LCA) methods (environmental and social LCA and life cycle costing) and systems dynamic modeling. With systems dynamic modeling, the framework introduced in this work can be expanded to cover as many important aspects as possible, and can check for areas of policy resistance that have been the reason for most policy failures.

Keywords: sustainability; circular economy; systems thinking; life cycle thinking; mining

1. Introduction

Mining faces adversity when it is examined under the lens of sustainability or sustainable development. The nature of mining is naturally connected with the destruction of mineral-rich areas, as huge amounts of rocks and dirt are processed to extract the metals and minerals that are demanded by the modern world [1]. The environmental impacts of mining are significant issues in the global mining debate [1]. These impacts show the true cost to people and the environment, not only locally, but also globally [1]. Particularly, Mudd (2009) [2] finds having sustainability in mining a challenging task, since minerals are finite but there is increasing demand [2] as economies worldwide continue to advance. According to Mudd (2009) [2], “the true sustainability of mineral resources is a much more complex picture that involves exploration, technology, economics, social and environmental issues, and advancing scientific knowledge.” Sustainability is, thus, a great challenge for mining to be guided in the extraction and processing of minerals, and in the management of its externalities, to protect people and the environment as key resources in sustainable development. Circular economy, as a concept explored here, has cornerstones (e.g., life cycle thinking, extended producer responsibility, and industrial ecology), which have already existed for years [3], and which have been attempted in some countries (e.g., Germany, Japan, and China) for the abatement of environmental problems.

Circular economy (CE) is a concept associated with the idea of closed-loop systems and economies, where wastes are put back into the system to become resource inputs for production processes. It emanates from the field of industrial ecology (IE) [4,5] that provides an agenda and overarching goal for industrial systems, in order to have the capacity to operate within the limits of the environment, by integrating circularity in the processes to eventually design waste out of the system [6]. The need for circular economy, especially over a broad scale (e.g., regional, economy-wide, etc.), is fueled by the need to attain the sustainable development goals (SDGs) over the next 15 years to address critical/priority areas (e.g., people (poverty, hunger, clean water and sanitation), planet (sustainable consumption and production, environmental conservation, and climate action), prosperity (inclusive economic growth, affordable and clean energy, sustainable cities and communities), peace and partnership) of global welfare [7]. Mining can worsen the criticality of the said priority areas if efforts to mitigate the environmental repercussions of its operations are not adequate, as mining activities can endanger terrestrial and aquatic ecosystems, forests, and biodiversity through environmental impacts [8–10].

This work reviews previous research to discuss the structure of a circular economy and the approach through which a policy basis can be produced to guide policy actions to help mining in the mitigation of its environmental impacts. Some countries (e.g., China and Germany) have already made serious efforts to establish CE with the aid of research and legislation for the mitigation of environmental impacts of industrial processes [11,12]. The aim of influencing policy directions and options is paramount in these efforts, and configuration of a circular economy is deemed necessary in developing viable steps towards policy development. The focus of this work is the possible application of circular economy for mining in order to minimize waste and for mining wastes to be re-utilized as resource inputs in order to institute sustainability in mitigation efforts. An approach is proposed to come up with a policy basis to guide future actions towards CE to effectively manage mining's environmental repercussions. Thus, previous works covering the nature, configurations, and efforts to develop a circular economy, and tools useful in empirical investigation for circular economy implications, are reviewed here to shape policies for mining sustainability.

2. Circular Economy and Its Configurations for Sustainability

A literature review on CE application in mining, followed by life cycle thinking and systems thinking, had been conducted to collate relevant information and determine the framework that can guide policy implications towards CE development in mining. Many of these research articles are written by Chinese authors and in the Chinese language. Although relevant to this work, the absence of an English version was the reason why many of the articles were finally dropped from this work's list of references. Of the selected articles, four were found to tackle the application of circular economy in the mining industry. However, for China to have many publications on CE is not surprising since the country has been aggressive in the pursuit of CE to address its environmental impacts as an industrialized country [4]. In fact, it is the first country to implement a Circular Economy Law, which is envisioned to develop a large-scale industrial ecology [3]. Profound and increasing concerns for the environment and for the economy for sustainability are the main reasons for China to advocate a circular economy as its overall sustainable development policy [13], since the policy is aimed at having industrialization and economic development in the country without compromising the environment too much [14].

