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Assessing The Policy Adoption And Impact Of Geoinformation For Enhancing Sustainable Mining In Africa

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Abstract. *This paper assesses the extent to which mineral rich African countries enable the creation of public geoinformation for enhancing sustainable mining in policy contexts. The paper reviews accessible works and searches databases of industry, governments, civil society, academia, and international organiza- tions. Focus is on 23 major producer countries of globally relevant minerals across Africa. The paper finds a disconnect between mining sector policy regimes and the desire to achieve sustainable development, lack of deliberate policy provision for the adoption and usage of geoinformation to enhance Free, Prior Informed Consent and public participation in mineral resource development projects. Out of the 23, only 2 countries (9%) have expressed the need for geoinformation in mining policies; as an input to public debate and data-driven decision making. Only 3 countries (13%) have set parameters for buffering around environmental and social variables. Out of these 3, only 2 have explicit parameters delineating explo- ration and mining areas. By not requiring public geospatial data, the implications are existence of poor benefit sharing, poor understanding of environmental risks, and a lack of integrated land use planning in resource-rich African countries. Hence, policy-oriented recommendations include expanding awareness on the value of and enhancing access to geoinformation, establishing paragraphs on geoinformation in Country Mining Visions, and strengthening local capacity for handling these data. Mineral-rich African countries must optimize benefits derivable from emerging Earth Observation technologies and associ- ated spatial data for measuring contributions of the mining sector to specific SDGs.*

Keywords – Sustainable development, Mining, Geoinformation, Environment, Resource, Africa.

1. **Introduction.** Globally, over 100 countries will rely on the extractives sector to generate the inputs and revenues necessary to advance progress towards meeting the 17 Sustainable Development Goals (SDGs) of the United Nations (UN) Agenda 2030 (Carvalho, 2017; UN, 2016). The goals aim to end poverty and hunger, reduce inequalities, improve health, well-being, education, ensure gender equality, improve work conditions, promote economic growth, peace, justice and strong institutions, and partnerships. The goals also aim to increase the availability of clean water, improved sanitation, and provide affordable and green energy and ecosystem protection (UN, 2016). Moreover, a shift to a low carbon future will fundamentally require the adoption of green technologies that are powered by a range of minerals and metals (Arrobas et al., 2017). As a result, the mining sector may be on the brink of another boom cycle and the governance framework placed around the sector will largely determine the positive impacts it could have towards sustainable development in many countries. While the potential benefits offered by the extractives sector are significant in many developed countries such as Canada, Australia, USA, and the Nordic countries, harnessing these opportunities present many challenges and pit- falls to the achievement of the SDGs in developing countries. To this end, this paper discusses an Africa region-specific approach to- wards addressing the SDGs in the mining sector. At the moment, there is little academic attention on this subject.

Focusing on Africa in this regard is important because, the re- gion has a unique set of development challenges and opportunities as compared to other developing regions in South America and Asia. There is a renewed scramble for Africa, from both western countries and emerging economies, owing to its growing economic opportunities driven by new-found viable mineral deposits (Besada and Martin, 2015; Carvalho, 2017). Examples include deposits of both fuel and non-fuel minerals such as petroleum, coal, uranium, gold, diamond, copper, tungsten and cobalt. As a result, Africa is considered as a new region for mineral resource development in- vestments in this 21st century (AU, 2011a; Shaw and Besada, 2013). Simultaneously, the extractives sector is plagued by decades of little public access to authoritative information about the environ- mental, economic and social risks that it is generating in African countries (Ray et al., 2016). Besides, an analysis of existing con- ceptual models for sustainability monitoring and assessment of the mining industry operations reveals that the frameworks fail to; establish the relevant links between sustainability variables and dimensions and, provide Spatio-temporal assessments (Fonseca et al., 2013; UNEP, 2019a). Thus, the AU (2011a); WHO-UNEP (2015) find that among all the world's geographic regions, Africa is the most vulnerable to environmental, economic and social im- pacts of surface mining. Hence, Africa requires a region-specific analysis of its challenges in meeting the Agenda 2030 SDGs from the mineral resource sector such that sets of context-appropriate solutions can be developed.

In a region-specific approach, African countries can tailor their mineral resource development objectives according to local, na- tional and institutional challenges (Yakovleva et al., 2017). Casper et al. (2017) find that the basic benchmark for addressing these challenges in a sustainable mining sector is equal access to trusted information by all stakeholders. Thus, McQuilken (2017), Jensen and Campbell (2019) suggest that an integration of technological innovations and policy perspectives is basic for ensuring public access to this kind of information, analysis and insights for eco- nomic growth, environmental protection and social responsiveness of the mining industry activities in developing countries. However, they do not provide details of the information format that can inform decision making on environmental and social risks mitigation processes to meet specific targets of the SDGs. Tech- nologies that can incorporate environmental, economic and social issues for delivering evidence-based approaches to harness out- comes of the mining sector for the SDGs have evolved significantly in the last 20 years. However, the extent to which African countries have recognised these in policy-practice is unknown. Challenges also exist in developing the needed data to link research findings with regional and local monitoring frameworks, adapting current social, economic and environmental data into existing regional and country operational policies; facilitating harmonization of sus- tainability indices of the mining industry activities; and assuring accessibility and reliability of information (Busia, 2017; Diallo, 2016).

These challenges must be overcome if Africa's resources are to contribute meaningfully to the objectives of the Africa Mining Vision and the Agenda 2030 SDGs. At the moment, the required linkages remain poorly developed. This paper, therefore, assesses the extent to which mineral rich African countries accommodate and enable generation of geoinformation as a pre-condition for enhancing sustainable mineral resource development in policy and in regulatory contexts. The paper further explores the extent to which countries' policy frameworks integrate the utilization of geospatial technologies to monitor development impact from the mining sector. It also appraises the extent that geoinformation can facilitate meeting Agenda 2030 SDGs including 1 (No Poverty), 2 (Zero Hunger), 6 (Clean Water and Sanitation), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation & Infrastructure), 11 (Sustainable Cities and Communities), 12 (Responsible Consump- tion and Production), 14 (Life Below Water), 15 (Life on Land), and 17 (Partnerships for the Goals), respectively. The subsequent sec- tions discuss the methods used in this paper, the conceptual frameworks for enhancing sustainable mineral resource develop- ment in Africa, and an overview of regional efforts for deployment of geospatial technologies to address key weaknesses and gaps on data creation and enhancement of sustainable mining in Africa. The paper concludes with discussions of the findings. This paper pro- vides new perspectives on the integral assessment of sustainable mineral resource development using geospatial technologies, in an African policy context. Empirical works on this important topic are lacking in the African-specific situation.

2. **Methods.** To strengthen the linkages between scientific knowledge, sus- tainable development and regional policies, the Agenda 2030 expressed the need to explore and use a wide range of data, including Earth Observations (EO) and geoinformation (UN, 2017). The research presented in this paper is based on extensive review of existing peer-reviewed literature and collecting relevant informa- tion from industry, civil society, governments, academia, and in- ternational organizations workings on the development and use of geoinformation for advancing sustainable mining sector activities in Africa. It did not consider literature that only commented on geoinformation and or sustainable mining in Africa as a subsidiary objective. The study did not also consider literature that used geospatial tools for data analysis to achieve objectives other than sustainable mining in Africa, though general discussions of such literature may be useful. It only searched for literature to assess the extent to which mineral rich African countries have identified geoinformation as a critical supporting tool for enhancing sus- tainable development in mineral resource extraction to: (1) enhance the sector's contribution to the UN's Agenda 2030 SDGs,
(2) achieve the primary objectives of the African Mining Vision (AMV), (3) monitor the impact of the mining sector at the local level in a data-driven manner and (4) assess the applications and impacts of geospatial data where it is required at a policy level.

