

Review

The Drive towards Consensual Perspectives for Enhancing Sustainable Mining

Abdul-Wadood Moomen ^{1,2,3,4,*}, Pierre Lacroix ^{2,5} , Michela Bertolotto ¹ and David Jensen ³

¹ School of Computer Science, University College Dublin (UCD), Bellfield, Dublin 4, Ireland; michela.bertolotto@ucd.ie

² Global Resource Information Division (GRID-Geneva), Institute for Environmental Sciences, University of Geneva, Bd Carl-Vogt 66, CH-1211 Geneva, Switzerland; pierre.lacroix@unige.ch

³ Environmental Cooperation for Peacebuilding, United Nations Environment Programme (UNEP), International Environment House, 11 chemin des Anémones, CH-1219 Chatelaine, Switzerland; david.jensen@un.org

⁴ School of Geosciences, University of Energy and Natural Resources, P.O. Box 214 Sunyani, Ghana

⁵ Institute for Environmental Sciences, EnviroSPACE Lab., University of Geneva, Bd Carl-Vogt 66, CH-1211 Geneva, Switzerland

* Correspondence: abdul-wadood.moomen@ucd.ie; Tel.: +233-20-074-4442

Received: 2 October 2020; Accepted: 14 December 2020; Published: 16 December 2020



Abstract: This paper investigates key innovative paradigms that seek enhanced consensus building on the sustainable mining agenda of the mineral resource development industry and realities on the ground. It reviews the 55 most relevant academic articles from 2000 to 2019, retrieved from the Web of Science, PubMed and International Conference on Sustainable Development Indicators in the Metals Industry databases. A systematic scoping review method was used to sieve the multitudes of entries obtained from the databases to generate appropriate publications that match the search terms used. Our survey finds a dearth of literature on the subject. Only one article directly confers the need for consensus building on sustainable mining. The existing literature does not suggest the modalities that would enhance indigenous groups' understanding and appreciation of sustainable mining. This creates a gap between stakeholders with regard to what flags sustainable mining. This study also finds a lack of efforts to incorporate sustainable mining concepts into academic courses focusing on either mining or sustainable development. Thus, this paper suggests that the existing delusions on sustainable mining can be addressed if the science of assessing and communicating the principles of sustainable development in mining is suitably developed and applied in higher educational curricula, environmental literacy feats, community-initiated research and outreach activities. Incorporating indigenous knowledge can address the existing gaps between stakeholder groups and in science.

Keywords: sustainable development 1; sustainable mining 2; sustainability 3; consensus 4

1. Introduction

In the feat of rising demand for mineral commodities and a rising conscience of the economic, social and environmental impacts of the mining sector, the concept of “Sustainable Mining” is not adequately understood and applied. Mining is an important economic and social development opportunity for many countries like the USA, Canada, China, Australia, South Africa, Botswana, Zambia and Mongolia. The global demand for mineral commodities from producing countries is anticipated to rise in the coming years. This demand is driven by population surges and related modern living, increasing levels of affluence and the associated technological needs [1,2]. To meet this demand implies expanding surface mining activities, energy consumption, land, water and chemical use in host communities and

regions [3]. Nevertheless, local stakeholders' perception of sustainable mining, which is contingent to the principles of sustainable development, is inconsistent with that of secondary stakeholders (government and industry). There are diverging perspectives on the ways through which the principles of sustainable development can be incorporated into mining activities effectively to show the weak or strong sustainability adherence of the mining sector. For many, mining activities are generally incompatible with the principles of sustainable development and for that matter, its sustainability is weak. However, Solow [4] and McPhail [5] explain that the revenues from unsustainable mining operations can build up a sustainable society outside of the mining operation, indicating a strong sustainability potential. Given the many opportunities that allow discussions of scientific ideas and views on this subject, the existing literature is limited in proffering pragmatic modalities for consensus building on a true understanding of sustainable mining. This makes it complex for local stakeholders to appreciate the value of sustainable mining for a holistic beneficiation of a country's natural bequest.

Sustainable development refers to "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6,7]. It is a system of development that meets the basic needs of all people now without compromising the ability of future generations to meet their own life-sustaining needs. That is, ensuring intergenerational and intragenerational equity. The 1992 Rio Earth Summit openly initiated public discussion on the social, economic and environmental issues referred to as the three pillars of sustainable development or the "triple-bottom-line" (TBL) [8]. This initiative instigated current scientific thoughts on sustainable development in the mining industry activities. Thus, Fraser [9] finds that in the context of mineral resource development, sustainable development is about the relationships and linkages between the environmental, economic and social implications of mining activities. Fuisz-Kehrbach [10], Deb and Sarkar [11] and Hodge [12], thus, define sustainable mining as operations that constantly strategize to reduce the negative impacts and maintain the health and safety of host communities. It means the ways in which mineral resource exploitation can take place without permanent damage to the social, environmental and economic livelihood of host local communities [13]. Han Onn and Woodley [14], Laurence [15] explains that sustainable mining seeks the adoption of methods of operation that ensure proper environmental management, community engagement and economic security of host local communities. That is, the use of enhanced mining methods that ensure transparent accountability, environmental protection, local communities' participation and socioeconomic development.

To this end, Corder [16] observes that the principles of sustainable development have earned recognition in the mining industry's activities. Meanwhile, a recent times key global challenge is on addressing the sustainable development agenda of the industry. Though del Mar Alonso-Almeida et al. [17] and Heenetigala and Armstrong [18] observe that the current industry-specific reforms on sustainable mining nurture its positive contributions to socioeconomic development of communities that host them, Kirsch [19] and Whitmore [20] consider sustainable mining as a rhetorical concept which is used to hide the economic, environmental and social ineptitude of companies. From these perspectives, evolving studies have investigated the potential of sustainable mining operations in different settings. Examples include the works of Dialga [21], Alves et al. [22] and Antwi et al. [23]. A content analysis conducted by Mancini and Sala [24] and Virgone et al. [25] indicates that in spite of a recent proliferation of sustainable mining assessment frameworks, a consensual understanding of what sustainable mining pertains still remains a misapprehension. The tenets of a sustainable mining discourse are understood by the industry players and governments. However, it remains an illusion to indigenous and local stakeholders, whose values and interest must be incorporated into all forms of sustainable mining ideas in order to build consensus on what the concept pertains.

In this regard, Aznar-Sánchez et al. [26] led a recent meta-analysis of publications trends in an attempt to understand how innovations and technology could be used to enhance the perspectives on sustainable mining. They collated and reviewed over 2500 articles, published on the lifecycle of a mine and the principles of sustainable development (TBL) [8], from 1998 to 2017. The study finds weak connections between the TBL and sustainable mining in the literature. According to Elkington [8],

the TBL refers to the social, economic and environmental scopes of sustainable development. Segura-Salazar and Tavares [27] also examined academic articles published within a 25-year period on sustainable mineral resource development. The study finds a lack of consensus in the literature on what sustainable mining entails. Thus, there is limited attempt in the literature that addresses the need to integrate perspectives from academia, industry, government, mining communities and Non-Governmental Organisations (NGOs) circles for building consensus on what sustainable mining pertains. Dialga [28] suggests a composite Mining Industry Sustainability Index (MISI) for addressing the gaps and for policy decision making. MISI uses social, economic and environmental dimensions to analyze the industry's contributions to sustainable development. However, the modalities for operationalizing such an index-based process remain unclear. Moreover, the MISI does not explicitly incorporate the factors that will enhance consensus building between various stakeholder groups on what sustainable mining pertains.

Notwithstanding the relevance of sustainable mining to the United Nations (UN) Agenda 2030 Sustainable Development Goals (SDGs), new scientific analysis on establishing an interface between sustainable mining and literacy in sustainable development towards consensus building remains largely underexplored. To address this gap in science, therefore, the main objective of this paper is to identify and harmonize novel ideas upon which foundations towards building a consensus on what sustainable mining pertains can develop. The paper appraises existing perspectives on sustainable mining and identifies key innovative paradigms that can contribute to enhance consensus building on the mining sector sustainable development agenda. Thus, the next section discusses the methods used in this review paper. Section 3 examines the various theoretical frameworks and perspectives on sustainable mining. Section 4 provides the general discussions and recommendations. The paper ends with conclusions in Section 5, with a summary of the salient issues identified and discussed.