As a known champion of circular economy in the world [3], the Ellen MacArthur Foundation (EMF) advocates that, with a circular economy, sustainability/sustainable development can be achieved with the synergy of innovation and resilience to provide a lasting economic growth [15]. The definition of circular economy offers an explanation for this. Circular economy, according to the Ellen MacArthur Foundation (2015) [15], embodies a “restorative and regenerative system by design, which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.” Zhijun and Nailing (2007) [11] portray it as a result of a balanced synergy of economic and ecological development, where modernization can go on without

compromising the environment through eco-friendly and innovative strategies that utilize resources and energy sources (shift to renewable energy sources) and reduce and reuse wastes. Particularly, China's CE policy emphasizes the 3Rs (reducing, reusing and recycling) of minimizing wastes, or preliminarily designing out wastes [5,11,16–19]. Such strategies of managing wastes have already been adopted in many countries, such as Japan, Germany and other European countries [5].

To achieve sustainability or sustainable development, CE has to stimulate rearrangement or restructuring of industrial systems to induce efficient and eco-friendly operations [5]. Thus, it has to have a blueprint for the transformation of the current industrial systems, in which the goals are set to influence the mechanisms through which the desired transformation works. With the repercussions of industrial processes, many of these goals are hinged on controlling the adverse environmental impacts of the said processes [5,20–23]. As CE is systemic [15], the system where mining operates, in particular, has to be reshaped to institute the capability of the system to minimize adverse environmental repercussions. Haas et al. (2015) [24] have noted that closing the loops in a circular economy can be done in many ways, which can include shifts away from fossil energy sources and having efficiency gains spent on ways to eventually attenuate resource consumption. Preston (2012) [5] concurs that having sustainability and circularity central in business models and efforts of industrial organizations lead to a circular economy, which can go global due to sustainability-conscious efforts made by international cooperation.

To establish CE in the case of the mining sector, a framework with specific CE configurations, showing the ease of tracking progress towards CE development to design out mining wastes given the current practices and experiences of a mining industry, is important. From these configurations, the details of implementation can be derived and revalidated. Knowledge on these possible configurations can be found in the works of the Ellen MacArthur Foundation (2015) [15], Centre International de Référence Sur le Cycle de Vie Des Produits, Procédés et Services (CIRAIG) (2015) [3], Reh (2012) [25], and some Chinese researchers, including Zhijun and Nailong (2007) [11], Geng and Doberstein (2008) [4], Geng et al. (2009) [16], Jun and Xiang (2011) [26], Kun and Jian (2011) [27], Li and Su (2011) [28], Ru-yin and Xiao-Ting (2009) [29], and Lihong and Hui (2011) [30] to name a few. Particularly, the Ellen MacArthur Foundation (2015) [15] has configured a model of circular economy whereby all sectors in a value chain have to undertake measures of improving efficiency and minimizing negative externalities (Figure 1).

This configuration is governed by the ReSOLVE (Regenerate, Share, Optimize, Loop, Virtualize and Exchange) framework, which indicates the key actions for the transition towards a circular economy. These actions imply the use of renewable energy and materials and continued protection of the environment (Regenerate), resource sharing, reusing and extending the end of life (EoL) of products (Share), avoiding wastes by further improving efficiency (Optimize), recycling and producing useful products from microbial decomposition/anaerobic digestion (Loop), dematerialization or use of e-based products and processes (Virtualize), and opting for advanced technologies and multi-functionality (Exchange) in the chain to manage wastes [15]. The said configuration demonstrates a broad scale of circularity, which involves many industries, sectors, and processes in the economy. However, while it indicates some ways to design wastes out, it lacks clarity on the strategic mechanisms through which inevitable mining wastes (e.g., gangue, mine tailings and mine water) can be dealt with, specifically in the re-processing of such wastes for use in the manufacture of other goods in the economy.