The OneSearch@UCD Library of the University College Dublin (UCD) was searched for relevant literature on the objectives. Other database sources engaged include Google Scholar, LexisNexis, Directory of Open Access Journals (DOAJ), SHERPA RoMEO, EBS- COhost, African Journals Online (AJOL), The African Digital Library (ADL), JSTOR's African Access Initiative, Emerald Publishing Limited, Elsevier BV, ProQuest and ResearchGate. Derivative terms used in search for literature include: "mapping sustainable devel- opment of the mining industry in Africa"; "The use of Geo-information and sustainable mining in Africa"; "Applications of Earth Observation Systems for mapping the mining sector activities in Africa"; "The adoption of geospatial technologies for sustainable mining in Africa"; "Contribution of Earth Observation to sustainable mining"; "The Contributions of geoinformation to sustainable mining"; "Geospatial tools for monitoring sustainable mining ac- tivities", "Development of geoinformation for sustainable mining"; "The use of geoinformation and earth observation for sustainable mineral resource development in Africa".

Hence, this study harmonizes data from reports of the World Mining Data (WMD), African Mining Vision (AMV), United

Nations Economic Commission for Africa (UNECA) and Country Mining Vision Guide Book. Other important sources of data include the Inter-Governmental Forum on Mining, Minerals and Sustainable Development (IGF), UNEP and UNDP. The choice of countries for this study was determined based on homogenous purposive sam- pling. The homogeneous purposive sampling technique is used to select a study population that has a shared characteristic or set of characteristics (Etikan and Bala, 2017). The sampling used the following criteria:

- Since the study seeks to assess mineral rich African countries' predisposition to apply the most efficient sustainable mining techniques, it is appropriate to select a country that can have a potentially important local footprint. Non-oil minerals are those that can be expected to have a direct and immediate social, economic and environmental impacts on local populations. Hence, the analysis focus on known non-oil mineral-rich countries in Africa.
- To identify these countries, the UNECA, AMV and African Min- erals Development Center (AMDC) and IGF registers of non-oil mineral-rich African countries were used. These registers pro- vide information on the non-oil mineral reserves in each African Country.

Stratified random sampling technique was then applied to sieve out those countries with significant global mineral production. This sampling technique involves dividing a population into smaller groups, known as strata, based on the shared attributes or char- acteristics (Sharma, 2017). In this case, the identified countries were interpolated over the WMD reports from 2012 to 2019 in a tabular matrix of minerals produced, global ranking and an inferred rank in Africa. Those countries that fall within the top 20 global ranking of 65 mineral commodities among 168 countries were then selected. Ranking higher implies that large tracts of land are leased for mineral extraction with the associated social, economic and environmental footprints that may go unnoticed. Details of statis- tical methods used in the rankings can be found in the summary reports of WMD (2019).

Furthermore, documents bearing the relevant administrative frameworks, national laws, policies, and conventions of mineral resource development in the selected countries were also assessed to identify the formal recognition of the reckonable role that geo- information can contribute towards enhancing sustainable explo- ration and production in local space. This process involves a desk survey of the relevant regulatory documents of each country. Again, a matrix table was designed to reflect the triple-bottom-line (social, economic, and environmental) of sustainable development (Elkington, 2013). The Action Plan for Implementation of the AMV has some strategic clusters, which include socioeconomic and environmental clusters. The specific goals of these clusters have been mapped onto relevant specific SDGs and the countries' mining policies.

Based on both field experiences and a survey of the countries' regulatory documents, the rows and columns of the matrix were further categorized, in Excel, into measurable socioeconomic and environmental variables that match with the specific objectives of the Agenda 2030 SDGs. These are: farmlands, pasturelands, surface water bodies, cities and settlements (residential), roads, cemeteries (burial sites), forests, monuments, national parks, railway, restricted areas, aerodromes, and security zones. Each country has its own standard parameters for regulating the mining sector ac- tivities with regards to the above socioeconomic and environ- mental variables. These parameters were read and recorded onto the corresponding matrix cells of the countries and the variables. The objective of this assessment was to identify the level of ap- plications of geospatial tools for strictly enforcing the existing in- struments in the mining sector sustainability enhancement in each country.

2.1. Conceptual framework.

2.2. **Sustainable development and mineral resource development in Africa.** The World Commission on Environment and Development (WCED) in its Brundtland report, "Our Common Future", defines Sustainable Development as: "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Burton, 1987; WCED, 1987). The report did not demonstrate any linkages between the economic, social, and environmental spaces within which de- velopments that meet the needs of all generations take place. Having realized these gaps, the World Summit on Sustainable Development (WSSD) held in Johannesburg (2002), further expanded the scope from inter-generational equity to include so- cial, economic and environmental dimensions (Buxton, 2012). The outcome of the WSSD is known as "The Johannesburg Declaration on Sustainable Development" (Hens and Nath, 2005). In this new definition, the declaration seeks "a collective responsibility to advance and strengthen the interdependent and mutually rein- forcing pillars of sustainable development at local, national, regional and global levels" (Hens and Nath, 2005; UN, 2002). These were overlooked in the earlier definition. The social, economic and environmental dimensions are denoted as the three pillars of Sustainable Development or the "triple-bottom-line" (TBL) (Elkington, 2013). The Johannesburg declaration did not also explain, in simple terms, the role of critical industries, such as mining, towards achieving sustainable development.

Therefore, in paragraph 46 of the Johannesburg Plan of Action (JPOI), the declaration introduced a section on Mining, Minerals and Metals for the first time in sustainable development discus- sions. The JPOI highlights the need for applications of scientific mechanisms and good governance to enhance contributions of the mining sector towards sustainable development (Hens and Nath, 2005; UN, 2002). Nonetheless, Aznar-Sánchez et al. (2019) find that over the last three decades, empirical works on general sus- tainable development have received much attention than a tailored focus on sustainable mining and minerals research. Besides, the JPOI failed to provide guidelines on the adoption and adaptation of survey of the relevant regulatory documents of each country. Again, a matrix table was designed to reflect the triple-bottom-line (social, economic, and environmental) of sustainable development (Elkington, 2013). The Action Plan for Implementation of the AMV has some strategic clusters, which include socioeconomic and environmental clusters. The specific goals of these clusters have been mapped onto relevant specific SDGs and the countries' mining policies.

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The AMV succeeds failed conceptual frameworks of several initiatives at sub-regional, regional and global levels (Diallo, 2016). Examples include Yaoundé Vision on Artisanal and Small-scale Mining, the Africa Mining Partnership's Sustainable Development Charter and Mining Policy Framework; SADC Framework and Implementation Plan for Harmonization of Mining Policies, Stan- dards, Legislative and Regulatory Frameworks, and the Summary Report of the 2007 *Big Table* on "Managing Africa's Natural Re- sources for Growth and Poverty Reduction". Mining is an important sector in the African economy and many African countries rank among the world top 20 producers of many key mineral com- modities. For example, in Fig. 2a below, while Botswana ranks as number 2 (second highest) world producer of Diamond, South Af- rica and Congo DR rank number 1 (highest) in the global production of Tantalum, Vanadium and Cobalt.
In Africa, South Africa, Botswana, DR Congo, Guinea and Namibia
rank number 1 producers of Aluminium, Bauxite, Cobalt, Copper, Diamond, Gold and Vanadium, respectively (Fig. 2b). South Africa and Ghana are first and second in Africa but sixth and ninth larger gold producers, globally. Though the benefits of mining to the na- tional economies of some African countries, such as South Africa and Botswana, are evident,

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its contribution to sustainable devel- opment in others is poor (Diallo, 2016; UNECA, 2009).