2. Materials and Methods

This paper reviews published scientific works and reports from think tanks, recognized civil and international organizations that have interest in mineral resource development, journals and proceedings of international scientific conferences. The snowball sampling technique was employed to identify populations of the literature that focus on sustainability in the minerals and mining industry. The advantage of this method is that it is efficient in a narrowly defined study population where the study subjects are difficult to identify or reach [29]. However, the method is generally plagued with elements of biasness [30,31]. To correct biases induced by the snowball method, several iterations were run on exclusive database sources with the three original search terms. Furthermore, based on the main objective of this study, the systematic scoping review approach was used. According to Im and Chang [32], the systematic review technique facilitates a comprehensive, unbiased synthesis of studies on a specific subject through an assessment of several relevant documents. In respect of the review development processes, guidelines for conducting a systematic review proposed by Lockwood and Oh [33] were used. These include three rudimentary process stages: (i) planning, (ii) development and (iii) catalogue of results and dissemination. At the planning and development stages, a strict scope was identified and used. Keywords and phrases used for the sample analysis include "sustainable mining", "sustainability in the mining industry" and "mining and sustainable development". These search terms were used on PubMed and Web of Science databases from the year 2000 to 2020. Advanced search options by Boolean operators (NOT, AND and OR) were used. The corresponding metadata of each published item were imported into Microsoft Excel 2016 and the results are shown in Figure 1.

On PubMed, about 1984 articles, book reviews, book chapters and proceedings of scientific conferences were retrieved. However, there were several duplications of many items, which made a detailed perusal time-consuming. Hence, a strict scoping technique was applied to select a sample of 20 published articles and book chapters. A total of 3878 journal articles, book reviews, book chapters and scientific conference proceedings were retrieved from the Web of Science database. From this, the 20 sampled items from the earlier PubMed searches were maintained, while an additional 31 items

that correspond with the search terms were identified and sampled for detailed perusal. Specifically, proceedings of the International Conference on Sustainable Development Indicators in the Minerals Industry (SDMI) were reviewed to identify papers that directly address the objectives of this study. A total of 55 journal articles, book reviews and scientific conference proceedings were retained and studied to identify those that align with the objectives of the current work. These are in Appendix A. According to Seuring and Müller [34], academic literature reviews address two main objectives: (i) provide a summary of existing published works by identifying the trends, themes and gaps, and (ii) identify conceptual basis of the field to make relevant contributions to theory advance.

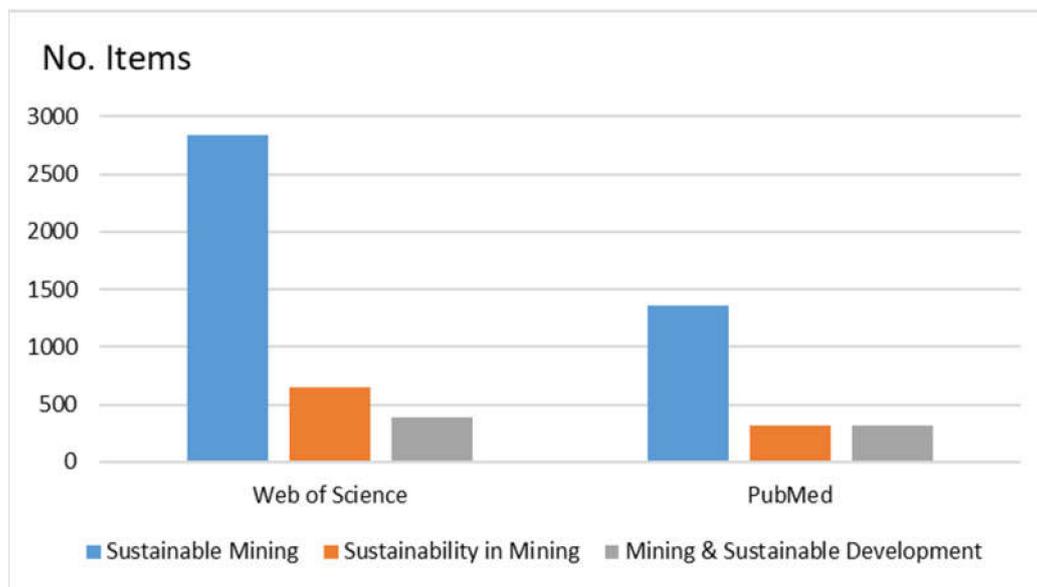


Figure 1. Academic papers retrieved from search databases.

On this basis, a set of four assessment categories were selected to guide the review. These are: objective, findings, targeted audience and recommendations. For the objective category, the study identified literature that sought to oppose the possibility of sustainable mining and references that align with the hypothesis of sustainable mining. Topics based on objectives range from incorporating sustainability in the mining sector activities; new methods for improving the integrity of the industry as practicing sustainable operations; and frameworks for guiding sustainability in a mining context. Examples include the work of Hilson [13], Fifka [35], Pimentel et al. [36], Hahn and Kühnen [37], Azapagic [38]. For the findings category, several references generally discuss the negative social, economic and environmental impacts of the mining industry on local communities and planetary boundaries (atmosphere, biosphere, hydrosphere and lithosphere). Examples include the works of Akabzaa [39], Erdiaw-Kwasie et al. [40], Schueler, Kuemmerle and Schröder [41] and Kitula [42]. For the targeted audience category, references were found addressing the industry and local communities on the longer-term effects of mining on social and economic livelihood and how to overcome the challenges. Examples are the works of Asr et al. [43], Batterham [44] and [45]. With regard to the recommendations category, references were found suggesting working guidelines on how to operationalize sustainable mining. Examples include: Hilson and Murck [46], Hilson and Basu [47], Moran et al. [48], Fonseca [49] and Hodge [12].

Limitations and Delimitations of the Methods

Thus, the snowball sampling technique facilitated a wider coverage of journals that publish works on the topic. The reference lists of accessed articles were examined with the snowball sampling technique and used to identify and retrieve relevant papers and journals. These were searched for in the databases and about 100% of the reference titles entered in the search dialogues were retrieved

and further perused in respect of the main objective of the study. Several articles used nuanced titles that contain one or two of the search terms used in the sampling. A search with the terms generated over 1,000,000 articles, book chapters and conference proceedings from Google Scholar, PubMed, Springer, UCD OneSearch and Web of Science databases. This made it difficult to locate the relevant literature, especially where each route to the full text of a document was different. There are also subscription restrictions on access to the full text of relevant literature from some publishing journals on Google Scholar and Springer in particular. This challenge was overcome by using the UCD OneSearch database, which provides free access to the full text of such literature.

However, there were also several duplications of the literature that was retrieved from UCD OneSearch, Springer and Google Scholar. PubMed and Web of Science did not provide such duplications. Hence, the data retrieved from the latter were used to validate the former. According to Im and Chang [32], the use of precise terms in advanced search options makes it easier to trim down the multiples of entries generated. Hence, the scoping review technique was employed in the advanced search options on PubMed and ISI Web of Science, which helped to prioritize documents in which the search terms appeared. PubMed and ISI Web of Science have been chosen because of their fidelity to retrieved data. On the SDMI proceedings, many have discussed topics that relate to mining, but few directly align with the search criteria and the objectives of this study.

3. Conceptual Framework

The introduction of the principles of sustainable development in the mining industry follows one of the many objectives of the UN Commission for Sustainable Development (UNCSD); that is, to introduce the development and adoption of SDGs by specific industries [38,50]. In 2002, the World Summit on Sustainable Development (WSSD) held in Johannesburg released what is known as “The Johannesburg Declaration on Sustainable Development”. The declaration expanded the scope of sustainable development from its original scope in the Brundtland report to include: “a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development at local, national, regional and global levels” [51]. However, Whitmore [20], Fonseca et al. [52] argue that after the inclusion of the mining sector at all levels of sustainable development discussions, there is still no change in the perspective of host communities about the sector’s land displacement and associated social impacts. For nearly two decades after the introduction of paragraph 46 in the Johannesburg Declaration of the WSSD, which outlines the ways that mining, minerals and metals can contribute to the sustainable development paradigm, there is a proliferation of literature curious about the practicality of the principles of the concept in mineral resource development. Finding consensus on the insinuations of sustainable mining is, therefore, as imperative as the rising demand for mineral commodities and the rising conscience of the economic, social and environmental impacts of the sector.

