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Effective Integrated Frameworks for Assessing Mining Sustainability

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Abstract

The objectives of this research are to review existing methods used for assessing mining sustainability, analyze the limited prior research that has evaluated the methods, and identify key characteristics that would constitute an enhanced sustainability framework that would serve to improve sustainability reporting in the mining industry. Five of the most relevant frameworks were selected for comparison in this analysis, and the results show that there are many commonalities amongst the five, as well as some disparities. In addition, relevant components are missing from all five. An enhanced evaluation system and framework was created to provide a more holistic, comprehensive method for sustainability assessment and reporting. The proposed framework has five components that build from and encompass the twelve evaluation characteristics used in the analysis. The components include Foundation, Focus, Breadth, Quality Assurance, and Relevance. The enhanced framework promotes a comprehensive, location-specific reporting approach with a concise set of well-defined indicators. Built into the framework is quality assurance, as well as a defined method to use information from sustainability reports to inform decisions. The framework incorporates human health and socio-economic aspects via initiatives such as community engaged research, economic valuations, and community-initiated environmental monitoring.

Keywords

sustainability; mining; indicators; environmental impact

1. Introduction

The mineral and metal extraction industry has enhanced economic prosperity and led to significant societal advancements. While the materials produced from mining are essential to

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Capsule:

Best practices for developing, assessing, and applying mining sustainability frameworks are reviewed and proposed.

the support of current living standards, the associated costs have become apparent with the degradation of ecosystem services and deleterious impacts on human health. Ecosystem services are defined as benefits that people obtain from ecosystems, and the human species is fundamentally dependent on their availability. Ecosystem services are divided into four categories, including *provisioning services* (i.e. food, water, timber, and fiber), *regulating services* (i.e. climate, floods, disease, wastes, and water quality), *supporting services* (i.e. soil formation, photosynthesis, and nutrient cycling), and *cultural services* (i.e. recreational, aesthetic, and spiritual benefits) (Millennium Ecosystem Assessment, 2005). Historic mining practices were conducted with little forethought to ecosystem services, failed to account for human health impacts, and did not consider monetary valuation of adverse impacts. Additionally, the costs of mine-site reclamation have routinely been underestimated, creating difficulties for adequate reclamation of legacy sites. Recently, the Bureau of Land Management has been instructed to increase evaluation of financial assurances (GAO, 2013).

The past few decades have brought forth an awareness and understanding of the full impacts of mining. As a result, those involved in mining and materials production have begun to implement sustainability goals and approaches, such as closure planning from the beginning (cradle to grave approach) (KGHM International, 2013), community involvement and social impact/public health assessments (NMFS, 2003), and more comprehensive economic valuation (Wang et al., 2010). This new approach has also led to the concept of the social license to operate, which involves working with local communities and other stakeholders to develop plans that are acceptable to all. These efforts, along with others related to corporate social responsibility (CSR), have ushered in a new generation of mines. Defined as those that are designed and permitted under contemporary environmental legislation (KGHM International, 2013), “modern” mines provide the opportunity to identify and study mining impacts in the wake of the transition towards sustainable materials development. However, questions remain as to the extent to which these approaches are being implemented, and it has been noted that in some cases CSR disclosures have not been representative of actual CSR performance (Emel et al., 2012). Significant progress towards sustainability can only be attained when such efforts are implemented with transparency and veracity.

The move towards evaluating the full impacts, both positive and negative, of mining requires methods by which to accurately and cost-effectively assess such impacts. Specifically, there is a need for sustainability assessment tools. Sustainability assessment is a recent trend in the mining industry, where companies voluntarily self-disclose information regarding their performance in terms of economic, environmental, and social impacts that result from mineral extraction and processing. Multiple methods have been proposed and developed for conducting sustainability assessments, and the most effective approach has yet to be determined. Only recently has research begun to review and critically analyze the methods available, and to discuss frameworks that may support successful application.

The objectives of this research are to critically review existing methods used for assessing mining sustainability, to analyze the limited prior research that has evaluated the methods, and to identify key characteristics that would constitute an enhanced sustainability framework that would serve to improve sustainability assessments in the mining industry. Specifically, this work addresses the following questions: (1) what are the primary

sustainability assessment methods used in the mining industry? (2) what are the similarities and differences among the methods? (3) do gaps exist in the methods? (4) which characteristics are most important and relevant to achieve effective sustainability assessments? (5) which components are essential to the design of an effective sustainability assessment framework for the mining industry that meets the goals of all stakeholders, and is readily implemented and communicated?

2. Background

2.1 Sustainability assessment and accounting

The concept of “sustainable development” was made popular by the release of *Our Common Future Report* in 1987 (WCED, 1987). While the definition of sustainable development has been the topic of much debate, the meaning specified in *Our Common Future* remains widely cited: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). The idea of sustainable development has been increasingly applied as a corporate concept, termed “corporate sustainability”. There is no universal definition of corporate sustainability. One working definition is “adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining, and enhancing the human and natural resources that will be needed in the future” (IISD, 1992).