In its eluding Implementation Plan of Action and the Country Mining Vision, AMV stresses the need for geoinformation to assist in sustainable mining (AMDC, 2014; Busia, 2017). It, however, does not provide guidelines and details on how such data can be generated and used in this regard. With no relevant data, it is difficult for effective planning and analysis of key environmental,

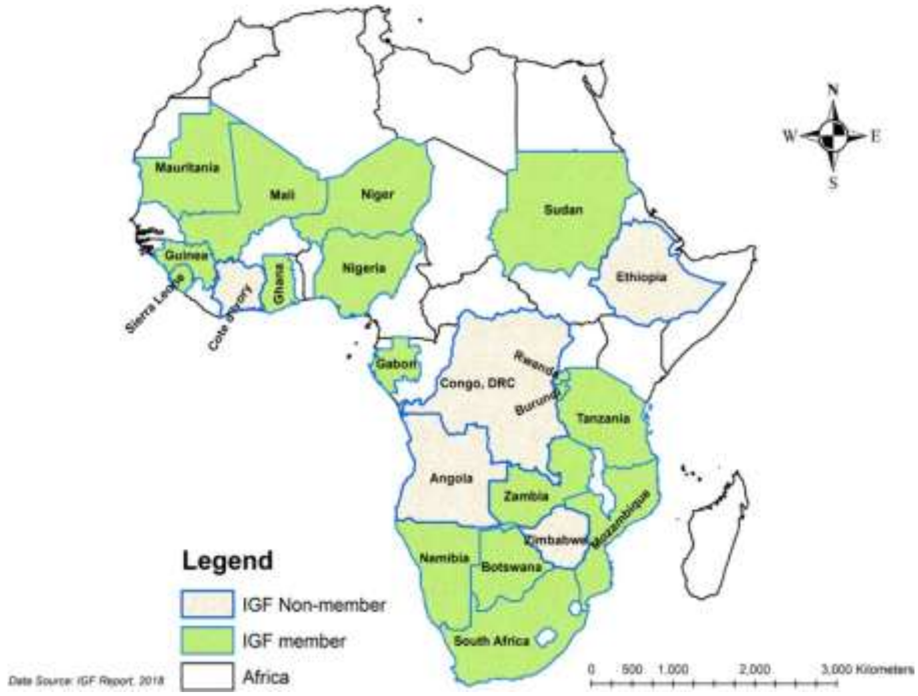

Fig. 1. Sampled countries vs. current IGF membership.

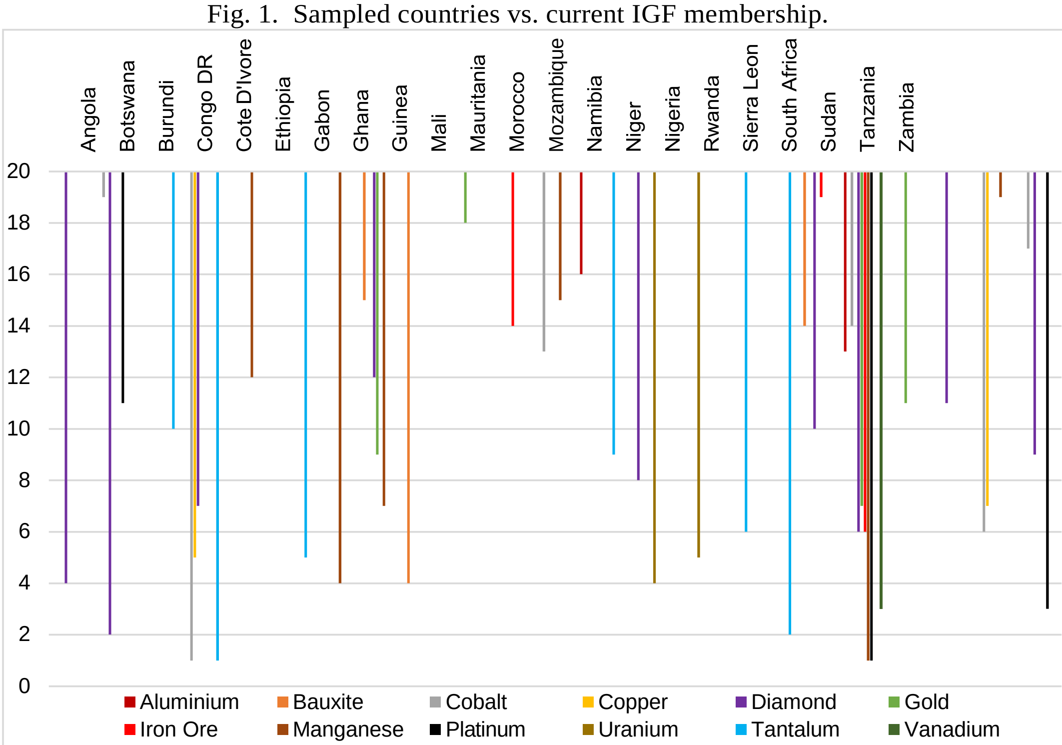

Fig. 2a. Global Ranking of African countries' major mineral production (Top 20) Data: collated from WMD & AMV.

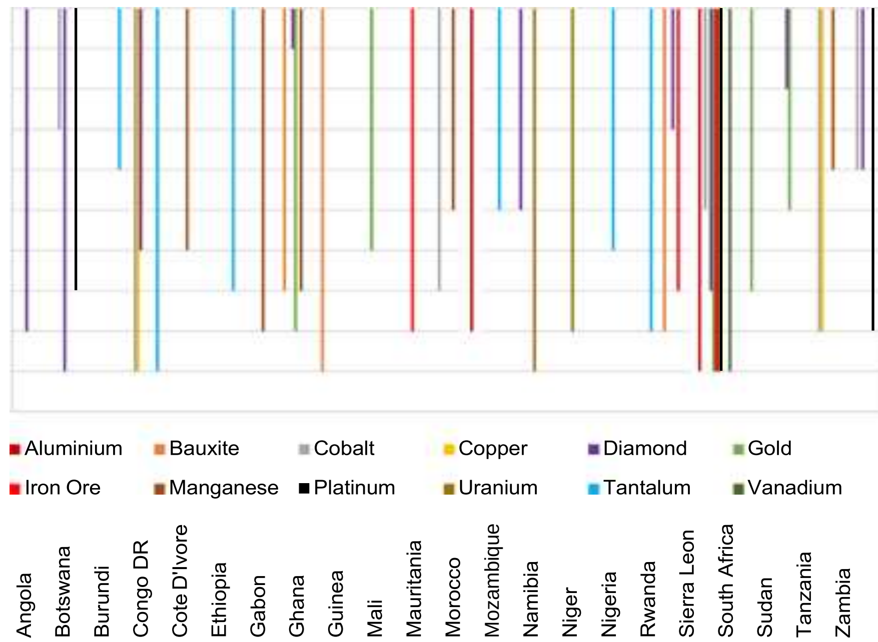

Fig. 2b. Countries Rankings of Mineral Production in Africa. *Data: collated from WMD* & *AMV*.

social and economic issues instigated by the mining sector. To this end, the African Union Agenda 2063 have expressed a need for and better access to Geospatial Information for Sustainable Develop- ment in Africa (ECA, 2017). This alone does not encourage an idea of tailoring the sophisticated suit of geoinformation tools to enhance contributions of the mining sector towards achieving specific tar- gets of the Agenda 2030 SDGs in resource-rich Africa.