Thus, Hodges [53] and Lottermoser [54] posit that inevitable industrial activities, including mining, can operate within the values of sustainable development through the mitigation of adverse effects, based on economic, social and environmental impact assessments and indicators. Allan [55] suggests that sustainable mining can be achieved if the rate of exploitation does not exceed the recoveries, acceptable substitutes or technological innovations for recycling existing metallic minerals. Ranängen and Lindman [56] find that, with little issues about its sustainable development feat in Europe, the positive contributions of the mining sector to the economies of Nordic countries are increasing. Gerasimov [57] is optimistic that the discovery of energy raw materials in the Komi Republic is a catalyst for its industrial and sustainable development. Furthermore, the African Mining Vision (AMV) presumes that with the right policy and regulatory regimes in place, mining can contribute to sustainable development [58]. However, the existing literature is limited and written in different contexts of understanding sustainable mining. Examples include the logical works of Solow [4], Whitmore [20], Kirschke [59]. To appreciate the relationship between sustainable development and mineral resource development, context analysis of the social, environmental and governance dimensions is inevitable.

3.1. The Social Dimensions of Sustainable Mining

Mining-related activities cannot be considered as sustainable in respect to the extraction of non-renewable minerals. The concept embraces traditional systems such as authority and power, culture, customs and sacred places of treasure to the people [60]. Improved knowledge about the social and cultural values, economic and environmental decision making and knowledge systems of a society are, therefore, required to address the theoretical discussions on sustainable mining [61]. Han Onn and Woodley [14] find that in spite of the discrete differences between “sustainable development” and “sustainability”, the terms are used synonymously with a contradiction of concepts. Thus, Hodge [12] defines sustainability as the persistence of certain necessary and desired features of both people and the enveloping ecosystem in which people live over an indefinite period. According to Hodge [12], sustainability is an open values-based system, where the prevailing needs of a society determine its ends and how to meet these ends. Hence, Vallance et al. [62] refer to social sustainability as the ability of society to have access to resources to meet its current needs and the needs of future generations. These needs include the provision of basic necessities such as food, jobs, energy, water, shelter and sanitation. To translate this into local knowledge and understanding of sustainable mining, a local communities’ level of participation in a mine development is inevitable.

Aside, to understand the relationships between mining and sustainable development in context, there is the need to examine the association between mining, movement (displacement and relocation) and development. According to Bebbington and Humphreys Bebbington [45], mining activities lead to permanent physical, emotional, political and economic mobility of people and biodiversity, for good or worse, and by force or voluntarily. Hence, Suopajarvi et al. [63] suggest that the relevant previous experiences of local people about the mining industry’s positive or negative impacts inform their perceptions of what pertains to sustainable mining. Thus, Didyk et al. [64] identified that the discernments of sustainable mining among local communities are dictated by the extent to which they can perceive the industry’s influence on their quality of life. In addition, Jordan [65] indicates that local perceptions about sustainable mining are subject to a process that integrates various views and interpretations from society. Towards building consensus on what pertains to sustainable mining, therefore, there is the need to specifically tailor development initiatives of the mines towards vulnerable groups in host communities [66,67]. Such initiatives should be extended to others from outside the host communities, who may also be affected by these projects by virtue of location association. Adopting such a model, a broader and comprehensive set of needs (present, past and future) of local communities that host mining activities can be identified, addressed and modified to inform the basis for consensus building on what sustainable mining pertains [68,69].

3.2. The Environmental Dimensions of Sustainable Mining

Goodland [70] defines environmental sustainability as the preservation of natural capital, protecting the factors and practices that contribute to environmental quality such as preservation of ecosystem services on a long-term basis. For instance, Fitzpatrick, Fonseca and McAllister [60] and Parameswaran [71] maintain that sustainable development is irreconcilable with the mining sector’s activities because of the sector’s inability to adhere to protocols that protect the environment. Examples of such protocols include “The Equator Principles”, and the “Environmental Health and Safety Guidelines” of the World Bank [72–74]. In addition, environmental sustainability requires the accomplishment of human activities in ways that do not have indefinite consequences on Earth’s life support systems, whether locally, regionally or at the global scale [75]. This is especially important for understanding the values of sustainable mining in context since the economy and social (traditional and cultural practices) life are symbiotic with the environment. Local communities need to base their decisions on an understanding of the environmental implications of mining activities and grant their approval or otherwise. In recent times, this is referred to as the social license to operate (SLO). In the context of sustainable mining, the SLO has been discussed extensively in the literature by Prno [76] and Owen and Kemp [77]. The level of skills in environmental literacy is not mutually exclusive to

stakeholders' perception and understanding of sustainable mining. Environmental literacy is especially a common challenge in sub-Saharan Africa and Latin American countries [78].

For a case in point, Alves, Ferreira and Araújo [22], Johnson et al. [79] and Mayes [80] have identified a lack of scientific evidence to explain sustainable mining to host mining communities in these regions. To this end, the use of remote sensing and satellite systems has become an inevitable process for mineral resource development. It provides a means for identifying past and current land uses, and the environmental footprint of mines [81,82]. Nevertheless, a major challenge with the use of remote sensing in mining sector assessment is that it is difficult to relate land cover information with environmental and socioeconomic data. Hence, Asr, Kakaie, Ataei and Tavakoli Mohammadi [43] maintain that sustainable mining should pertain to the involvement of indigenous knowledge (IK) at the planning, exploration and feasibility stages and be maintained throughout a mine's lifecycle. This calls for policy initiatives that would build connections between sustainability science, research models and IK in order to ascertain a true understanding of sustainable mining in these regions. With such a policy model, the capacity of local communities to apply knowledge on environmental values in decision making would be enhanced in mining project areas [83]. This drive aligns with SDGs 4 (Quality Education) and 10 (Reduced Inequalities) of Agenda 2030 [58,84]. Sedogo [85] posits that a combination of IK, remote sensing and other environmental data collection methods is promising in sustainable development planning, especially in the Sahelian West Africa sub-region.

3.3. *The Governance Dimensions of Sustainable Mining*

According to Nafziger [86], economic sustainability of the mining sector should be interpreted as an improvement in the standard of living of the people who are directly affected by the activities of a project. Improved human capital, infrastructure, local production levels, job creation and other long-term initiatives for social and environmental benefits reflect the strong sustainability of the mining sector [4,5,54]. Mineral resource extraction has the potential for "green-branding" of a country's products and diversification of local people's economy into agroforestry, fishing and tourism [87,88]. Thus, Wayne et al. [89] and Brereton and Pattenden [90] suggest that sustainable mining implies reinvestment of the sector's revenues on local communities' development objectives in ways that promote Sustainable Development Goals (SDGs). Examples include SDGs 12 (Responsible consumption and production), 14 (Conserve life below water) and 15 (Protection of life on land). To maximize these opportunities towards building consensus on sustainable mining, Bond [91] suggests an integrated analysis of the "triple-bottom-line". That is, taking inventory of the economic, social and environmental baseline conditions of host local communities. This should be repeated throughout the mine's lifecycle so that local stakeholders can remain up-to-date with the levels of evolving trends on the environmental, social and economic impacts of a project in their vicinity.