Analogous to the earlier model, with clearer mechanisms on what and how to gradually work towards CE, is the layered CE model from China [3], where the layers correspond to the industrial enterprise (micro), the inter-enterprise (meso) and the societal (macro) levels [31], in an effort to design wastes out and to close the loop. The micro level emphasizes the industrial enterprise initiatives to avoid wastes through cleaner production technologies; the meso level highlights the eco-industrial parks and industrial symbiosis to reutilize wastes; and the macro level stresses large-scale sustainable production and consumption to minimize the build-up of waste [3]. This framework observes the 3Rs

(Reduce, Reuse and Recycle) to address the waste issues [20], which Reh (2012) [25] anticipates will be comprised of complex structures and processes. Particularly, Reh (2012) [25] recognizes the need to fully utilize clusters of complex industrial processing to get rid of wastes in resource consumption.

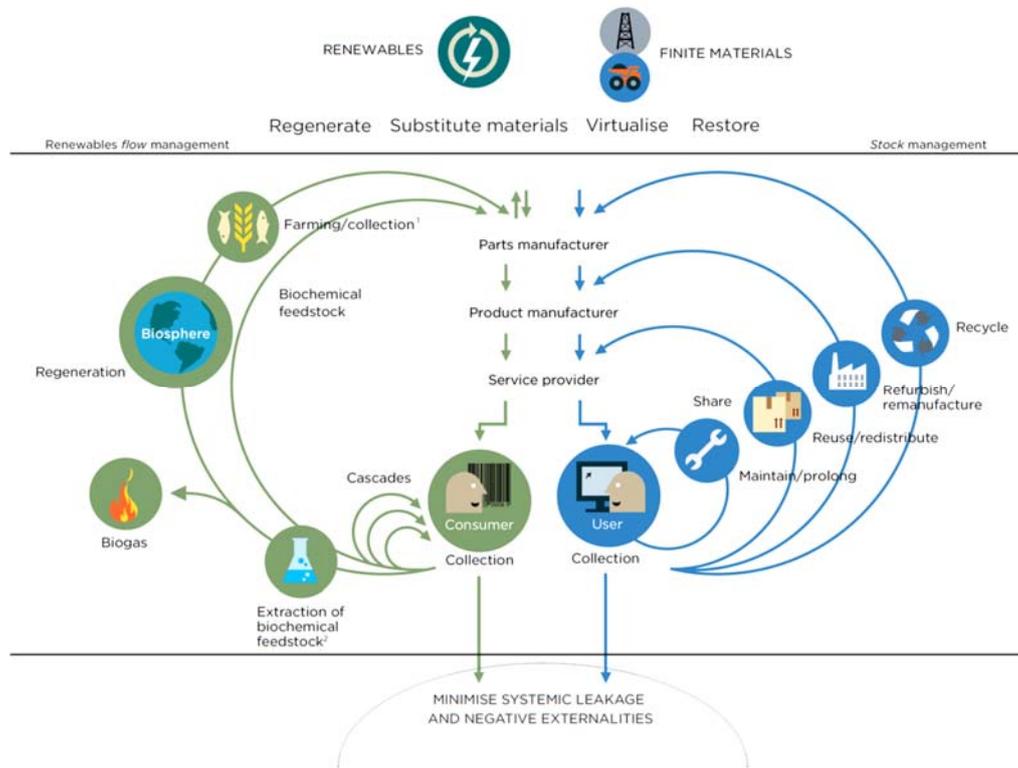


Figure 1. The circular economy, conceptualized by the Ellen MacArthur Foundation [15].

In the Chinese CE model, industrial enterprises have to continually work on the requirements for the reduction, reuse and recycling (3Rs) of wastes to achieve both environmental and economic improvement at the micro level [20]. These can be done, for instance, by applying eco-design of manufacturing plants, cleaner production technologies, and environmental management systems [20,32]. At the meso level, the eco-industrial parks highlight the mutual partnership of industries to undertake energy and by-product exchanges, use of shared infrastructure, and recycling of wastes, etc. [23]. The macro level takes on the pursuit of a broad-based sustainable production and consumption with eco-friendly cities, municipalities, and provinces and the local environmental protection bureaus to facilitate the discussion of environmental issues with decision makers [23]. In all these stages in Chinese CE development, political and technical underpinnings are strengthened with the participation of the public and many enterprises, industries, and sectors [23,32].