As mining and its links with the Triple-Bottom-Line (TBL) are location-based, the application of geospatial information is required at three different stages of a mine lifecycle; prospecting, mining, and closure (Aznar-Sánchez et al., 2019). First, it is required for baseline surveys and analysis at the prospecting stage. In this regard, the existing socioeconomic and environmental conditions of a lease area are inventoried to identify the potential short-term and long-term negative impacts of the mining activities (Edwards et al., 2014). This stage is important for efficient planning and implementation of the project's activities. Vicente-Serrano et al. (2012) explain that geospatial tools, such as satellite remote sensing, can generate the biophysical data of the location and analyse these data for potential changes to be tracked by the use of various indictors. However, it will not be cost-effective to invest in taking high resolution satellite data of an area that has been granted prospecting leases until proven reserves are found. For instance, Eggert (2010) suggests that 1 out of 10 prospecting in- vestments translate into feasibility stages, which is a high-stakes risk. Hence, high resolution historical data, for purposes of base- line analysis, may not be available in deprived areas of African remote communities. Besides, once feasibility is reached, scientist may acquire historical data from commercial vendors, in respect of the extent of spatial resolution and accuracy required. But would such data cover the historical and nuanced land use activities that are crucial for socioeconomic analysis in an area?

For instance, the nightlight data captured by satellite or un- manned aerial vehicles (UAVs), such as a drone, can be used to identify human settlements, development and measure proxy economic activities prior to the introduction of a mine in a locality (Punam et al., 2017). These data can be retrieved and analysed to detect the positive or negative impacts of a mine during operation. However, this method may not be effective since most local com- munities in Africa have no access to the electrification systems and cannot be sensed by the satellite based on night light. It could still be used to define the Corporate Social Responsibility (CSR) of a mine through the provision of electricity for advanced economic activities in the host localities (Fraser, 2018). Thus, nightlight could be a proxy measure of the economic benefit of a mine to its host and neighbouring local communities. It could also be used to measure the hypothesis that mining increases urbanisation (Sonter et al., 2014). Punam et al. (2017) used the Normalized Vegetation Index (NDVI) approach to investigate the spatial relationship between mining and local agricultural development in Ghana, Tanzania, Mali and Burkina Faso. The objective was to identify the negative effects of mining on agriculture or otherwise. Comparing data prior to mining and during mining, Punam et al. (2017) find that host areas of mining operations are greener than distant areas. This implies that mining does not have negative effects on agricultural expan- sion and vegetative cover in the study area.

Secondly, geoinformation can be used to monitor the social, economic and environmental impacts of mine operations (Goparaju et al., 2017). Impacts include avoidable community displacement, livelihood disruption, pollution, forests depletion and ecosystems disturbance (Craynon et al., 2016). For example, focusing on Ghana and Peru, Cuba et al. (2014)

used rudimentary GIS tools to evaluate the spatial interactions between active mining and exploration concessions on one hand and land use activities and land cover phenomena such as agriculture, river basins and protected areas, on the other hand. The study found that conces- sions cover large proportions of agricultural areas and settlements but little overlaps with protected areas. Using the Geita Gold Mine (GGM) in Tanzania as a case study area, Emel et al. (2014) combined a suit of geospatial tools and methods to monitor open cut-gold mine disturbance on local topography and surface hydrology and their associated effects on farmers, village water supply systems and community forests. The results of such analysis can inform efficient decision making by government agencies responsible for regulating and monitoring mining activities. Christensen (2019) also used geospatial analysis to monitor the systematic relation- ship between mining and the expansion of social or armed conflicts in Africa. The findings reveal that the dearth of relevant information on the environmental impacts of mining is a catalyst to mining related conflicts in Africa. Similar examples can be found the work of Akiwumi and Butler (2008); Merem et al. (2017); Mielke et al. (2014).

Geoinformation can also be used to detect disaster risks, such as subsidence and tailings dam leachate, and vulnerability assessment of mining areas. For instance, Sanmiquel et al. (2018) used GIS- based models to monitor the levels of subsidence generation at two mining sites in Spain. The GIS determined the direction of displacements, the sinking velocity and the associated impacts of subsidence on infrastructures and buildings. Blachowski (2016) applied a GIS-based weighted spatial regression method to model underground mining-induced land subsidence in Walbrzych, Southwest Poland. Thus, the studies demonstrate that geospatial tools can determine the evolution of subsidence in mining areas and predict their future economic, social and environmental im- pacts as well as develop mitigation measures. The Mariana and Fundao Tailings dam failures in Brazil are attributed to poor monitoring systems. Thus, works on the use of geospatial tools in monitoring the disaster risks in mining sites can be found in Fernandes et al. (2016); Ge et al. (2007); Kumar (2016); Moridi et al. (2015). It would, however, be noted that there are no examples of applications of geospatial tools in mine site disaster risk monitoring in Africa, which supports the findings of Aznar-Sánchez et al. (2019).

Finally, with regards to mine closure; Baeten et al. (2016) ana- lysed historical data in GIS to identify the spatial extents of previous mines across Lake Superior Iron District in the USA; places of ore processing and waste dump sites. The study found that tailings from the previous mines were polluting nearby waterbodies and settlements. Similarly, DeWitt et al. (2017) used multi-temporal satellite data to assess and compare the environmental and socio- economic impacts of previous diamond mines and existing arti- sanal small-scale mines in the rural northern region of Cộte d'Ivoire. The applications of geoinformation in such studies could be used to explain the sustainability impacts of previous mines. Khalil et al. (2014) combined an environmental database with geospatial tools to assess the environmental impacts and extents of Acid Mine Drainage (AMD) pollution from abandoned mines in Kettara, Morocco. Environmental database includes geochemistry, hydrochemistry, hydrology, land cover, geology and climates. These examples demonstrate the efficiency of integrating multidisci-plinary data and geospatial technologies to assess post-mining environmental impacts. Similar studies on the applications of geospatial tools on mine closure, land reclamation and post-mining land use assessments can be found in the works of Karan et al. (2016); Masoumi et al. (2014) and Szostak et al. (2018). However, a major challenge with the efficient applications of geospatial technology across the lifecycle of a mine in Africa is the absence, incompleteness, inadequacy or inaccuracy of geoinformation (Aznar-Sánchez et al., 2019; Cuba et al., 2014).