Amidst a growing interest in green technologies in recent times, which entails advanced production of mineral resources to meet incipient input demands, minerals facilitate modern living through ensuring an acceptable quality of life to many people in the 21st century. Examples include the provision of employment, fertilizers for optimum farm yield and materials for the manufacture of electrical wiring, airplane frames or paint pigments [92]. Modern society requires a mineral material supply chain for industrial uses. The Information Age has ushered in many new mineral uses in a number of products including cell phones (e.g., tantalum) or liquid crystal displays (e.g., indium), foreign exchange earnings and tax revenues for both local and central governments [2,24]. Operating according to the protocols envisaged by the Agenda 2030 SDGs should, therefore, define the governance values of sustainable mining [84,93]. In spite of the many benefits to a country, communities that host mining activities seldom see any real benefits. Pegg [94] notes that developing countries that depend on mineral resource development for economic growth generally suffer its negative effects and the poor are most vulnerable. Vulnerable groups such as women and girls suffer the negative effects of mining [95]. Effects include displacement and resettlement with difficulties in economic livelihood restoration,

posing a major risk to the future of communities and, thereby, making the mining process ostensibly unsustainable [96].

Recent literature shows proliferation of frameworks that analyze sustainable development in the mining context. These frameworks present a holistic analysis and synthesis of the social, economic and environmental sustainability of the mining sector global operations. Examples include the works of Azapagic [38]. However, the challenges of existing frameworks towards building consensus on what pertains in sustainable mining were discussed in detail by Fuisz-Kehrbach [10], Mancini and Sala [24], Worrall, Neil, Brereton and Mulligan [97] and Fonseca et al. [98]. These include inadequate evaluation tools and inappropriateness of the existing frameworks for all environmental, economic and social issues in all regions. Using only an environmental or economically or socially motivated framework is inadequate to advance towards consensus building on sustainable mining. These frameworks imply uniform conditions exist in all localities and are, therefore, not acceptable to stakeholders, especially in developing countries where there exist unique economic, environmental and social conditions from one locality to another. Rather, frameworks should embrace benchmarking of local environmental, social and economic indicators that can be validated by local communities, governments and companies [99,100].

Gorman and Dzombak [3] suggest the following four elements to be adopted and adapted for assessing sustainable mining in a region: (i) minimal land disruption, (ii) reduced inputs (land), (iii) reduction in outputs and (iv) responsible reclamation and rehabilitation of mined lands. Thus, perspectives on what pertains to sustainable mining can be improved towards consensus building if all these elements, which are linked to the economic and social life of local people, can be addressed in the Lifecycle of a mine [61,101,102]. In that case, “strong sustainability” can be derived. However, in situations where the environmental footprint of mining outstrips its economic influence and community beneficiation, such a locality is experiencing “weak sustainability” [4,44,69,103].

4. Discussions and Recommendations

Horowitz [104] asserts that the objectives of an observation give meaning to what defines sustainable mining. Thus, the observations of host local communities in terms of cultural values and economic livelihood, which is linked to environmental endowments, inform their perceptions of sustainable mining. The profit and revenue interests of both governments and industry players inform their definitions of what sustainable mining pertains. In this regard, building consensus on what sustainable mining pertains requires a dispassionate academic analysis and model building. Rajaram et al. [105], Eggert [106] and Kokko et al. [107] suggest that sustainable mining is a set of practices that promote balance between local community interests on one hand and development objectives of state governments and multilateral companies on the other hand. Although no single mine can last forever, sustainable mining embraces more values than extracting finite resources. Virgone, Ramirez-Andreotta, Mainhagu and Brusseau [25], therefore, proposed a five-component, location-specific framework: Foundation, Focus, Breadth, Quality Assurance and Relevance, for a contextual understanding of sustainable mining. This framework proposes community-engaged research, community-initiated environmental monitoring and economic valuations as its tools for assessment. However, the framework in its current form requires high-level skills to participate effectively in the research and environmental monitoring processes.

Hence, this paper recommends a policy-oriented formalization of environmental literacy, which is essential for an understanding of the links between environmental problems and the economic and social life of vulnerable local communities. This could be pursued with the establishment or improvement of environmental education in mining in mineral resource-rich countries. Improved environmental education focusing on region- and locality-specific dimensions to draw sustainable development strategies should also be implemented. Topics to consider include the transformation of waste mining sites to viable agricultural lands; grazing trials on rehabilitated mine lands to ensue post-mining sustainable rural livelihood; and geology and human health conditions. In most mining areas, people do

not know that several health problems are directly or indirectly related to the geological conditions of the area where they live. For instance, the United Nations Environment Programme (UNEP) has developed the SPEAK package to facilitate environmental education programs in Afghanistan [108]. This package seeks to reinforce local and institutional capacity to enable planning and protection of communities, ecosystems and economic development in line with the UN Agenda 2030 SDGs. Thus, local communities' exposure to the links between mining activities and their environmental, social and economic livelihood can facilitate the SLO and consensus building. Using problem-solving tasks and cases will strengthen the environmental literacy of local communities and further enhance people's motivation to optimize the benefits of sustainable mining for social transformation [78,109].

To effectively analyze environmental, economic and social issues of mining activities in host local communities, technological innovation processes must be adopted and systematically adapted to serve the interests of these communities. Technologies include diagnostic tools, such as Earth observatory satellite systems (EOS), for environmental risk analysis and mitigation. The adoption of these technologies will ensure that community members have the knowledge base and motivation to participate in a dialogue on sustainability issues [110,111]. Aznar-Sánchez, Velasco-Muñoz, Belmonte-Ureña and Manzano-Agugliaro [26] find that modern technologies improve the social, economic and environmental sustainability performance of the mining sector. For example, Schueler, Kuemmerle and Schröder [41] used EOS datasets together with community triangulations to identify the impacts of large-scale surface mining activities on community land uses in southwest Ghana. Kitula [42] attests the results of community-initiated assessment of the impacts of a large-scale mine on the community's environment and economic livelihood in Tanzania. The study used community perceptions and participatory geographic information systems (PPGIS). Thus, with the EOS, the local people can contribute meaningfully to knowledge on sustainable mining. An understanding of the spatial link between local livelihood, mining and social activities can be derived from an objective interpretation of the data. This reinforces stakeholders' motivations for consensus building on sustainable mining.

This paper recommends an incorporation of basic lessons on environmental technologies to the environmental literacy programs. Specific topics to cover should include community drones deployment, spectral signatures of environmental features, spectral signatures of specific minerals and chemicals, drone operations, digital data management, mobile communications and Global Positioning System (GPS) handling. This makes the monitoring and evaluation of mining activities participatory and inclusive. Community members can spot and report environmental irregularities on or near mine sites for appropriate remediations. Academic agents in pre-tertiary and tertiary institutions must be encouraged by policy to incorporate these basic units of the technologies in their curricula development. As a policy recommendation, Moomen et al. [112] suggest the creation of paragraphs on the mining sector policy document of countries with large mine operations. These paragraphs will require the joint use of Earth observation (EO) data and spatial technologies by both primary and secondary stakeholders for enhancing understanding of sustainable mining. Hence, the capacity strengthening of local communities for handling these data and technologies, either through public private partnerships or localized, should be formalized as part of governments' policies, especially in developing countries. Public servants who oversee the management of sustainable mining initiatives must also be resourced with basic lessons in spatial data handling to monitor sustainable mining. Durrieu and Nelson [113], however, caution that adoption of these new technologies should be compatible with sustainability principles.

Apart from natural capital management, sustainable mining-specific educational curricula may include fundamental lessons on social and human capital management and rural sociology at the undergraduate mining-related programs in universities. Higher educational institutions must adopt innovative teaching methods that both convey content knowledge about sustainable mining and build the skills required to support sustainability thinking. Methods may include workshops, group assignments on hypothetical mine issues, case study discussions on sustainable mining issues

and participant observations. This will expose future mine workers to realities and problem-solving critical thinking and strengthen the industry's sensitivity to local community concerns, which can be an inevitable compliment to technological solutions. If well implemented, such curricula shall develop the professional ability among students to collect mining-related data from various platforms. This will provide students with a sound foundation in the sustainable mining basics necessary to formulate, solve and analyze social, economic and environmental problems associated with a particular mine. Ultimately, it will promote student's awareness of sustainable mining principles and introduce them to professional ethics and codes of responsible mining to assist with policy making, capacity building and efforts in formalization.

