Mining in the context of sustainable management of natural capital: the importance of waste recycling and reuse

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Abstract

Purpose

In the traditional modern economy, natural resources are mined and extracted, turned into products and finally discarded, with this linear development model driven by heavy industrial growth and resource-intensive infrastructure. While the debate surrounding 'peak minerals' and the potential threat posed by resource scarcity is ongoing, addressing the ever-growing consumption and demand for raw materials comes down to the need to manage environmental resources more sustainably .

Methods

Mining can form an integral part of wider resources management, with the need for re-assessing the potential of mining in the context of sustainable management of natural capital, and with a renewed focus on its the role from a systems perspective. Waste reclamation and reuse provides a unique and viable opportunity to augment traditional resource supplies. As a multi-disciplined and important element of resource development and management, resource reuse can help to close the loop between supply and waste disposal.

Results

Findings demonstrate that the energy costs first in collecting, extracting, conveying, and distributing materials for manufacturing products and secondly in treating and disposing of the waste once the products reach the end of their life or they are simply discarded, are increasingly becoming significant. On the other hand, although it requires additional energy to treat wastes for recycling, the amount of energy required to treat and/or transport other sources of resources is generally much greater.

Conclusions

As a result the need for a life cycle perspective in closing the loop between mining, production, consumption and waste generation is emerging as a new more attractive option. Rather than releasing high quality wastes back into the environment while paying to extract it as minerals through traditional mining, it is more sustainable and energy efficient to close the loop.

Keywords: sustainability; systems thinking; mining; sustainable resources management

Introduction

In a world expected to reach 9 billion people by 2030, with 3 billion additional new middle-class consumers – the challenges of meeting demand resources are unprecedented. Although increasing public and scientific concern in recent years has led to the introduction of both national and international regulations, the ever-growing consumption and demand for materials, and the growing evidence of associated serious and irreversible ecological consequences clearly demonstrate the need to manage environmental resources more sustainably [1].

Identifying and building sustainable resource management systems is one of the most critical issues that today's society is trying to address. Recent trends with regard to mineral resources have presented many new challenges for resource management, including mining. Operations research is becoming increasingly prevalent in the natural resource sector, specifically in agriculture, fisheries, forestry and mining. While there are similar research questions in these areas, e.g., how to harvest and/or extract the resources and how to account for environmental impacts, there are also differences, e.g., the length of time associated with a growth and harvesting or extraction cycle, and whether or not the resource is renewable. Research in all four areas is at different levels of advancement in terms of the methodology currently developed and the acceptance of implementable plans and policies [2].Owing to population growth and rises in incomes, per capita resource use has been increasing sharply [3]. At the same time, there is a need to achieve more with less by improving the living standards of the poor while improving the sustainability of resource use and shrinking our ecological footprint. While technological advancements and clean production approaches have vastly improved environmental management and material and energy efficiency in mining [4], these new challenges threaten to overwhelm our capacity to adapt through technological improvements alone.

Mining is one of humanity’s earliest activities, with archaeological remains of mining sites dating back to Palaeolithic times, and indeed entire historical eras being named according to their use of metals, e.g. the bronze and iron ages [5]. From prehistoric flint quarries, mining has evolved dramatically over history to the carefully and scientifically managed and often highly mechanised process it is today [6]. As a result, mining has been of critical importance to industrialisation, urbanisation and modern society as a whole [7-8]. The raw materials provided by mining, together with agriculture, fisheries and forestry, are vital to virtually all human activities and sustain industries as diverse as ceramics, fossil fuels, construction, pharmaceuticals, jewellery and electronics, among many others [9].

While there has been contentious debate surrounding the validity of the term ‘sustainable mining’ [7, 10-11], the paper assesses how mining can form an integral part of wider sustainable resources management.The need for re-assessing the potential of mining in the context of sustainable management of natural capital is discussed and a renewed focus on the role of mining from a systems perspective is proposed.