Today, there exist several sources of data for developing geoinformation including ground surveying (citizen science and cadastral mapping), aerial and space photography as well as Earth Observation systems (EO). The emergence of new environmental technologies, such as the EO systems linked to artificial intelligence and machine learning algorithms or in-situ data collection through sensors, presents new approaches for supporting the acquisition of geoinformation and public participation in projects management, particularly through applied research at local, sub-regional, regional and national levels (Anadon et al., 2016; Giuliani et al., 2015). In recent times, however, EO have experienced significant advances in technology; more satellites with improved sensors are in proliferation in space and can collect environmental data at increasingly higher levels of spatial and temporal resolution to serve the growing interest in larger spatial coverage of datasets (Belward and Skøien, 2015; Denis et al., 2017; Jensen and Campbell, 2019). For instance, Planet Labs has 170 ± Dove satellites that take a full picture of the earth every day at 3 m' resolution to monitor land cover changes due to land use activities and trends at regional and country levels (Schingler, 2017). However, it is not clear the extent to which these technologies can be tailored to the interest of Afri- can resources for relevant data generation and sustainability enhancement.

To this end, the African Earth Observation community has developed AfriGEOSS (the regional Africa initiative of the Group on Earth Observation System of Systems). It is underscored that the coordination goal of AfriGEOSS shall enhance African countries' capacity to produce, manage and use locally tailored EO to partic- ipate in and contribute to Agenda 2030 SDGs (Agbaje and John, 2018). This provides an opportunity to create synergies and mini- mize duplication of data for the benefit of the continent. African Regional Data Cube (ARDC) is also a new initiative that aims to harmonize and transform historical EO satellite data to provide geoinformation for addressing Africa's challenges in sustainable development (Georgiadou et al., 2011; Lance et al., 2013). Pre- processing of raw data into Geodata may enhance free public ac- cess to data, participation and decision making on sustainable development (Magan, 2018). In spite of a growing mining sector activities and associated challenges in Africa, the AfriGEOSS does not provide a specific element for generating geoinformation specially tailored for the mining sector sustainability enhancement. Apart from being high technical-skill demanding, at the moment, both ARDC and AfriGEOSS are yet to operationalize. The main challenge here is a lack of parallel country-level human capacity that can leverage the promising data for sustainability enhance- ment in the mining sector. What is needed is to provide policy- makers with understandable and actionable information from this type of product. Nonetheless, while there are many opportu- nities to leverage geospatial information from these global or regional partnerships, none are actually operationalized towards this direction.

1.1. ***Countries' policy assessment on social and environmental sustainability plans.*** Fonseca et al. (2013) assessment of key trending sustainability frameworks in the mining industry suggest the absence of an effective mechanism that considers time lapses in information processing and spatial variability of indicators for a proper under- standing of the legacy of mining operations. For instance, in Fig. 2a, it is found that 23 African countries rank in the top 20 global pro- ducers of 7 important minerals and their virtual ranking in relevant production in Africa. However, in many of these countries, poverty, unemployment, inequality and environmental disruption is on the rise (Carvalho, 2017). Hence, Table 1 below shows the extent that governments of these countries have recognised the role of geo- information and technological advances for addressing the mining sector sustainability drive as deliberately captured in policy statements.

From Table 1 above, it is clear that where there is no equal access to relevant information there cannot be adequate consultation of local communities before EIAs approvals. Thus, there is limited knowledge and understanding of the implications of concessions on the part of local communities. This is an affront to the achievement of FPIC and SDGs 10 (Reduced inequality), 11, 12, 16 and 17. Apart from South Africa, the rest of the countries do not have policy lines that seek to establish strong linkages between local research institutions and the industry such that technological innovations can be tested and adapted for enhancing EIAs and SIAs
in affected mining areas. This largely accounts for the sporadic environmental and social impacts of the mining sector in Africa in the form of water pollution, avoidable community and farmland displacement and ecosystem disturbances. The dearth of equal access to quality data further stifles local governments' capacity on social responsiveness, environmental monitoring and efficient spatial planning.

There exist many domestic legal systems and international policy instruments set to protect designated nature and cultural sites. These provisions limit or prohibit mining operations therein. The assessment identifies key strengths, weaknesses and gaps in the countries' mining laws and policies with regards to a country's readiness to strictly apply such instruments through its existing government measures. Governments' measures complimentary to EIAs and SIAs include zoning and buffering to set limits for explo- ration and mining operations. With the use of spatial buffering, only 3 (13%) countries (Botswana, Mozambique and Zambia) have clearly stated parameters around a set of variables measurable by applying geospatial tools and geoinformation analysis (Fig. 3). The rest are popular narratives and carry implicit meaning. Out of the 3, only 2 (67%) have explicit parameters delineating sustainable exploration and mining areas. For instance, in Zambia and Mozambique, mining is banned within 2 km of restricted lands and 1 km of national parks. This is especially noteworthy given the dramatic expansion of mining operations and given that the im- pacts of mining expansions are expected to rise in these countries. From Fig. 3 below, it is evident that only Botswana, Mozambique and Zambia have standard buffer parameters, up to 200 m, in place to safeguard these risks. There is, therefore, a need for further research to increase understanding of the vulnerability of humans to the social, economic and environmental risk factors of mining and the best approaches to leverage these factors in mineral resource-rich African countries to achieve the Agenda 2030 SDGs.

3.2. **Some challenges in ensuring sustainable mining in Africa.** Table 1 above illustrates the weaknesses and gaps on laws and policies governing Africa's most dominant mining countries. The weaknesses and gaps identified explain the challenges of these countries in ensuring Sustainable Mining and achieving the SDGs. Some of these challenges track around socially friendly and envi- ronmentally responsible exploration and mining operations. For case in point, UNEP (2008) identified examples of major environ- mental impacts of mining across Africa. These include: The exten- sive impacts of diamond mining on Angolan lands, where it is noticed that the recovery of one carat of diamond resulted in more than a ton of material displaced; displacement of ecosystems in the forest reserves of DR Congo and; a displacement of alternative land uses and users in the Wassa West District of Ghana. Others also include widespread air, soil and water pollution in the Zambian copper belt; acid mine drainage and land displacement by mining waste in South Africa; potential threats on ecologically-sensitive areas in the Sangaredi Mine in Upper Guinea Forest of Republic of Guinea (Guinea Conakry) from bauxite mining and processing and; human health threats from uranium mining in Niger (UNEP, 2008). Importantly, with regards to health, it is acknowledged by African ministers for health and the environment in the Libreville Decla- ration of August 2008 that Over 23% of deaths in Africa (>2.4 million people per annum) are attributable to avoidable environ- mental risk factors (WHO, 2008). The poorest and the vulnerable groups (children, women, rural poor, people with disabilities, dis- placed populations and the elderly) are most affected in these occurrences.

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Thus, relevant questions to address in relation to policy issues in Africa should include: a) the status and trend of the environment in Africa, b) the important environmental issues in each country, c) the progress countries have made towards Envi- ronmental Sustainability, d) scientific evidence of significant local environmental issues, and e) provide early warning signs of the places with emerging issues (Oldekop et al., 2016; UNEP, 2008). However, the challenge is the capacity of countries to address and enforce these important issues. Means of generating relevant data for analyzing less visible potential impacts of mining on systems, like sedimentation and groundwater, are not usually incorporated in policy instruments and laws, as seen in Table 1. For instance, out of the 23 countries under review, only 2 (9%) (Ghana and South Africa) have publicly stated the need for Geodata in their mining sector policies. All the same, the two countries do not establish clear plans for the generation of Geodata; where Geodata even implies Geological surveys (De Mulder and Cordani, 1999). Conse- quently, strategic impact assessment of projects (exploration and mining) is still rudimentary in Africa. The dearth of relevant
Geodata is, particularly, liable for the failure to effectively evaluate the potential impacts of a mining project on human health, as acknowledged in the Libreville Declaration (WHO-UNEP, 2015), and also responsible for a lack of public participation and informed discussions on benefit sharing.