At present, Poon [114] finds that the extent to which universities' incorporate sustainable mining units into their curriculum design is weak, especially in developing countries. Burns and Weaver [115] led the creation of dedicated sustainability science research institutions and educational curricula in some mine operations host countries, including South Africa and Ghana. This has resulted in the "Education for Sustainable Development" (ESD) initiative. The ESD initiative premises that sustainable development goals can be achieved if people are properly educated [116]. Thus, promotion of flexible competencies across transdisciplinary areas in academic institutions, as proposed by the ESD, can transform the future of the mining sector into sustainable mining. Currently, the extent to which sustainable mining is considered as relevant to incorporate in university course units cannot enhance public understanding and perception formation towards consensus building. For instance, Le Tourneau et al. [117] observe that the fundamental problem of sustainable mining is a lack of adequate public knowledge and understanding. Batterham [44] and Franco et al. [118] support this claim with the position that educational curricula that incorporate basic lessons on sustainable mining will prove the compatibility of the sector with the sustainable development principles and enhance consensus building.

Graduates who have the knowledge base and motivation on sustainable mining could become community reference points to participate in a dialogue around sustainability issues. In addition, such graduates could form external sustainable mining advisory groups to provide advice on the direction of community-based projects and ensure that the local communities are kept in the loop on evolving ideas pertaining to sustainable mining. Such community-based graduate groups could leverage on indigenous knowledge (IK) and bridge the gaps between communities and companies in terms of the social license to operate and achieving strong sustainability. Understanding the levels of social, economic and environmental benefits of a project, which are the factors that inform local considerations of sustainable mining, should incorporate IK capabilities [9]. The training and adoption of IK represent an asset that can help to overcome identified gaps. For instance, Tenke Fungurume, a copper mining company in DR Congo, developed training programs for both staff and host local communities to assist in IK enhancement towards consensus building on what sustainable mining pertains [59,119]. For local communities and governments, mining is a critical partner towards achieving longer-term ends [120]. To enhance consensus building towards sustainable mining, therefore, the processes require collaborations between local communities, governments and companies, as well as addressing their values differences based on knowledge and data.

5. Conclusions

This paper holds that sustainable mining is about enhancing the contributions of the mining sector to the principles of sustainable development while being responsive to the economic and social values of host communities. However, there is little work on exploring modalities that will enhance local stakeholders' perspectives towards consensus building on what sustainable mining pertains. This is attainable through improved environmental education focusing on region- and locality-specific dimensions. Topics to consider include transformation of waste mine sites to viable agricultural lands; grazing trials on rehabilitated mine lands; post-mine sustainable rural livelihood; and geology and human health conditions. In most mining areas, people do not know that some health problems are

directly or indirectly related to the pre-existing geological conditions of their locality. This paper also recommends the incorporation of basic lessons on environmental technologies. These technologies include GPS, Earth observatory satellite systems and drones for environmental risks monitoring, analysis and mitigation at the community level. Specific topics to cover may include community drone deployment, spectral signatures of specific local minerals and chemicals, spectral signatures of environmental features, digital data management, drone operation, GPS handling and mobile communications. With these, community members can spot and report environmental anomalies on or near mine sites for appropriate remediations, which may be referred to as “precision sustainable mining”. The adoption of these technologies gives community members the knowledge base and motivation to participate in dialogues on sustainability issues. Sustainable mining-specific educational curricula may include lessons on social and human capital management and rural sociology at the university level. Higher educational institutions must adopt innovative teaching methods such as participant observations in mining communities, case study discussions on mining issues and group assignments on hypothetical mine issues. This conveys both content knowledge and application skills required to support sustainability thinking, expose future mine workers to problem-solving critical thinking and strengthen the industry’s sensitivity to local community concerns, which can rarely be resolved by technological solutions alone.

Author Contributions: Conceptualization, A.-W.M. and P.L.; methodology, A.-W.M.; validation, P.L., M.B. and D.J.; formal analysis, A.-W.M.; investigation, A.-W.M.; resources, D.J.; data curation, A.-W.M.; writing—original draft preparation, A.-W.M.; writing—review and editing, P.L.; visualization, P.L.; supervision, M.B.; project administration, M.B. and D.J.; funding acquisition, A.-W.M., M.B. and D.J. All authors have read and agreed to the published version of the manuscript.

Funding: This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 713279 and was cofunded by the Irish Research Council.

Acknowledgments: The University of Energy and Natural Resources, Sunyani, Ghana, is hereby acknowledged for allowing access to their premises for outreach and dissemination activities.

Conflicts of Interest: The authors declare no conflict of interest. Likewise, the funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Reviewed papers in the interest of the topic and objective of the study.

References

1. Hooke, R.L. On the history of humans as geomorphic agents. *Geology* **2000**, *28*, 843–846. [[CrossRef](#)]
2. Klinger, J.M. Rare earth elements: Development, sustainability and policy issues. *Extr. Ind. Soc.* **2018**, *5*, 1. [[CrossRef](#)]
3. Gorman, M.R.; Dzombak, D.A. A review of sustainable mining and resource management: Transitioning from the life cycle of the mine to the life cycle of the mineral. *Resour. Conserv. Recycl.* **2018**, *137*, 281. [[CrossRef](#)]
4. Solow, R.M. *An Almost Practical Step toward Sustainability*; Resources for the Future: Washington, DC, USA, 1992.
5. McPhail, K. The Challenge of Mineral Wealth: Using Resource Endowments to Foster Sustainable Development. In *Mining, Society, and a Sustainable World*; Richards, J., Ed.; Springer: Berlin/Heidelberg, Germany, 2010.
6. Brundtland, G.H.; Khalid, M.; Agnelli, S.; Al-Athel, S.; Chidzero, B.J.N.Y. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
7. Wbcsd, I.A. Breaking New Ground: Mining, Minerals and Sustainable Development. 2002. Available online: <http://www.iied.org/mmsd> (accessed on 25 May 2019).
8. Elkington, J. Enter the triple bottom line. In *The Triple Bottom Line*; Routledge: New York, NY, USA, 2013; pp. 23–38.
9. Fraser, J. Mining companies and communities: Collaborative approaches to reduce social risk and advance sustainable development. *Resour. Policy* **2018**. [[CrossRef](#)]