In the case of mining, the layered Chinese model of circular economy is worth exploring. With the extensiveness and the accumulation of mining impacts over the years, mining is not capable of dealing with its own mitigation of environmental impacts, while, at the same time, meeting the world’s demand for metals and minerals. It needs to gradually work on the elements of sustainability (economic, social and environmental) with clear directions and the help of various sectors (e.g., industries, civil societies, and the government). The emphasis of each layer in the Chinese CE model provides a guide on what and how strategies will have to be implemented to design out wastes. In contrast to the Ellen MacArthur Foundation’s (EMF) CE model, the Chinese CE model provides some details on the potential approach, or the strategic mechanism, of attaining the end result, where designing out wastes, closing the loop, and sustainability, are instituted by the synergy of many sectors (government, civil society and private actors/stakeholders) through the upper layers [3]. But the ReSOLVE framework of

the EMF's CE model elaborates some specific actions to apply for the 3Rs of the Chinese CE model. Bermejo (2014) [33] has broached circular economy in mining as a way to achieve sustainability, only there are still issues to consider. This work has particularly looked into circular economy in mining from the studies of Zhao et al. (2011) [21], Ru-yin and Xiao-ting (2009) [29], Pauliuk et al. (2012) [34], and Ma et al. (2013) [35].

3. Life Cycle and Systems Thinking in Circular Economy Configuration for Policy Directions

Getting to the bottom of successfully implementing a circular economy, especially for mining, is, perhaps, a tall order at this time, yet the efforts of working towards this goal, especially in China and Europe, are observed to have progressed constantly. Approaches to deal with it proactively are evolving quickly, and their use in research is key in anticipating some stumbling blocks towards achieving CE implementation at any level. Life cycle thinking and systems thinking are among the approaches that are identified with circular economy efforts [3]. Life cycle thinking provides the paradigm for examining the alternatives in products, services and technologies over the entire life cycle, in order to manage any resulting environmental impacts [36]. It helps to prevent burden shifting [36] by properly attributing the environmental damages and interventions to the responsible actor/organization over a product's life cycle [37]. Life cycle assessment (LCA) is anchored on life cycle thinking, which has variants covering the pillars of the triple bottom line sustainability framework [38,39]. The environmental LCA, life cycle costing, and social LCA are the tools used to investigate the environmental, economic and social repercussions of producing a product over its life cycle, respectively; the use of which, in mining, is similarly aimed at finding the environmental and socioeconomic hotspots of the mining process [10,40–47]. Through understanding these hotspots, the mining industry can further know its mitigation options and to self-regulate through technology shifts and recycling, and partnerships with other industries in the reutilization of mining wastes for other industrial products [48].

Life cycle thinking is not only associated with life cycle assessment, but also with life cycle management, in which the goal is to reduce environmental impacts with the use of the International Organization for Standardization (ISO) methodologies [3]. Meanwhile, the various hotspots indicated through the use of LCA methods are important inputs to broaden empirical analysis via systems thinking. Systems thinking is central in both industrial ecology and circular economy [3], because designing out wastes and closing the loop needs a holistic understanding and support for broad-based acceptance and success of interventions towards circularity. It lends a backbone to systems dynamic models that can study complex inter-linkages between or among processes [49] for sensible policy formulation. Particularly, the work of Arbault et al. [49] has demonstrated the integration of life cycle assessment and systems dynamic modeling in the impact assessment of ecosystem services. Circular economy, according to the Ellen MacArthur Foundation, is a framework that is hinged on systems thinking [3], because it is necessary to understand the elements that catalyze circularity, and holding these elements together to be effective. Both the CE models of the Ellen MacArthur Foundation and of China convey the importance of systems thinking, since the concerned system involves complex interrelationships among enterprises, civil societies, and the government.