Public participation is important for monitoring and evaluating the environmental and social impacts of mining projects as well as discussing benefit sharing with local communities. It can ensure an overall sustainable mineral resources development. Through public participation, local knowledge often provides valuable information for assessing a project before approval (Morse et al., 2014). Public participation further enhances a project's social license to operate through a wider community acceptance. However, a lack of geo- information does not allow informed public participation and the processes of Free, Prior Informed Consent (FPIC) of a project. Meanwhile, there is a strong relationship between access to infor- mation and participation in decision-making. For instance, Princi- ple 10 of the Rio Declaration states that: "each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous

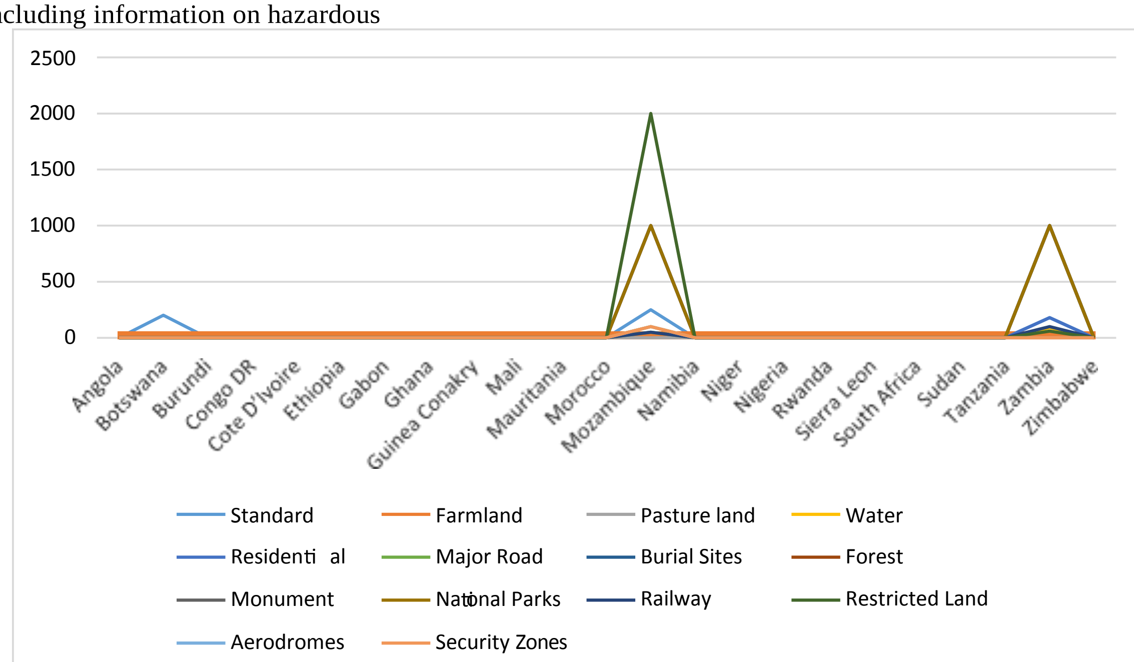

Fig. 3. Buffer parameters (shown in meters on the vertical axis) for Social & Environmental Sustainability analysis.
Data Source: Country's Mining Policy & Law.

materials and activities in their communities and the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making in- formation widely available" (UN, 2000). Thus, to enhance public participation in decision making; overcome inequality, persistent pockets of poverty, hunger, and environmental degradation in mineral rich African countries, UN (2018) and UNEP (2019b) sug- gest the establishment of policies that would support the devel- opment of robust geospatial data. Ensuring access to geospatial data would improve building safe and ecologically friendly cities, protecting ecosystems, and instituting sustainable consumption and production patterns.

4. **Discussions.** Apart from popular narratives of environmental regulations and social protection, there are few policies that adequately capture the term 'Sustainable Development'. That is, only South Africa, Ghana and Botswana have reflected

sustainable development within their policy narratives. However, these countries' policies do not include geospatial considerations to help measure and monitor the contribution of the sector to the relevant SDGs (see Table 1 and also Fig. 3). Even so, it is evident from Table 1 that these countries do not provide details on how to measure sustainable development under mining regimes in terms of concrete indicators. Meanwhile, the number of both large-scale and small-scale industrial mining op- erations continue to increase across Africa. In countries, such as Guinea, Sierra Leone and Tanzania, mining has posed real envi- ronmental challenges. These countries experience poverty and high rates of unemployment (AMDC, 2014; AU, 2011a). In Guinea, for example, more than 50% of the population still lives in poverty; reflecting a lack of access to clean drinking water (SDG6), health centres (SDG3), and unbearable hunger (SDG2) (AMDC, 2014; AU, 2011a; UN, 2019). Environmental impacts remain a major chal- lenge to sustainable mining and are yet to be adequately addressed in African countries.

Ten years after adopting AMV, the challenges facing the African mining sector persist. These include issues of governance, lack of public participation, environmental, economic, social and health impacts of exploration and mining operations; and a failure to make provisions for related research, development, technological innovations and their collective role towards the SDGs. Although AMV aims to leverage the mineral resource endowment of African countries to catalyse its economic diversification and industriali- sation prospects, analysis of the countries' mining sector policies and laws in Table 1 indicate a lack of understanding of the linkages between mineral resource development and environmental stew- ardship in the African mining discourse (AU, 2011b). Meanwhile, an earlier definition of sustainable development entailed the aspira- tion to use environmental resources in a way that will satisfy the needs of both current and future generations. Therefore, since mineral resources are environmental features, discussions on mining development are, by default, integral to sustainable devel- opment (Hodge, 2014). While there are pressures on environmental resources in Africa, which are driven by increasing demands for mineral products to provide the needs of a dynamic global popu- lation (Fig. 2), there are also management constraints evidently influenced by an absence of basic information on the state of the environment (Moomen and Dewan, 2017). Thus, sustainable min- eral resource development entails an understanding of its linkages with environmental sustainability and the other two pillars of sustainable development (Purvis et al., 2019).

Although the use of satellite data is not new in Africa, its pro- cessing and generation of information for governing the mining sector has traditionally been difficult to access and use. This has limited its potential to help governments meet key SDGs. It is, therefore, a call on mineral rich African countries, in particular, to optimize the benefits derivable from the emerging Earth Observa- tion (EO) technologies including the AfriGEOSS, the Africa Regional Data Cube and their associated spatial data. This data must be transformed into actionable insights and indicators that can be used to measure the contribution of the mining sector to specific SDGs. As suggested by Aznar-Sánchez et al. (2019), apart from South Africa, the rest of the African countries generate little new knowledge in mining-related sustainability indicators as a benefit from these new technologies. Thus, more technological work is required in African countries to develop core local sustainability indicators and align these with the Agenda 2030 SDGs. This inno- vative approach rests on the availability of scientists, quality research institutions, university-industry research collaborations, funding and advanced technology. Presently, there is no policy provision that states publicly the need for these in any major mineral resource-rich African economy. Consequently, there is a weak connection between science and technology capacity, and sustainable development in the mineral resource sector of Africa. It is important for state governments to deliberately encourage, in their mining sector policy regimes, development of geoinformation and research in order to pursue the goals of the AMV and to measure the progress of countries towards the SDGs.