10. Fuisz-Kehrbach, S.-K. A three-dimensional framework to explore corporate sustainability activities in the mining industry: Current status and challenges ahead. *Resour. Policy* **2015**, *46*, 101–115. [[CrossRef](#)]
11. Deb, M.; Sarkar, S.C. Issues of Sustainable Development in the Mines and Minerals Sector in India. In *Minerals and Allied Natural Resources and Their Sustainable Development: Principles, Perspectives with Emphasis on the Indian Scenario*; Springer: Singapore, 2017.
12. Hodge, R.A. Mining company performance and community conflict: Moving beyond a seeming paradox. *J. Clean. Prod.* **2014**, *84*, 27–33. [[CrossRef](#)]
13. Hilson, G. Putting Theory into Practice: How has the Gold Mining Industry Interpreted the Concept of Sustainable Development? *Miner. Resour. Eng.* **2001**, *10*, 397. [[CrossRef](#)]
14. Han Onn, A.; Woodley, A. A discourse analysis on how the sustainability agenda is defined within the mining industry. *J. Clean. Prod.* **2014**, *84*, 116–127. [[CrossRef](#)]
15. Laurence, D. Establishing a sustainable mining operation: An overview. *J. Clean. Prod.* **2011**, *19*, 278–284. [[CrossRef](#)]
16. Corder, G. Mining and Sustainable Development. In *Mining in the Asia-Pacific: Risks, Challenges and Opportunities*; O’Callaghan, T., Graetz, G., Eds.; Springer International Publishing: Cham, Switzerland, 2017.
17. Del Mar Alonso-Almeida, M.; Llach, J.; Marimon, F. A Closer Look at the ‘Global Reporting Initiative’ Sustainability Reporting as a Tool to Implement Environmental and Social Policies: A Worldwide Sector Analysis. *Corp. Soc. Responsib. Environ. Manag.* **2014**, *21*, 318–335. [[CrossRef](#)]
18. Heenetigala, K.; Armstrong, A. The Impact of Sustainability Reporting Determined from the Response of Mining Corporations to Environmental Risk. In *Clean, Green and Responsible? Soundings from Down Under*; Eweje, G., Bathurst, R.J., Eds.; Springer International Publishing: Cham, Switzerland, 2019.
19. Kirsch, S. Sustainable Mining. *Dialect. Anthropol.* **2010**, *34*, 87–93. [[CrossRef](#)]
20. Whitmore, A. The emperors new clothes: Sustainable mining? *J. Clean. Prod.* **2006**, *14*, 309–314. [[CrossRef](#)]
21. Dialga, I. A Sustainability Index of Mining Countries. *J. Clean. Prod.* **2018**, *179*, 278. [[CrossRef](#)]
22. Alves, W.; Ferreira, P.; Araújo, M. Sustainability awareness in Brazilian mining corporations: The case of Paraíba state. *Environ. Dev. Sustain.* **2018**, *20*, 41. [[CrossRef](#)]
23. Antwi, E.K.; Owusu-banahene, W.; Boakye-danquah, J.; Mensah, R.; Tetteh, J.D.; Nagao, M.; Takeuchi, K. Sustainability assessment of mine-affected communities in Ghana: Towards ecosystems and livelihood restoration. *Sustain. Sci.* **2017**, *12*, 747. [[CrossRef](#)]
24. Mancini, L.; Sala, S. Social impact assessment in the mining sector: Review and comparison of indicators frameworks. *Resour. Policy* **2018**, *57*, 98. [[CrossRef](#)]
25. Virgone, K.M.; Ramirez-Andreotta, M.; Mainhagu, J.; Brusseau, M.L. Effective integrated frameworks for assessing mining sustainability. *Environ. Geochem. Health* **2018**, *40*, 2635. [[CrossRef](#)]
26. Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; Belmonte-Ureña, L.J.; Manzano-Agugliaro, F. Innovation and technology for sustainable mining activity: A worldwide research assessment. *J. Clean. Prod.* **2019**, *221*, 38. [[CrossRef](#)]
27. Segura-Salazar, J.; Tavares, L.M. Sustainability in the Minerals Industry: Seeking a Consensus on Its Meaning. *Sustainability* **2018**, *10*, 1429. [[CrossRef](#)]
28. Dialga, I. A Mining Industry Sustainability Index: Experiences from Gold and Uranium Sectors. In *Development and Quantification of Sustainability Indicators*; Muthu, S.S., Ed.; Springer: Singapore, 2019.
29. Johnson, T.P. Snowball Sampling: Introduction. In *Wiley StatsRef: Statistics Reference Online*; John Wiley & Sons: New York, NY, USA, 2014.
30. Sadler, G.R.; Lee, H.-C.; Lim, R.S.-H.; Fullerton, J. Research Article: Recruitment of hard-to-reach population subgroups via adaptations of the snowball sampling strategy. *Nurs. Health Sci.* **2010**, *12*, 369–374. [[CrossRef](#)]
31. Atkinson, R.; Flint, J. Accessing hidden and hard-to-reach populations: Snowball research strategies. *Soc. Res. Update* **2001**, *33*, 1–4.
32. Im, E.-O.; Chang, S.J. A Systematic Integrated Literature Review of Systematic Integrated Literature Reviews in Nursing. *J. Nurs. Educ.* **2012**, *51*, 632–640. [[CrossRef](#)] [[PubMed](#)]
33. Lockwood, C.; Oh, E.G. Systematic reviews: Guidelines, tools and checklists for authors. *Nurs. Health Sci.* **2017**, *19*, 273. [[CrossRef](#)] [[PubMed](#)]
34. Seuring, S.; Müller, M. From a literature review to a conceptual framework for sustainable supply chain management. *J. Clean. Prod.* **2008**, *16*, 1699–1710. [[CrossRef](#)]

35. Fifka, M.S. Corporate Responsibility Reporting and its Determinants in Comparative Perspective—A Review of the Empirical Literature and a Meta-analysis. *Bus. Strategy Environ.* **2013**, *22*, 1–35. [[CrossRef](#)]
36. Pimentel, B.S.; Gonzalez, E.S.; Barbosa, G.N.O. Decision-support models for sustainable mining networks: Fundamentals and challenges. *J. Clean. Prod.* **2016**, *112*, 2145. [[CrossRef](#)]
37. Hahn, R.; Kühnen, M. Determinants of sustainability reporting: A review of results, trends, theory, and opportunities in an expanding field of research. *J. Clean. Prod.* **2013**, *59*, 5–21. [[CrossRef](#)]
38. Azapagic, A. Developing a framework for sustainable development indicators for the mining and minerals industry. *J. Clean. Prod.* **2004**, *12*, 639–662. [[CrossRef](#)]
39. Akabzaa, T. Boom and Dislocation, Environmental and Social Impacts of Mining in Wassa West District of the Western Region of Ghana, Africa. *Third World Netw. Afr.* **2000**, 131.
40. Erdiaw-Kwasie, M.O.; Dinye, R.D.; Abunyewah, M. Impacts of mining on the natural environment and wellbeing of mining—Fringe communities in Prestea, Ghana. *Greener J. Soc. Sci.* **2014**, *4*, 108–122. [[CrossRef](#)]
41. Schueler, V.; Kuemmerle, T.; Schröder, H. Impacts of Surface Gold Mining on Land Use Systems in Western Ghana. *Ambio* **2011**, *40*, 528–539. [[CrossRef](#)] [[PubMed](#)]
42. Kitula, A. The environmental and socio-economic impacts of mining on local livelihoods in Tanzania: A case study of Geita District. *J. Clean. Prod.* **2006**, *14*, 405–414. [[CrossRef](#)]
43. Asr, E.T.; Kakaie, R.; Ataei, M.; Mohammadi, M.R.T. A review of studies on sustainable development in mining life cycle. *J. Clean. Prod.* **2019**, 229, 213. [[CrossRef](#)]
44. Batterham, R.J. The mine of the future—Even more sustainable. *Miner. Eng.* **2017**, *107*, 2. [[CrossRef](#)]
45. Bebbington, A.; Bebbington, D.H. Mining, movements and sustainable development: Concepts for a framework. *Sustain. Dev.* **2018**, *26*, 441. [[CrossRef](#)]
46. Hilson, G.; Murck, B. Sustainable development in the mining industry: Clarifying the corporate perspective. *Resour. Policy* **2000**, *26*, 227–238. [[CrossRef](#)]
47. Hilson, G.; Basu, A.J. Devising indicators of sustainable development for the mining and minerals industry: An analysis of critical background issues. *Int. J. Sustain. Dev. World Ecol.* **2003**, *10*, 319–331. [[CrossRef](#)]
48. Moran, C.J.; Lodhia, S.; Kunz, N.C.; Huisingh, D. Sustainability in mining, minerals and energy: New processes, pathways and human interactions for a cautiously optimistic future. *J. Clean. Prod.* **2014**, *84*, 1–15. [[CrossRef](#)]
49. Fonseca, A. How credible are mining corporations' sustainability reports? a critical analysis of external assurance under the requirements of the international council on mining and metals. *Corp. Soc. Responsib. Environ. Manag.* **2010**, *17*, 355–370. [[CrossRef](#)]
50. Holden, E.; Linnerud, K.; Banister, D. Sustainable development: Our Common Future revisited. *Glob. Environ. Chang.* **2014**, *26*, 130–139. [[CrossRef](#)]
51. Hens, L.; Nath, B. The Johannesburg Conference. In *The World Summit on Sustainable Development: The Johannesburg Conference*; Hens, L., Nath, B., Eds.; Springer: Dordrecht, The Netherlands, 2005; pp. 1–33.
52. Fonseca, A.; Fitzpatrick, P.; McAllister, M.L. *Government and Voluntary Policymaking for Sustainability in Mining Towns: A Longitudinal Analysis of Itabira, Brazil*; Natural Resources Forum, 2013; Wiley Online Library: New York, NY, USA, 2013; pp. 211–220.
53. Hodges, C.A. Mineral resources, environmental issues, and land use. *Science* **1995**, *268*, 1305. [[CrossRef](#)] [[PubMed](#)]
54. Lottermoser, B. *Environmental Indicators in Metal Mining*; Springer: Berlin/Heidelberg, Germany, 2017.
55. Allan, R. Introduction: Sustainable mining in the future. *J. Geochem. Explor.* **1995**, *52*, 1–4. [[CrossRef](#)]
56. Ranängen, H.; Lindman, Å. A path towards sustainability for the Nordic mining industry. *J. Clean. Prod.* **2017**, *151*, 43. [[CrossRef](#)]
57. Gerasimov, N.N. The resource potential as the basis for sustainable development of the Komi Republic. *Russ. J. Gen. Chem.* **2011**, *81*, 1262–1276. [[CrossRef](#)]
58. Sturman, K.; Toledano, P.; Akayuli, C.F.A.; Gondwe, M. African Mining and the SDGs: From Vision to Reality. In *Africa and the Sustainable Development Goals*; Ramutsindela, M., Mickler, D., Eds.; Springer International Publishing: Cham, Switzerland, 2020.
59. Kirschke, J. Communities and Sustainability: More Than Mitigation. *Eng. Min. J.* **2014**, *215*, 54–63.
60. Fitzpatrick, P.; Fonseca, A.; McAllister, M.L. From the Whitehorse Mining Initiative Towards Sustainable Mining: Lessons learned. *J. Clean. Prod.* **2011**, *19*, 376–384. [[CrossRef](#)]
61. Richards, J. *Mining, Society, and a Sustainable World*; Springer: Berlin/Heidelberg, Germany, 2009.