In the application of sustainability to mining, the Chinese model of circular economy presents a viable configuration to reach the CE, as conceptualized by the Ellen MacArthur Foundation. The eco-industrial park (meso) level of circular economy gives an idea of industrial symbiosis through mutual cooperation and partnership of industries in the recapture and re-utilization of mining wastes that impact the environment. According to Lottermoser (2010) [50], mine waste constitutes the greatest amount of waste produced by an industrial operation, in the range of millions of tons per year for solid wastes alone [50]. Additionally, mineral processing activities produce tailings and mine water contaminated with heavy metals, such as mercury, arsenic and lead, which are harmful to humans and other living things when in high concentrations [51]. However, Lottermoser (2007, 2010) [50,51] has considered these wastes to be useful in the future with the discovery of new technologies and markets

for products made out of said wastes. In a proactive way of tackling circular economy for mining, the approaches anchored on life cycle and systems thinking are important in determining the dimensions and the specific problem areas to focus on for policy action. Integrated approaches through which the complex relationships of units in a broad-based system can be handled are also relevant.

One integrated approach that can be explored for this aspect is the integrated model developed by Halog and Manik (2011) [52], which had been used in the evaluation of supply chain networks of wood-based ethanol and palm-oil biodiesel, and of the forest-based eco-industrial park in Maine, USA. This approach is noted to consist of the environmental and social LCA and life cycle costing and systems dynamic modeling, among other tools, in the analysis of a system's performance with respect to sustainability [52]. The insights from the said model can be used in rethinking the issues that have challenged CE development with respect to mining. Bermejo (2014) [33] identified these issues as having to do with the usage of metals (of which demand is increasing) in many, but small quantities, long metal product chains, and the infeasibility of large-scale metal recovery (many metals of small quantities to be recovered). Longer and complex products chains can undermine CE implementation [33]. On the other hand, Zhao et al. (2011) [21], Pauliuk et al. (2012) [34], and Ma et al. (2013) [35] have identified challenges associated with the need to retool technologies to be eco-friendly, efficient, and able to process the by-products from processing; to manage the current production and consumption of mining products (e.g., steel) to avoid overproduction and build-up of scraps in the long run; to improve the quality of recycled materials (e.g., secondary steel can be weaker in strength); and to deal with the complexity of developing circular economy at the societal level in order to meet the requirements of closing the loop.

4. A Proposed Framework for Developing Circular Economy Policy Recommendations for Mining

In addition to Europe and in other parts of the world, CE research has flourished across China over the past few years. In fact, most of the articles reviewed in this work are written by Chinese researchers for China's CE implementation. Particularly, Zhijun and Nailing (2007) [11], Geng and Doberstein (2008) [4], and Geng et al. (2009) [16] have tracked down the mechanisms of implementation and development of a circular economy in China. Jun and Xiang (2011) [26] discussed CE as a strategy to achieve sustainable development in Chinese agriculture. Kun and Jian (2011) [27] dealt on CE in the exploitation of oil and gas, while Li and Su (2011) [28] evaluated the development of circular economy in Chinese chemical enterprises, with a criteria based on resource use, biological efficiency, economic development, effluents production, and development potential. Lihong and Hui (2011) [30] analyzed the industrial structure relative to the circular economy development in Shandong Province. All of these works admit the difficult challenge of working towards the establishment of CE in order to have both environmental and economic soundness for sustainability. Thus far, CE is still a work in progress across the world. However, in the interest of developing CE in the mining sector, the works of Ru-yin and Xiao-Ting (2009) [29], Zhao et al. (2011) [21], Pauliuk et al. (2012) [34], and Ma et al. (2013) [35] have been reviewed, as these works have dealt directly with CE in mining. Ru-yin and Xiao-ting (2009) [29] used entropy flows in analyzing the configuration of industries in the mining sector to absorb the entropy flows from mining processes and to maintain balance in the environment. Pauliuk et al. (2012) [34] used dynamic material flow analysis in analyzing the Chinese steel industry. Zhao et al. (2011) [21] discussed CE in mining based on the 3R principle, while Ma et al. (2013) [35] evaluated the performance of the Chinese steel and iron industry in Wu'an City towards CE with a system of circular economy efficiency composite index (CEEI).