A proliferation of frameworks for evaluating sustainable devel- opment in the extractive sector, including environmental sustain- ability, have evolved significantly in the last 15 years. Examples include the works of Azapagic (2004); IGF (2019); Kokko et al. (2015); Missimer et al. (2017); Pimentel et al. (2016); Provasnek et al. (2017). However, the applications of these prolific frame- works in the mineral resource-rich African countries have not developed adequately. From the analysis of Fig. 3, it is evident that even in African countries where these frameworks have been developed, their policy dimension is missing. Rather, there is a burgeoning Knowledge of opportunities for unfettered access to all sorts of information, especially, through the internet. Internet sources and the growing role of NGOs in the African mining sector have facilitated local communities' access to information regarding mineral resource development and sustainability, however inac- curate this might be. Communities affected by mining and civil society organizations (CSOs) often use these evidence to criticize the poor management and regulation of environmental and social impacts of mining (Falck and Spangenberg, 2014; Fraser, 2018; Moomen et al., 2016). These negative perceptions, however, can significantly change when the public has proper information on mineral resource projects and is willing to be engaged in decision making (Diallo, 2016). It is, therefore, crucial for the AMV to address these challenges beginning with the commitment of governments to design and enforce viable mining sector policies that will inspire development of environmental sensitive information that can be shared with stakeholders.

In this regard, the role of geoinformation for better streamlining the accuracy of information that the public and local communities receive on mineral resource sustainability enhancement cannot be underestimated. For case in point, the Nairobi statement on spatial information for sustainable development observed that to achieve sustainable development, there must be a balance between resource exploitation, knowledge and technological advancement for informed decision making at all times (Mwange et al., 2018). In the 21st century, limitless access to relevant spatial information is an important trajectory for improving sustainable mineral resource development outcomes. Accurate spatial information offers many opportunities for development and execution of efficient strategies for sustainable use and management of mineral resources. In particular, the “Free, Prior Informed Consent” (FPIC) principle would be reinforced with availability of relevant geoinformation to all stakeholders during the development of mining projects. This would enhance SDGs 5, 10, 11, 16 and 17 of Agenda (2030). FPIC is ‘the principle that indigenous peoples and local communities must be adequately informed about oil, gas and mining projects in a timely manner and should be given the opportunity to approve (or reject) a project prior to commencement of operations’ (Hanna and Vanclay, 2013; UNHCR, 2013; Yupsanis, 2010).

There may be an economically attractive quantities of mineral resource endowment in a country. However, analysis of local geo- information may provide the appropriate knowledge of realities on the ground on the basis of which appropriate responses to EIAs and SIAs can be validated. With availability of geoinformation, the costs involved in monitoring and evaluation of projects sites can be reduced while obtaining relevant data in real-time or test near-real time (Ayanlade et al., 2008). The development of National Geo- spatial Data Infrastructure (NGDI) will be an important source through which all stakeholders can provide and access geo- information for mineral resource development projects. Resolute national and regional efforts are, therefore, needed to create NGDI in all the countries. These efforts should include expanding awareness of the value and relevance of geoinformation, estab- lishing paragraphs on geoinformation in country mining visions (CMV), enhancing access to geoinformation and strengthening local capacity for handling spatial data. The capacity-building drive shall ultimately assist governments to design and implement viable environmentally sensitive mining policies. Addressing these gaps in policy context shall enhance a major step in moving Africa for- ward in the spirit of sustainable mineral resource development.

5. **Conclusions.** It would have been a fairly difficult task to conduct a compre- hensive policy context analysis on the status of the applications of geoinformation in sustainable mineral resource development in all African countries. This paper rather focused on 23 relatively sig- nificant producer countries of relevant minerals resources across Africa to provide a basis for discussions. Overall, the patterns observed suggest that there is a disconnect between mining sector policy regimes and the desire to achieve sustainable development in mineral resource-rich African countries. That is, a lack of delib- erate policy provision for the adoption and usage of geoinformation to enhance FPIC; public participation in mineral resource devel- opment projects in these countries. Implications are: poor benefit sharing, poor understanding of environmental risk, and a lack of integrated land use planning. There is also a dearth of literature and research, highlighting the value of geoinformation for the attain- ment of the goals of the African Mining Vision (AMV). This last point establishes a lack of evidence base that can be mobilized as part of policy discussions on the feasibility of the Action Plan for Implementation of the AMV. The paper also examined the regional efforts at achieving sustainable development through the avail- ability of satellite data and Earth Observation systems (EO). These include the AfriGEOSS and the Africa Regional Data Cube projects. The objectives of these initiatives are capable of improving the sustainable development drive of Africa if individual countries are able to rise to the demand for relevant information for effective management and monitoring of the mining sector. The significance of geoinformation in moving African countries towards sustainable mineral resource development and Agenda 2030 has also been explored. In this regard, policy-oriented recommendations include: expanding awareness of the value and relevance of geoinformation, establishing paragraphs on geoinformation in Country Mining Vi- sions, enhancing access to geoinformation and strengthening local capacity for handling these data. International Organizations, like the ECA and AU, also need guidance on how to integrate geo- information in projects. Addressing these gaps, in policy context, shall move Africa a major step forward in the spirit of sustainable mineral resource development.

References

Agbaje, G.I., John, O.N., 2018. Cooperation in earth observation missions in Africa: a role for afrigeoss. GeoJournal 83, 1361e1372. https://doi.org/10.1007/s10708- 017-9840-5.

Akiwumi, F.A., Butler, D.R., 2008. Mining and environmental change in Sierra Leone, West Africa: a remote sensing and hydrogeomorphological study. Environ. Monit. Assess. 142, 309e318. https://doi.org/10.1007/s10661-007-9930-9.

AMDC, 2014. A Country Mining Vision Guide Book. African Minerals Development Centre, Addis Ababa.

Anadon, L.D., Chan, G., Harley, A.G., Matus, K., Moon, S., Murthy, S.L., Clark, W.C., 2016. Making technological innovation work for sustainable development. Proc. Natl. Acad. Sci. 113, 9682e9690. https://doi.org/10.1073/pnas.1525004113.

Arrobas, D.L.P., Hund, K.L., McCormick, M.S., Ningthoujam, J., Drexhage, J.R., 2017. The Growing Role of Minerals and Metals for a Low Carbon Future. The World Bank, Washington, DC, USA.

AU, 2011a. Minerals and Africa’s development. The international study group report on Africa’s mineral regimes. In: AMV (Ed.), Economic Commission for Africa/ African Union. http://www.africaminingvision.org. Addis Ababa, Ethiopia.

AU, 2011b. Exploiting natural resources for financing infrastructure development: policy options for Africa. In: Paper Presented at the 2nd Ordinary Session of AU Conference of Ministers Responsible for Mineral Resources Development. Af- rican Union Commission. Addis Ababa, December. African Union, Addis Abab, Ethiopia.

Ayanlade, A., Orimoogunje, I.O.O., Borisade, P.B., 2008. Geospatial data infrastruc- ture for sustainable development in sub-Saharan countries. Int. J. Digit. Earth 1, 247e258. https://doi.org/10.1080/17538940802149940.