62. Vallance, S.; Perkins, H.C.; Dixon, J.E. What is social sustainability? A clarification of concepts. *Geoforum* **2011**, *42*, 342–348. [CrossRef]
63. Suopajarvi, L.; Poelzer, G.A.; Ejdemo, T.; Klyuchnikova, E.; Korchak, E.; Nygaard, V. Social sustainability in northern mining communities: A study of the European North and Northwest Russia. *Resour. Policy* **2016**, *47*, 61. [CrossRef]
64. Didyk, V.; Bay-Larsen, I.; Sandersen, H.; Ivanova, L.; Isaeva, L.; Kharitonova, G. Sustainability and Mining: The Case of the Kola Peninsula. In *The Will to Drill—Mining in Arctic Communities*; Dale, B., Bay-Larsen, I., Skorstad, B., Eds.; Springer International Publishing: Cham, Switzerland, 2018.
65. Jordan, A. The Governance of Sustainable Development: Taking Stock and Looking Forwards. *Environ. Plan. C Gov. Policy* **2008**, *26*, 17–33. [CrossRef]
66. Pelenc, J.; Wallenborn, G.; Milanese, J.; Sébastien, L.; Vastenaekels, J.; Lajarthe, F.; Ballet, J.; Cervera-Marzal, M.; Carimentrand, A.; Merveille, N.; et al. Alternative and Resistance Movements: The Two Faces of Sustainability Transformations? *Ecol. Econ.* **2019**, *159*, 373. [CrossRef]
67. Skorstad, B.; Dale, B.; Bay-Larsen, I. Governing Complexity. Theories, Perspectives and Methodology for the Study of Sustainable Development and Mining in the Arctic. In *The Will to Drill—Mining in Arctic Communities*; Dale, B., Bay-Larsen, I., Skorstad, B., Eds.; Springer International Publishing: Cham, Switzerland, 2018.
68. Kapelus, P. Mining, corporate social responsibility and the “community”: The case of Rio Tinto, Richards Bay minerals and the Mbonambi. *J. Bus. Ethics* **2002**, *39*, 275–296. [CrossRef]
69. Lebre, E.; Valenta, R.; Kemp, D.; Owen, J.; Corder, G. Complex orebodies: The role of social and environmental complexities in current mine projects development. In Proceedings of the 9th International Conference on Sustainable Development in the Minerals Industry (SDIMI 2019), Sydney, NSW, Australia, 27–29 May 2019.
70. Goodland, R. The Concept of Environmental Sustainability. *Annu. Rev. Ecol. Syst.* **1995**, *26*, 1–24. [CrossRef]
71. Parameswaran, K. Sustainability Considerations in Innovative Process Development. In *Innovative Process Development in Metallurgical Industry: Concept to Commission*; Lakshmanan, V.I., Roy, R., Ramachandran, V., Eds.; Springer International Publishing: Cham, Switzerland, 2016.
72. Wright, C.; Rwabizambuga, A. Institutional pressures, corporate reputation, and voluntary codes of conduct: An examination of the equator principles. *Bus. Soc. Rev.* **2006**, *111*, 89–117. [CrossRef]
73. Amalric, F. *The Equator Principles: A Step towards Sustainability*; CCRS: Ottawa, ON, Canada, 2005.
74. International Finance Corporation. Environmental, Health, and Safety Guidelines for Breweries. Available online: <https://www.ifc.org/wps/wcm/connect/595149ed-8bef-4241-8d7c-50e91d8e459d/Final%2B-%2BMining.pdf?MOD=AJPERES&CVID=jqezAit&id=1323153264157> (accessed on 18 October 2020).
75. Revuelta, M.B. Environment and Sustainability. In *Mineral Resources: From Exploration to Sustainability Assessment*; Springer International Publishing: Cham, Switzerland, 2018.
76. Prno, J. An analysis of factors leading to the establishment of a social licence to operate in the mining industry. *Resour. Policy* **2013**, *38*, 577–590. [CrossRef]
77. Owen, J.R.; Kemp, D. Social licence and mining: A critical perspective. *Resour. Policy* **2013**, *38*, 29–35. [CrossRef]
78. Scholz, R.W. *Environmental Literacy in Science and Society: From Knowledge to Decisions*; Cambridge University Press: Cambridge, UK, 2011.
79. Johnson, J.T.; Howitt, R.; Cajete, G.; Berkes, F.; Louis, R.P.; Kliskey, A. Weaving Indigenous and sustainability sciences to diversify our methods. *Sustain. Sci.* **2016**, *11*, 1. [CrossRef]
80. Mayes, R. Mining and (Sustainable) Local Communities: Transforming Ravensthorpe, Western Australia. In *Resource Curse or Cure? On the Sustainability of Development in Western Australia*; Brueckner, M., Durey, A., Mayes, R., Pforr, C., Eds.; Springer: Berlin/Heidelberg, Germany, 2014; pp. 223–237.
81. Craynon, J.R.; Sarver, E.A.; Ripepi, N.S.; Karmis, M.E. A GIS-based methodology for identifying sustainability conflict areas in mine design—A case study from a surface coal mine in the USA. *Int. J. Min. Reclam. Environ.* **2016**, *30*, 197. [CrossRef]
82. Sonter, L.J.; Moran, C.J.; Barrett, D.J.; Soares-Filho, B.S. Processes of land use change in mining regions. *J. Clean. Prod.* **2014**, *84*, 494–501. [CrossRef]
83. Kamenopoulos, S.; Agioutantis, Z. Rare earth elements: Building a best practices roadmap to sustainable mining. In Proceedings of the 6th International Conference on Sustainable Development in the Minerals Industry, Milos Island, Greece, 30 June–3 July 2013.