Three of these four papers on CE in mining have demonstrated some methods to identify areas of industrial symbiosis development, while one paper has shown how a mining industry could be gauged in terms of its performance towards waste minimization. However, an integrated approach that looks into the aspects of the environment, society and economy for the policy underpinnings of a mining-based CE is not tackled in these works, including those not associated with mining. Thus, this section shows the proposed approach of research with concern on those three aspects and on

how to influence policy interventions for a circular economy in mining. Based on these insights, the said approach is guided by four elements—the need to reuse mining wastes, the layers of circular economy, life cycle thinking, and systems thinking. It consists of an integrated framework to produce policy insights for the three aspects (environment, society and economy) across the layers of CE development. Perhaps, this approach might not be new to some practitioners of integrated analysis, specifically in developed countries and in countries where circular economy research is more intense and advanced. However, it is relevant for mining countries, especially the developing to the least developed ones that have continuously contended with how to address the environmental impacts of mining (large- and small-scale) effectively and sustainably. Thus, the proposed approach shows a framework exhibiting the layers of CE based on the Chinese model, and the analytical tools for each layer. The emphasis of this framework is to gain policy insights towards designing out mining wastes.

Figure 2 demonstrates the importance of a systematic trans-disciplinary approach of arriving at policies for a mining-based CE, in order to design out mining wastes and to eventually mitigate the environmental repercussions of mining. The said approach is vital in evaluating and verifying the technical and socio-economic soundness of technology options for addressing the environmental impacts of mining. Table 1 shows some of the technologies that have been currently worked out to deal with the said impacts and wastes from mining operations. These technologies are categorized with respect to the layers and the 3R principle from the Chinese CE model and the ReSOLVE framework of the Ellen MacArthur Foundation's CE model (Table 1). In Figure 2, the enterprise level is at the bottom, where the main concern is finding the performance of a mining process (particularly on the extraction and processing of minerals and transport of the mineral products) towards environmental, social, and economic sustainability. With the LCA methods, the environmental, social, and economic hotspots of the mining process or over the life cycle of the mineral products can be identified for policy implications (e.g., provision, feasibility, and adoption of eco-friendly technological changes and occupational practices and application of bioremediation) to contain wastes and to protect people. The use of material flow analysis (MFA) provides the material balances and efficiency of the mining process, which provides the basis for characterizing the wastes for potential uses in the promotion of industrial symbiosis. MFA can also focus on industrial and socio-economic metabolisms of mining, in order to see the scope of mining impacts for the purpose of policy intervention.

For the second layer, industrial symbiosis anchored on mining wastes can be configured on the basis of by-products and waste exchanges (Figure 2). Characterizing the mining wastes at this point is a requirement to identify the industries that are likely to re-utilize said wastes, and the technologies associated with reutilization. An inventory of technologies for mining waste re-utilization and of industries to re-utilize said wastes is important to identify the gaps for policy insights. An example of industrial symbiosis with respect to mining is exhibited by the synergy of industries operating in the industrial areas of Kwinana, Western Australia, and Gladstone, Queensland, where some industries take the wastes and by-products of mineral processing for separation, reuse, and conversion into useful products (e.g., fertilizers, cement, and plasterboard) [53]. Synergy on energy (e.g., superheated steam and electricity) has been also demonstrated particularly in the industrial area of Kwinana, Western Australia [53]. Meanwhile, systems dynamic modeling is an approach relevant for analyzing the development of industrial symbiosis on the basis of by-product and waste exchanges between or among industries to minimize mining wastes. Scenario analyses can be made through said approach to find the outcomes of developing such an industrial symbiosis in the mining industry.