Azapagic, A., 2004. Developing a framework for sustainable development indicators for the mining and minerals industry. J. Clean. Prod. 12, 639e662.

Aznar-Sa´nchez, J.A., Velasco-Munroz, J.F., Belmonte-Urenra, L.J., Manzano- Agugliaro, F., 2019. Innovation and technology for sustainable mining activity: a worldwide research assessment. J. Clean. Prod. 221, 38e54. https://doi.org/10. 1016/j.jclepro.2019.02.243.

Baeten, J., Langston, N., Lafreniere, D., 2016. A geospatial approach to uncovering the hidden waste footprint of Lake Superior's Mesabi Iron Range. Extr. Ind. Soc. 3, 1031e1045. https://doi.org/10.1016/j.exis.2016.09.003.

Belward, A.S., Skøien, J.O., 2015. Who launched what, when and why; trends in global land-cover observation capacity from civilian earth observation satel- lites. ISPRS J. Photogrammetry Remote Sens. 103, 115e128. https://doi.org/10. 1016/j.isprsjprs.2014.03.009.

Besada, H., Martin, P., 2015. Mining codes in Africa: emergence of a 'fourth' gen- eration? Camb. Rev. Int. Aff. 28, 263e282. https://doi.org/10.1080/ 09557571.2013.840823.

Blachowski, J., 2016. Application of GIS spatial regression methods in assessment of land subsidence in complicated mining conditions: case study of the Walbrzych coal mine (SW Poland). Nat. Hazards 84, 997e1014. https://doi.org/10.1007/ s11069-016-2470-2.

Burton, I., 1987. Report on reports: our common future. Environment 29, 25e29. https://doi.org/10.1080/00139157.1987.9928891.

Busia, K., 2017. Harnessing mineral resources for Africa's development. In: Centr, A.M.D. (Ed.), African Minerals Development Centr: Governance and Participation. Economic Commission for Africa, Adisa Ababa, Ethiopia.

Busia, K., Akong, C., 2017. The African mining vision: perspectives on mineral resource development in Africa. J. Sustain. Dev. Law Policy (The) 8, 145e192.

Buxton, A., 2012. MMSD 10 Reflecting on a Decade. International Institute for Environment and Development (IIED), London (United Kingdom).

Carvalho, F.P., 2017. Mining industry and sustainable development: time for change.
Food Energy Secur. 6, 61e77. https://doi.org/10.1002/fes3.109.

Casper, S., Gillian, D., Lisa, S., 2017. Mapping Mining to the Sustainable Development Goals: an Atlas. United Nations Development Programme (UNDP), World Eco- nomic Forum (WEF), Columbia Center on Sustainable Investment (CCSI), Columbia University., Geneva, Switzerland.

Christensen, D., 2019. Concession stands: how mining investments incite protest in Africa. Int. Organ. 73, 65e101. https://doi.org/10.1017/S0020818318000413.

Craynon, J.R., Sarver, E.A., Ripepi, N.S., Karmis, M.E., 2016. A GIS-based methodology for identifying sustainability conflict areas in mine design e a case study from a surface coal mine in the USA. Int. J. Min. Reclam. Environ. 30, 197e208. https:// doi.org/10.1080/17480930.2015.1035872.

Cuba, N., Bebbington, A., Rogan, J., Millones, M., 2014. Extractive industries, liveli- hoods and natural resource competition: mapping overlapping claims in Peru and Ghana. Appl. Geogr. 54, 250e261. https://doi.org/10.1016/j.apgeog.2014.05. 003.

de Lange, W., de Wet, B., Haywood, L., Stafford, W., Musvoto, C., Watson, I., 2018. Mining at the crossroads: sectoral diversification to safeguard sustainable mining? Extr. Ind. Soc. 5, 269e273. https://doi.org/10.1016/j.exis.2018.06.005.

De Mulder, E.F., Cordani, U.G., 1999. Geoscience provides assets for sustainable development. Episodes 22, 78e83.

Denis, G., Claverie, A., Pasco, X., Darnis, J.-P., de Maupeou, B., Lafaye, M., Morel, E., 2017. Towards disruptions in Earth observation? New Earth Observation sys- tems and markets evolution: possible scenarios and impacts. Acta Astronaut. 137, 415e433. https://doi.org/10.1016/j.actaastro.2017.04.034.

DeWitt, J.D., Chirico, P.G., Bergstresser, S.E., Warner, T.A., 2017. Multi-scale 46-year remote sensing change detection of diamond mining and land cover in a con- flict and post-conflict setting. Remote Sens. Appl.: Soc. Environ. 8, 126e139.
https://doi.org/10.1016/j.rsase.2017.08.002.

Diallo, P., 2016. The Africa Mining Vision: A Panacea to the Challenges of the African Mining Sector or Another Mirage? Leadership & Developing Societies 1.

ECA, 2017. Geospatial Information for Sustainable Development in Africa: African Action Plan on Global

Geospatial Information Management - 2016-2030. Eco- nomic Commission for Africa, Addis Ababa, Ethiopia.

Edwards, D.P., Sloan, S., Weng, L., Dirks, P., Sayer, J., Laurance, W.F., 2014. Mining and the African environment. Conserv. Lett. 7, 302e311. https://doi.org/10.1111/ conl.12076.

Eggert, R.G., 2010. Mineral exploration and development: risk and reward. Int. Conf. Min. Phnom Penh, Cambodia 26.

Elkington, J., 2013. Enter the Triple Bottom Line. The Triple Bottom Line. Routledge, pp. 23e38.

Emel, J., Plisinski, J., Rogan, J., 2014. Monitoring geomorphic and hydrologic change at mine sites using satellite imagery: the Geita Gold Mine in Tanzania. Appl. Geogr. 54, 243e249. https://doi.org/10.1016/j.apgeog.2014.07.009.

Etikan, I., Bala, K., 2017. Sampling and sampling methods. Biometrics Biostat. Int. J. 5, 00149.

Falck, W.E., Spangenberg, J.H., 2014. Selection of social demand-based indicators: EO-based indicators for mining. J. Clean. Prod. 84, 193e203. https://doi.org/10. 1016/j.jclepro.2014.02.021.

Fernandes, G.W., Goulart, F.F., Ranieri, B.D., Coelho, M.S., Dales, K., Boesche, N., Bustamante, M., Carvalho, F.A., Carvalho, D.C., Dirzo, R., Fernandes, S., Galetti, P.M., Millan, V.E.G., Mielke, C., Ramirez, J.L., Neves, A., Rogass, C., Ribeiro, S.P., Scariot, A., Soares-Filho, B., 2016. Deep into the mud: ecological and socio-economic impacts of the dam breach in Mariana, Brazil. Natureza & Conservaçao 14, 35e45. https://doi.org/10.1016/j.ncon.2016.10.003.

Fonseca, A., McAllister, M.L., Fitzpatrick, P., 2013. Measuring what? A comparative anatomy of five mining sustainability frameworks. Miner. Eng. 46e47, 180e186. https://doi.org/10.1016/j.mineng.2013.04.008.

Fraser, J., 2018. Mining companies and communities: collaborative approaches to reduce social risk and advance sustainable development. Resour. Policy. https:// doi.org/10.1016/j.resourpol.2018.02.003.

Ge, L., Chang, H.-C., Rizos, C., 2007. Mine subsidence monitoring using multi-source satellite SAR images. Photogramm. Eng. Remote Sens. 73, 259e266.