Environmental impacts of mining

While its economic importance is clear, mining has also been the cause of many serious environmental and human health problems. Throughout all of its five lifecycle stages, prospecting, exploration, mine development, exploitation and reclamation [12], mining can cause numerous impacts ranging from soil or water contamination resulting from metalliferous mining and smelting to corruption of authorities in communities near mining corporate activities [13]. Specific impacts can include habitat loss, soil contamination, contamination of ground and surface water, creation of voids or sinkholes and physical disturbance for the construction of roads and infrastructure, among others [14]. Deforestation can also occur in the vicinity of mines to provide space for the storage of debris, soil and waste resulting from mining [15], while natural hazards can present further environmental risks, such as mining in seismically active areas [16]. As well as causing environmental damage, chemical contamination caused by mining can affect the health of the local population [17-18]. In many countries, mining must adhere to environmental regulations, including for instance requirements for the reclamation and restoration of mine sites [19]. However, certain mining methods or poorly managed operations can have particularly adverse impacts on both the environment and public health [20]. Mining and smelting are some of the largest sources of environmental pollution from heavy metals even today. For example, in China, one of the largest producers and consumers of lead and zinc, large amounts of these elements and others related ones, such as cadmium, have been released into the environment due to mineral processing activities and have impacted water resources, soils, vegetables, and crops. In many areas concentrations of pollutants such as Lead (Pb) and cadmium (Cd) are associated with human health effects including high lead blood levels in children, arthralgia, osteomalacia, and excessive cadmium in urine [21].

On the other hand, often physical and economic causalities of mining are overestimated when included in life cycle assessments, as many mines have multiple functions and produce multiple metals. The ability to reflect changes in production and the economic value of metals is often a limitation in environmental studies related to metal mining [22]. In general, most of today's mines are highly regulated and make extensive use of pollution prevention and environmental protection technologies [23], and have been more recently complemented by the increased use of more comprehensive environmental management and clean production approaches by mining companies [24]. Recognition has grown that the possible environmental and social risks of mining expose not only mining companies directly, but also financial institutions, insurance companies, and metals product buyers who might be subject to consumer pressure [16]. In addition, the growing profile of sustainability and corporate social responsibility has led to at least some large mining companies to improve their reporting on social and environmental impacts, though still with no generally accepted international standards or consistency [16, 25]. Even in China, there has recently been concern expressed about the decline of ecosystem services, calling for the need to integrate ecological and environmental impacts into decision-making systems and the need for environmental management to decrease the harmful impact of mining and restore injured natural ecosystems [26].

Mining in the context of sustainable resources management

One of the most profound failures of our industrialised society is the way in which our production processes are so entirely linear. While this approach is perhaps "efficient" in the traditional sense (more product, less time, fewer inputs), when we consider the larger costs of production, those that are most often seen as externalities (e.g. wastewater discharge, air emissions, depleted soils, razed forests), it is harder to demonstrate overall net benefit from many of our practices [27]. Rather than releasing high quality wastes back into the environment while paying to extract it as minerals through traditional mining, it is more sustainable and energy efficient to close the loop (Figure 1). As a result, resource reuse can help to close the loop between supply and waste disposal, providing a sustainable alternative to mining of virgin stocks. Achieving more from less by closing resource loops is paramount given the two-fold need of protecting the environment and recognizing the importance of natural capital while at the same time enhancing our economic prosperity and improving living standards of developing countries and the world's poor.

In addition, in light of increasing concerns of material security, shortages and environmental pollution, realistic frameworks have emerged for processing mining waste as a resource in many parts of the world [28-31]. Mining and mineral-processing wastes are one of the world's largest chronic waste concerns. If properly evaluated, mining waste can be reused to reextract minerals, provide additional fuel for power plants, supply construction materials, and repair surface and subsurface land structures altered by mining activities themselves. The chemical composition and geotechnical properties of the source rock determine which uses are most appropriate and whether reuse is economically feasible [32]. More broadly, waste reclamation and reuse can provide a viable opportunity to augment traditional resource supplies, at the same time reducing the need for waste disposal [33].

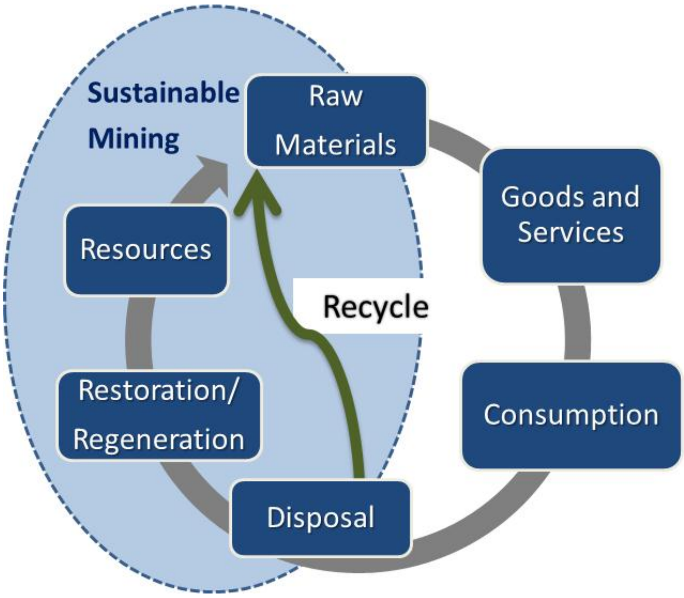

Figure 1: Closing the loop: mining in the context of sustainable resources management