Although partnerships with industries, at this point, are based on the reuse and recycling of mining wastes for industrial production, the possibility of sharing other resources (e.g., technologies and infrastructure) among industry partners can be also looked into. A policy window is seen important for industry partnerships, because trust, mutual cooperation, and self-governance are essential for the success of industrial symbiosis. At the regional level, implications for sustainable production and consumption in relation to mining products can be looked at, which also has implications on the utilization of electronic products. Most mining products (metals and minerals) are key ingredients

in the production of electronic products, which comprise the build-up of e-wastes across the world. With the framework (Figure 2), some policy platforms can be drawn from analyzing support for the provision of R&D services for mining waste reutilization and renewable energy research, for investment agenda and business incubation related to mining wastes, and for mining waste monitoring, etc. The systems dynamic model is an expandable model, which can cover the relevant micro and macro variables for the regional level of analysis. Systems dynamic modeling is also identified for such an analysis because it can assess policy resistance, which has been a reason for most policy failures. The abovementioned framework for policy insights on mining CE is a modification of Halog and Manik’s (2011) [52] integrated model, which is holistic, applicable to a subpart (e.g., gold mining, nickel mining, etc.) of the mining industry, and expandable in scope to cover the interrelationships, inside and outside of the mining industry.

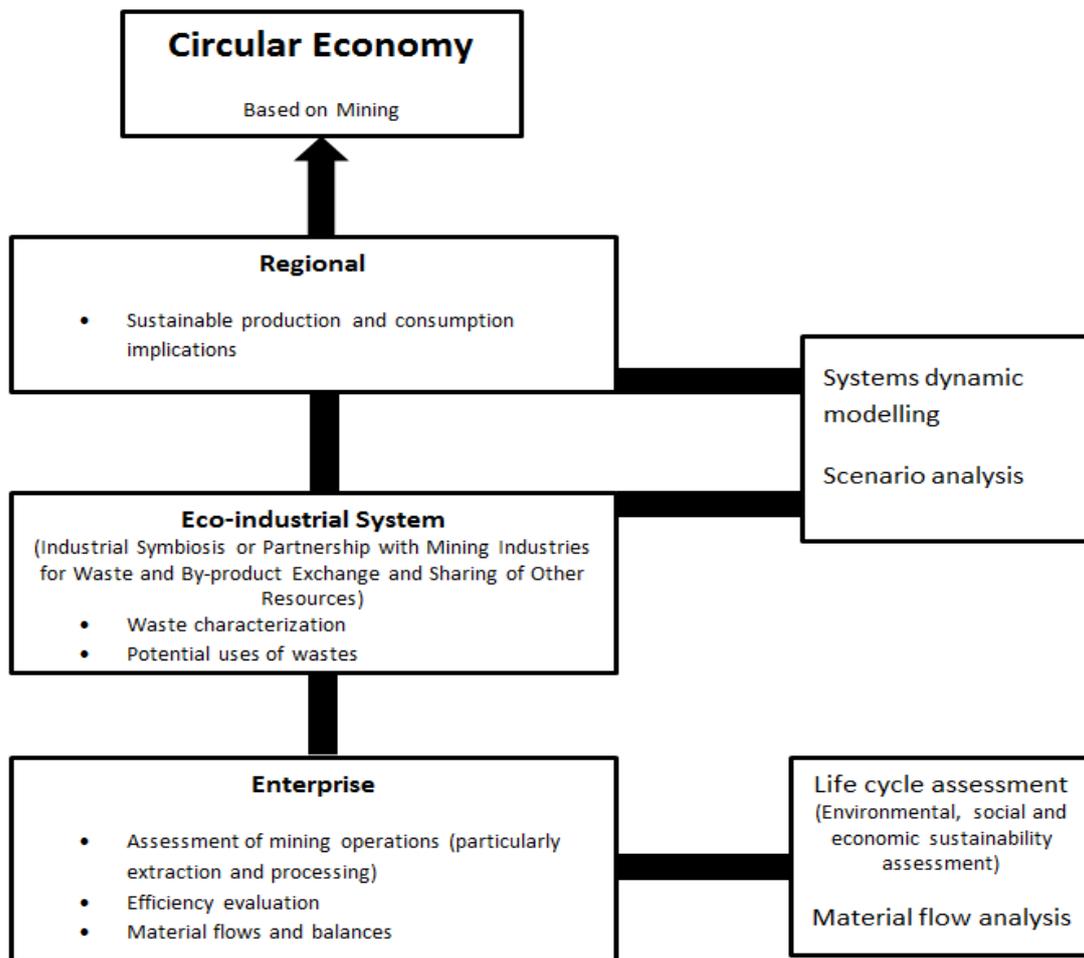


Figure 2. The framework for developing policy insights for a mining CE.