84. Monteiro, N.B.R.; da Silva, E.A.; Moita Neto, J.M. Sustainable development goals in mining. *J. Clean. Prod.* **2019**, *228*, 509. [[CrossRef](#)]
85. Sedogo, L.G. *Integration of Local Participatory and Regional Planning For Resources Management Using Remote Sensing and GIS*; Wageningen University: Wageningen, The Netherlands, 2002.
86. Nafziger, S. Serfdom, Emancipation, and Off-farm Labour Mobility in Tsarist Russia. *Econ. Hist. Dev. Reg.* **2012**, *27*, 1–37. [[CrossRef](#)]
87. Clifford, M.J.; Ali, S.H.; Matsubae, K. Mining, land restoration and sustainable development in isolated islands: An industrial ecology perspective on extractive transitions on Nauru. *Ambio* **2019**, *48*, 397. [[CrossRef](#)]
88. Langefeld, O.; Clausen, E.; Kellner, M. “Blue Mining”-The future of mining. In Proceedings of the 6th International Conference on Sustainable Development in the Minerals Industry, Milos Island, Greece, 30 June–3 July 2013.
89. Waye, A.; Young, D.; Richards, J.P.; Doucet, J.A. Sustainable Development and Mining—An Exploratory Examination of the Roles of Government and Industry. In *Mining, Society, and a Sustainable World*; Richards, J., Ed.; Springer: Berlin/Heidelberg, Germany, 2010; pp. 151–182.
90. Brereton, D.; Pattenden, C. Measuring what matters: Monitoring the contribution of a new mining project to community sustainability. In Proceedings of the 3rd International Conference on Sustainable Development Indicators in the Minerals Industry, Milos Island, Greece, 17–20 June 2007.
91. Bond, C.J. Positive peace and sustainability in the mining context: Beyond the triple bottom line. *J. Clean. Prod.* **2014**, *84*, 164–173. [[CrossRef](#)]
92. Council, N.R. *Minerals, Critical Minerals, and the US Economy*; National Academies Press: Washington, DC, USA, 2008.
93. Ali, S.H.; Giurco, D.; Arndt, N.; Nickless, E.; Brown, G.; Demetriades, A.; Durrheim, R.; Enriquez, M.A.; Kinnaird, J.; Littleboy, A.; et al. Mineral supply for sustainable development requires resource governance. *Nature* **2017**, *543*, 367. [[CrossRef](#)] [[PubMed](#)]
94. Pegg, S. Mining and poverty reduction: Transforming rhetoric into reality. *J. Clean. Prod.* **2006**, *14*, 376–387. [[CrossRef](#)]
95. Salim, E. Conclusions and Recommendations of the Final Report of the Extractive Industries Review. 2003. Available online: <http://documents1.worldbank.org/curated/en/222871468331889018/pdf/842860v10WP05t00Box382152B00PUBLIC0.pdf> (accessed on 18 October 2020).
96. Van der Ploeg, L.; Vanclay, F. Challenges in implementing the corporate responsibility to respect human rights in the context of project-induced displacement and resettlement. *Resour. Policy* **2018**, *55*, 210. [[CrossRef](#)]
97. Worrall, R.; Neil, D.; Brereton, D.; Mulligan, D. Towards a sustainability criteria and indicators framework for legacy mine land. *J. Clean. Prod.* **2009**, *17*, 1426–1434. [[CrossRef](#)]
98. Fonseca, A.; McAllister, M.L.; Fitzpatrick, P. Measuring what? A comparative anatomy of five mining sustainability frameworks. *Miner. Eng.* **2013**, *46*, 180–186. [[CrossRef](#)]
99. Chattopadhyay, S.; Chattopadhyay, D. How Sustainability Helps Coal and Other Mining Operations. In *Encyclopedia of Sustainability Science and Technology*; Meyers, R.A., Ed.; Springer: New York, NY, USA, 2017.
100. Roumpos, C.; Pavloudakis, F.; GalEtaKIS, M. Benchmarking and sustainability indicators for surface mining operations. In Proceedings of the 3rd International Conference on Sustainable Development Indicators in the Minerals Industry, Milos Island, Greece, 17–20 June 2007; pp. 17–20.
101. Walker, M.; Jourdan, P. Resource-based sustainable development: An alternative approach to industrialisation in South Africa. *Miner. Energy Raw Mater. Rep.* **2003**, *18*, 25–43. [[CrossRef](#)]
102. Tiainen, H. Contemplating governance for social sustainability in mining in Greenland. *Resour. Policy* **2016**, *49*, 282. [[CrossRef](#)]
103. Pelenc, J.; Ballet, J.; Dedeurwaerdere, T. Weak Sustainability Versus Strong Sustainability. Brief Gsdr United Nations. 2015. Available online: <https://sustainabledevelopment.un.org/content/documents/6569122-Pelenc-Weak%20Sustainability%20versus%20Strong%20Sustainability.pdf> (accessed on 17 October 2020).
104. Horowitz, L. Section 2: Mining and sustainable development. *J. Clean. Prod.* **2006**, *3*, 307–308. [[CrossRef](#)]
105. Rajaram, V.; Dutta, S.; Parameswaran, K. *Sustainable Mining Practices: A Global Perspective*; CRC Press: Boca Raton, FL, USA, 2005.
106. Eggert, R. Mining, sustainability and sustainable development. In *Australian Mineral Economics*; Australasian Institute of Mining and Metallurgy: Carlton, VIC, Australia, 2006.
107. Kokko, K.; Buanes, A.; Koivurova, T.; Masloboev, V.; Pettersson, M. Sustainable mining, local communities and environmental regulation. *Barents Stud.* **2015**, *2*, 50–81.

108. UNEP. *Keeping the World Environment under Review: Enhancing the United Nations Environment Programme Science-Policy Interface and Endorsement of the Global Environment Outlook*; United Nations Environment Assembly (UNEA) of the United Nations Environment Programme, Fourth Session: Nairobi, Kenya, 2019.
109. Temper, L.; Walter, M.; Rodriguez, I.; Kothari, A.; Turhan, E. A perspective on radical transformations to sustainability: Resistances, movements and alternatives. *Sustain. Sci.* **2018**, *13*, 747. [[CrossRef](#)]
110. Kumar, D. Application of Modern Tools and Techniques for Mine Safety & Disaster Management. *J. Inst. Eng. Ser. D* **2016**, *97*, 77. [[CrossRef](#)]
111. Anadon, L.D.; Chan, G.; Harley, A.G.; Matus, K.; Moon, S.; Murthy, S.L.; Clark, W.C. Making technological innovation work for sustainable development. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 9682. [[CrossRef](#)]
112. Moomen, A.-W.; Jensen, D.; Lacroix, P.; Bertolotto, M. Assessing the policy adoption and impact of geoinformation for enhancing sustainable mining in Africa. *J. Clean. Prod.* **2019**, *241*, 118361. [[CrossRef](#)]
113. Durrieu, S.; Nelson, R.F. Earth observation from space—The issue of environmental sustainability. *Space Policy* **2013**, *29*, 238–250. [[CrossRef](#)]
114. Poon, J. Engaging sustainability good practice within the curriculum design and property portfolio in the Australian higher education sector. *Int. J. Sustain. High. Educ.* **2017**, *18*, 146. [[CrossRef](#)]
115. Burns, M.; Weaver, A. *Exploring Sustainability Science: A Southern African Perspective*; African SUN Media: Stellenbosch, South Africa, 2008.
116. Holfelder, A.-K. Towards a sustainable future with education? *Sustain. Sci.* **2019**, *14*, 943. [[CrossRef](#)]
117. Le Tourneau, F.-M.; Marchand, G.; Greissing, A.; Nasuti, S.; Droulers, M.; Bursztyn, M.; Léna, P.; Dubreuil, V. Assessing the impacts of sustainable development projects in the Amazon: The DURAMAZ experiment. *Sustain. Sci.* **2013**, *8*, 199–212. [[CrossRef](#)]
118. Franco, I.; Saito, O.; Vaughter, P.; Whereat, J.; Kanie, N.; Takemoto, K. Higher education for sustainable development: Actioning the global goals in policy, curriculum and practice. *Sustain. Sci.* **2018**. [[CrossRef](#)]
119. Kabila, J.D. Impact Assessment and Quality Analysis of Corporate Social Responsibility (CSR) Programs of Mining Companies and Their Contribution to Sustainable Development in the Communities They Operate: Case Study Tenke Fungurume Mining SA in the Democratic Republic of Congo (DRC). Available online: <http://bibliotecadigital.fgv.br/dspace/handle/10438/16574> (accessed on 17 October 2020).
120. AU. *Africa Mining Vision (AMV)*; African Union: Addis Ababa, Ethiopia, 2009.

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).