Recycling valuable materials is a highly efficient way of reintroducing them into the economy, hence supporting value creation, while lowering environmental impacts and energy intensity of materials supply. Non-ferrous metals can help this business case, with their endless recyclability meaning they can be re-used again and again, truly contributing to a Circular Economy. High volume metals including aluminium, copper, nickel, zinc and lead already having high recycling rates in Europe, and a great potential for increased recycling of other metals remains, including other valuable and critical raw materials.

Sustainable mining

While it has been often accepted that it is the responsibility of governments to impose solutions upon resource users in the form of regulation in order to achieve sustainable resource use, some government policies have been shown to accelerate resource destruction, and conversely some resource users have seen the benefit in making the investment needed for increased sustainability [34]. Achieving this sustainability, however, requires our many ecological/environmental, economic and social issues to be accounted for (Figure2). A better understanding of demand and pressure on resources is needed, followed by appropriate pricing that is inclusive of all environmental costs, with new opportunities for mining in the wastes we generate.

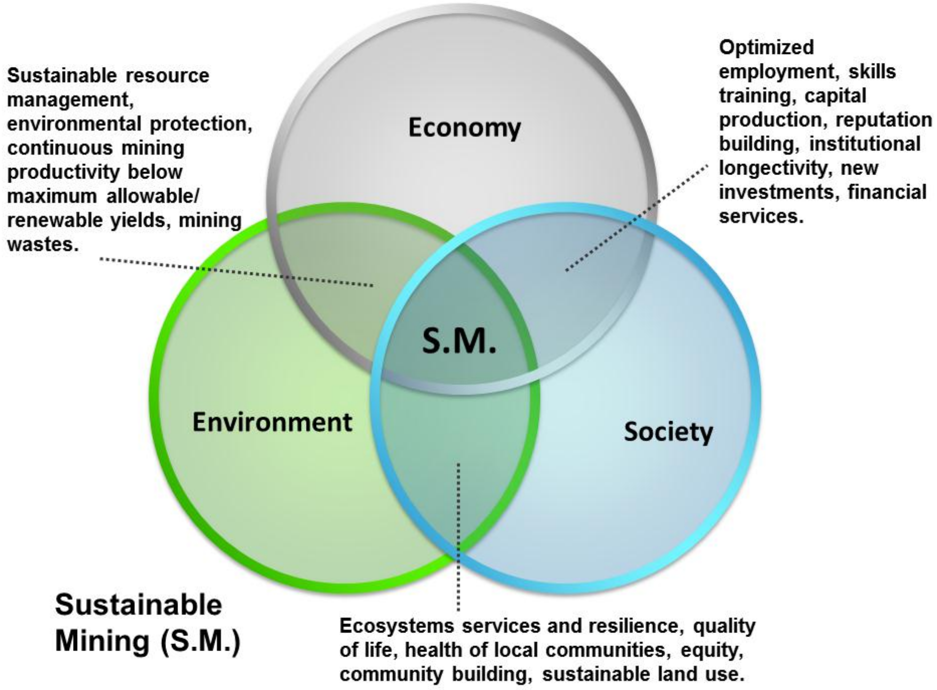

Figure 2: Sustainable mining.

There is a need for more appropriate pricing that is inclusive of all environmental costs and for environmental externalities to be better accounted for in decision and policymaking in relation to the mining sector. The carrying capacity of the natural environment is an unpriced input to resource production, and it is increasingly accepted that resource users should be made to pay for the environmental impacts they cause [35]. While several methods for the monetary valuation of environmental impacts have been developed [36], the internalisation of environmental costs have yet to be fully mainstreamed in practice [37]. In addition, the World Bank Group (WBG) has continued to promote the expansion of mining activities in resource-rich client-countries, maintaining its mantra on the economic benefits of the sector in cash-strapped countries, though slowly in recent years also increasingly including the importance of poverty reduction and environmental sustainability (often justifying the need for the WBG to remain actively involved in the sector). Although in many cases this new socio-environmental narrative has helped influence a wave of new mining regimes which comprise multilateral social and environmental safeguards, often these in conjunction with the highly political nature of the role played by the WBG in the mining sector of its country-clients have been criticized to be more for circumscribing the risks faced by industry, rather than by local populations [38]. This partly positive influence has also been a barrier to more integrated systems for resource management.