Table 1. Some innovative options and approaches towards CE in mining.

CE Layers	Some Examples of Technologies and Approaches	Sources
Enterprise (micro)	Facility and process engineering improvement (e.g., dry quenching and dry-dedusting techniques for blast furnaces and converter flue gas, comprehensive use of water, flue gas and all solid wastes, regenerative combustion technology, gas recycling technology, blast furnace top gas recovery unit technology, sintering desulfurization, use of retorts, etc.) ^{Red, Rec, O, L}	[29,35]
	Mine water recycling ^{Rec, L}	[54,55]
	Mine water management ^{Red, O}	[56,57]
	Bioremediation ^{Red, E}	[58–61]
	Mine rehabilitation (e.g., progressive type) ^{Red, R}	[55,62]
Inter-enterprise (meso)	Shift to renewable energy and decarbonization ^{Red, R}	[63,64]
	Mine waste re-utilization ^{Reu, S, E}	[29,55]
	Metals recycling ^{Rec, L}	[65–67]
	Heavy metals recovery (from tailings and mine water) ^{Reu, E}	[68–70]
Society (macro)	Structural adjustment (improvement in industrial layout: regional industrial transfers and relocation) ^{Red, O}	[35]
	Dematerialization ^{Red, V}	[71,72]
	Extension of end of life (EoL) of products from mining ^{Red, V}	[73–75]

Note: ^{Red} Reduce; ^{Reu} Reuse; ^{Rec} Recycle (3Rs); ^R Regenerate ^S Share; ^O Optimize; ^L Loop; ^V Virtualize; ^E Exchange (ReSOLVE Framework).

5. Conclusions

The importance of a circular economy in the discourse of sustainability or sustainable development is made clear, with ongoing efforts to push towards a sustained economic development, without compromising the health of the environment. China has adopted a tiered circular economy for this, which is looked at for application in mining to mitigate environmental impacts. Other countries (e.g., Japan and Germany) have also done so for their enterprises, following their respective frameworks, but, across the world, CE is still a work in progress. Adding up these tiers or layers in the Chinese model of circular economy results in the same broad scale CE conceptualized by the Ellen MacArthur Foundation. The Chinese model of CE has been the focus of conceptualizing a framework for mining because of clearer strategic mechanisms (implied by the tiers) to develop CE, although the working principles for both models are similar. Particularly, the progression of effort towards designing out mining wastes, finding value out of wastes, and instituting sustainability in mining, can be easily tracked with the layers in the Chinese model of circular economy.

Life cycle thinking and systems thinking are identified with the circular economy concept and are applied in the framework designed for the development of policy insights to design out mining wastes. The said framework is a holistic approach, modified from Halog and Manik's (2011) [52] work, which can be applicable to a part of the mining industry, and can be expanded to cover the important aspects of analyzing for the circular economy in mining. Life cycle assessment methods and systems dynamic modeling are the key methods in the framework to analyze the environmental, social, and economic sustainability of the mining process, to identify and properly evaluate the technology options and strategic mechanisms, and to cover as many important aspects as possible in a holistic analysis for sensible policy implications. Systems dynamic modeling is an approach that has been recognized for its ability to check for policy resistance. Thus, the framework is an integrated approach that is based on the triple bottom line of sustainability, and is intended to give policy directions to start the possibility of developing CE for mining sustainability, especially in developing to the least developed mining countries faced with the challenges on mining wastes.

Acknowledgments: The Schlumberger Foundation Faculty for the Future is acknowledged in this work for the fellowship award it has granted to the first author, which made this manuscript possible.

Author Contributions: Raquel Balanay has taken part in conceptualizing and writing the manuscript. Anthony Halog has taken part in conceptualizing, preparing and checking the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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