Working towards corporate sustainability and responsibility, companies have adopted global environmental management system standards such as the International Organization for Standardization (ISO) Standard 14001 for environmental management systems, which specify performance indicators as a required element. Furthermore, many have developed more functional definitions of sustainability for program planning and operational management that are aligned with their specific focus and values. These are often based on the “three pillars” of sustainability (economic, environmental/resource/ecosystem-services, and social) and place more or less emphasis on each of the three (EPA, 2011). Many authors have noted that corporate sustainability is synonymous with the term “corporate social responsibility” and the concept of the “triple-bottom-line” (e.g., Roca and Searcy, 2012).

The advent of sustainability as a critical element to development led to the need for tools to assess the impact of corporate actions on sustainability. The development and application of sustainability assessment tools is a burgeoning field. It is relevant to point out that there is overlap between the more recent sustainability assessment efforts and the long-existing environmental impact assessments associated with land-use planning. The connection between these two has been discussed in detail (e.g., Ness et al., 2007; Hacking and Guthrie, 2008).

2.2 Sustainability assessment for the mining industry

The mineral extraction industry is regarded as one of the most environmentally and socially disruptive businesses (e.g., Jenkins and Yakovela, 2006). As a result, there have been major efforts to incorporate sustainability assessment into their operations. The majority of major mining companies now release sustainability assessment reports (Dashwood, 2014).

The International Council on Mining and Metals (ICMM), established in 2001, is a global industry organization that represents 21 mining and metals companies as well as 35 national and regional mining associations and global commodity associations in sustainability related issues. The ICMM has developed a Sustainable Development Framework (SDF) for sustainability assessment (ICMM, 2014). Participating members are expected to implement the SDF and publish independently verified sustainability reports regarding their performance. The SDF consists of 10 principles (Table 1), which are based on issues identified in the Mining, Minerals and Sustainable Development project- a two-year project that included consultation with stakeholders to identify key issues relating to mining and sustainable development.

The 'Public Reporting' component of the SDF states that member companies are committed to publicly report on their sustainable development performance on an annual basis, in line with the guidelines and protocols set by the Global Reporting Initiative (GRI). ICMM members are to report specifically with the GRI's Mining and Metals Sector Supplement. 'Independent assurance' was added to the SDF in 2008, requiring members to obtain independent third party assurance to review and assess the quality of their sustainability reports. Specifically, they audit to ensure that systems and processes are in line with the five aspects of ICMM's Assurance Procedure:

1. The alignment of the member company's sustainability policies to ICMM's 10 Sustainable Development (SD) Principles and any mandatory requirements set out in ICMM Position Statements.
2. The company's material SD risks and opportunities based on its own review of the business and the views and expectations of its stakeholders.
3. The existence and status of implementation of systems and approaches that the company is using to manage the identified material SD risks and opportunities.
4. The company's reported performance during the given period for a selection of identified material SD risks and opportunities.
5. The company's self-declared application level of the Global Reporting Initiative's G3 Sustainability Reporting Guidelines.

While multiple efforts are progressing, sustainability assessment and reporting is not mandatory nor uniform in the industry. Several theories explain a company's motivation to disclose such information. The legitimacy theory states that in order to survive as an organization, it is necessary to legitimize its existence to society. An organization can attempt to accomplish this through sustainability accounting and reporting. The stakeholder theory states that the organization needs to manage various stakeholders in order to legitimize its existence (Lodhia and Hess, 2014). Along the same lines, Jenkins and Yakovela (2006) suggest reasons as to why voluntary sustainability reporting initiatives are important for mining. They indicate that publishing standalone reports on the environment, health, and safety performance helps to modify the industry's negative reputation. Also, interest groups consistently target and challenge the sectors legitimacy on both local and global levels. And finally, there is a consistent challenge for mining companies to maintain 'social license to operate' (Jenkins and Yakovela, 2006). Whatever the incentive may be, the

shift towards sustainable business practices has led to the development of sustainability assessment frameworks to guide and critically evaluate sustainable development in the mining industry.

2.3 Prior investigations of sustainability frameworks

Lodhia and Hess (2014) and Moran et al. (2014) provided reviews of the prior research literature for sustainability accounting and reporting in the mining industry. However, they did not examine nor evaluate specific frameworks. Fonseca and colleagues present some of the first critical evaluations of specific assessment frameworks (Fonseca et al., 2013, 2014).

Sustainability assessment frameworks provide guidance for mining companies to measure and disclose their performance towards sustainable development. Identifying, characterizing, and quantifying the impacts of mining on ecosystem services and on local communities is a multifaceted, complex process. Robust, cost-effective methods are still being developed and evaluated. Although the frameworks exhibit similar contexts and unit analysis, there is no agreement on the correct approach to assess mining sustainability. The Global Compendium of Sustainability Indicators Initiatives (IISD) includes at least 20 records of frameworks that can be used to assess mining sustainability (IISD, 2012), and scholars are proposing a number of similar frameworks as well (e.g., Fonseca et al., 2013).