Properly accounting for natural capital in resources management first requires a more comprehensive understanding of how materials and their waste by-products, including those produced through mining activities, are used and discarded [39]. Economies are largely dependent on linear systems where resources are extracted from virgin stocks before ending up as discarded waste after proceeding through a supply chain which itself produces waste at every stage [40]. While the debate surrounding 'peak minerals' and the potential threat posed by resource scarcity is ongoing [41-45], it is regardless essential to address inefficiencies of this system, especially when social and environmental constraints are taken into account in addition to physical ones [46]. At the same time, mined materials (such as platinum group elements (PGEs)) are increasingly used in a variety of environmentally-related technologies, such as chemical process catalysts, catalytic converters for vehicle exhaust control, hydrogen fuel cells, electronic components, and a variety of specialty medical uses, among others, almost all of which have strong expected growth to meet environmental and technological challenges. Although even if some economic geologists have been arguing on the case of abundant geologic resources, environmental impacts associated with any increases in production will still require management [47].

Though technological advancements and the changing economic climate are likely to make the exploitation of new virgin stocks viable, opportunities found in alternative non-virgin stocks such as waste must be better taken advantage of. Information on the scale and distribution of such stocks is limited, however, with individual components of the supply chain too often viewed in isolation [48]. Material Flow Analysis (MFA) is one tool that can be utilised to address this, helping to inform analysis of resource availability, energy consumption, environmental degradation and government policy [48]. Figure 3below provides an example of such MFA accounting, showing the copper cycle in Australia.

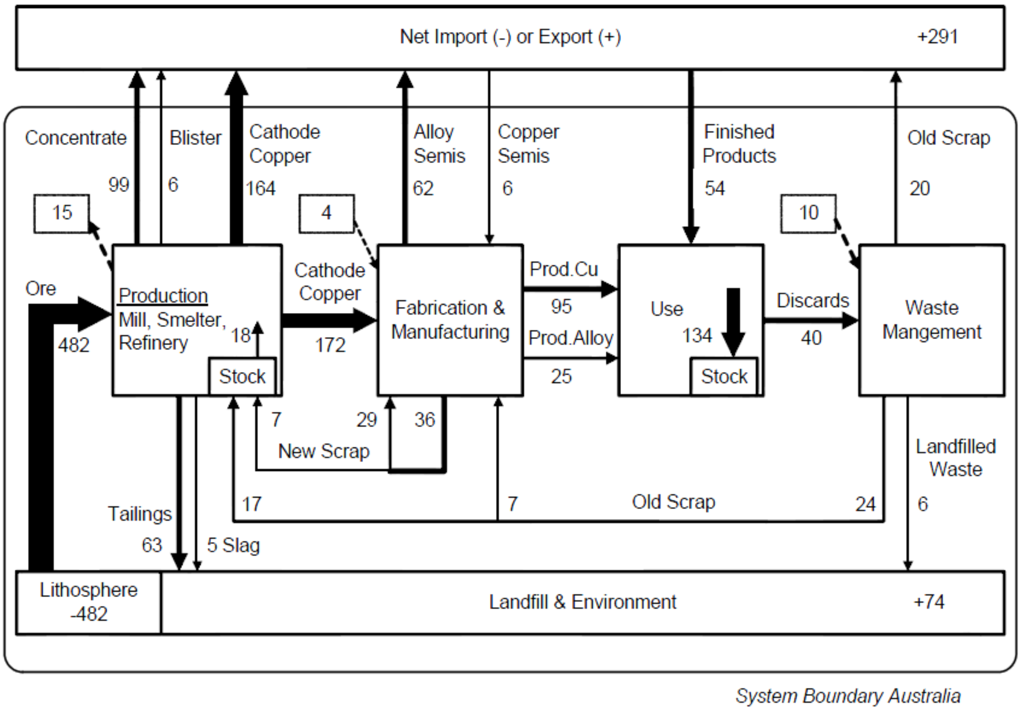

Figure 3: Australia Copper Cycle [48]

The alumina industry worldwide has reduced the volume of waste produced by about fifty percent. Valuable raw materials are recovered, and the risk of storage failure is reduced significantly. For example, dry disposal produces a paste for stacking and drying instead of a water-like suspension to be stored in a dam or pond and other options demonstrating a greater positive change in the waste management practices, motivated by a number of factors, including public perception, water recovery, the necessity to earn the right to operate, and perhaps even by common sense accounting [49]. Similarly in the case of copper, there have been efforts to mitigate some of the negative effects of increased copper use and copper mining. Recent progress in microbiological and biotechnological aspects of microorganisms in contact with copper could lead to more thermo-tolerant, copper ion-resistant microorganisms that could improve copper leaching and lessen copper groundwater contamination. Copper ion-resistant bacteria associated with plants might be useful in biostabilization and phytoremediation of copper-contaminated environments [50].

Owing to legislation such as REACH and other drivers such as corporate social responsibility (CSR), in mining the focus has already grown from being primarily on economic and health and safety concerns to more broadly encompass a full range of environmental, social and economic impacts. However, the emergence of new threats such as climate change and resource scarcity will drive further changes in management. Growing unpredictability in the climate will need to be more adequately accounted for, as will potential increases in water scarcity or energy costs for mining.

Discussion

Sustainability necessitates a more integrated and interdisciplinary approach to mining and resources management that takes into account interrelationships between resources, people and the environment. Our current understanding of the wider processes that govern natural resources is still limited, because scientific disciplines use different concepts and languages to describe and explain complex ecological systems [34]. This problematic focus on individual components rather than wider systems has hindered the development of more effective and integrated solutions to managing environmental, and indeed economic and social, problems associated with mining [1]. Because of the current limited understanding of wider processes, advancements in individual fields and disciplines have not been matched with major improvements in understanding the complex interrelationships among them. Achieving such a 'systems mindset' with an emphasis on interdisciplinary and holistic thinking is a prerequisite to addressing resource management challenges and solving the environmental problems of mining.

The nexus of water, energy and materials is slowly becoming recognised as a system that needs to be examined, but solutions have so far not been nearly integrated enough to deliver overall benefits across the sectors, especially in light of the many emerging challenges facing resources management. Rising global demand for mining commodities will increase the sector's impact on water resources, a trend exacerbated by the fact that mining activities are increasingly taking place in water scarce regions, that climate change presents further challenges in terms of water scarcity, and that globally declining ore grades for many major commodities are likely to increase water demands for most future mines [51]. Meeting the growing demand for commodities will of course also bring additional demand for energy used in extraction, processing and transport, while it is additionally evident that material constraints could have an impact on the sustained growth of the renewable energy sector [52-54].

The mining industry still faces challenges at all stages of the metals value chain, but recovery from wastes is an important issue. In Europe for example, this is limited by leakage of waste outside of Europe, to the continued lack of implementing measures to reduce landfilling in several EU Member States.

A Circular Economy Package currently in discussion could address some of these challenges altogether, by implementing several measures across each stage of the metals lifecycle to achieve priority objectives:

- Secure cost-efficient access to secondary raw materials. as a complementary approach to mining and resource-efficient manufacturing and use of materials

- Move from “waste” management to “resource” management, by prioritising the efficient recovery of valuable materials from recyclable waste and end-of-life products.

Achieving these objectives will be an environmental and economic “win-win” for Europe, helping to establish an EU circular economy, while supporting the continued competitiveness and growth of its industry and others.

Again it comes down to systems thinking. Systems thinking, for any kind of system, natural, scientific, engineered, human, or conceptual, provides a very useful framework for really solving problems rather than just taking decisions. It is the complexity of natural systems that create the real challenge for environmental problem solving, and the reason why for example further research on system analysis tools could provide further opportunities for interdisciplinary, integrated and holistic solutions to resources management that will shape the future of mining operations. The last few years have seen a shift from policy in reaction to high profile events, then to control of releases to single environmental media, and to the present position of moving toward integrated management of all environmental media. This development has moved away from classical chemical risk assessment toward environmental holism, including recognition of the ecological value of these media and resources management in the whole life cycle [55]. Challenges for environmental policy will increase in the future and the role of mining will be central to any discussions. The question remains if mining will be perceived as part of the problem or part of the solution for a sustainable future. Before that, mining companies might soon face the choice between two roles: that of exploiters of natural resources or that of managers of natural resources cycles.

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