Sustainability assessment frameworks based on the use of indicator analysis to characterize the impacts of mining and materials production activities is an approach that is developing into an industry-scale standard practice. The performance-indicator model seeks to provide quantitative and qualitative metrics to evaluate sustainability. For example, the GRI sustainability reporting framework evaluates economic, environmental, and social impacts for the mining and metals sector through the evaluation of comprehensive, well-defined, and specific indicators within each of the three sustainability categories. (GRI, 2010).

Ness et al. (2007) and Hacking and Guthrie (2008) conducted in-depth analyses of sustainability assessment methods for general application (not specific to mining). They identified critical elements for effective frameworks. Fonseca et al. (2013) present a comparative analysis of five sustainability frameworks developed specifically for mining. Given the large number of sustainability frameworks that exist, the sample was selected based on the authors' judgment about which frameworks best represented those that are used by, or proposed for, mining companies (specifically large ones). Three of the five frameworks — seven questions of sustainability (7QS), innovation and technology driven sustainability performance management framework (ITS-PM), and a modified GRI-based framework (Azapagic, 2004)-have been proposed but have received little to no use in the field. The fourth, Toward Sustainable Mining (TSM), was developed by the Mining Association of Canada (MAC) in the early 2000s. The fifth method is the GRI, the most widely adopted framework in the mining sector.

Fonseca et al (2013) evaluated and compared the frameworks based on five characteristics: (a) temporal orientation; (b) geographical focus; (c) comprehensiveness; (d) integration (trade-offs and synergies); and (e) scale and scope considerations. These characteristics were chosen based on the prior work of Ness et al. (2007) and Hacking and Guthrie (2008). The

objectives were to describe, compare, and critically analyze the five frameworks and to assess the effectiveness and limitations of each. The authors conclude that there is a general lack of assessing trade-offs and synergies among the sustainability dimensions and that none of the frameworks shed light on effects of mineral operations across geographical scales. Their work highlights the value in further researching mining sustainability frameworks, and they suggest that future work should analyze and compare frameworks based on more specific criteria.

In a follow-up, Fonseca et al. (2014) focused specifically on the GRI approach, as it is the most widely used framework for assessing and reporting sustainability in the mining industry. The evaluation is guided by an assessment of the extent to which the GRI meets a number of principles of sustainability assessment and reporting, known as the BellagioSTAMP principles. The ten Bellagio Principles were originally developed in 1996 by a group of international sustainability measurement experts meeting in Bellagio, Italy. The International Institute for Sustainable Development (IISD) and the Organization for Economic Co-operation and Development's (OECD) Measuring the Progress of Societies initiative revised them in 2009 into eight more concise principles. The Bellagio Principles are not a framework in itself; instead they are designed and used to evaluate existing and proposed sustainability frameworks. Fonseca et al. (2014) analyzed the practice of GRI reporting by mining corporations by focusing on principles 1, 2, 3, and 4 (guiding vision, essential considerations, appropriate geographic and temporal scope, and conceptual framework and indicators), which the authors argued are the most relevant in terms of the design and reliability of the GRI framework. The findings of this study indicate that the GRI framework for sustainability reporting in the mining industry partly meets Bellagio Principles 1, 2, 3 and 4. It is established that GRI reporting issues are often the result of misuse; i.e., mining companies who often 'cherry-pick' which indicators they decide to report (Fonseca et al., 2014). However, the results show that even if mining companies were to fulfill the framework's reporting guidelines, gaps within each analyzed principle still exist.

Issues with extent of disclosure are highlighted by Emel et al. (2012), who evaluated some of the challenges associated with sustainability reporting in the mining sector using a case study from Tanzania, where there is a new focus on CSR projects. Through interviews with members of the public and focus groups, and photography and video recording during site visits, Emel et al. (2012) investigated four main themes-water supply, education, health, and agroforestry. Reports from mining companies were shown to be incongruent with citizen accounts, indicating that companies have the potential to make inconsistent claims, be ambiguous, and disregard asset losses (like grazing and water resources). They propose that the solution to this problem could lie in third-party certification, an increased involvement of government inspection and fines, citizen involvement in monitoring and reporting, or in stricter accounting standards. The first element, third-party certification, was addressed for example in the "independent assurance" component that was added to the SDF in 2008 by the ICMM, as noted above.

Giurco and Cooper (2012) presented the *Mineral Resources Landscape* as a conceptual tool to understand the extraction and use of minerals within a systems view. They proposed that

the landscape tool can be used to visualize the results of annual sustainability reports and to show achievements and areas of concern within sustainability dimensions. Four themes are evaluated in the landscape: resources, technology for extraction and processing, use (including embedded value and service provided by the ultimate use of the metal), and rates of production and consumption. Using a case study of prospective Australian deep-sea mining, the authors carried out stakeholder workshops to understand the issues and concerns perceived by different stakeholders. Then, the key questions raised by government, industry, and “other” stakeholder groups were mapped within the Mineral Resource Landscape to see how they align with the four above-mentioned themes. The results showed that key questions raised by the stakeholder groups all relate to the ‘resource’ and ‘extraction and processing technologies’, and ignore two key points in the Mineral Resources Landscape — the ‘level of service’ offered by minerals resources to society, and the ‘consumption trends’ which assimilate these services into society. Therefore, the authors argue that mapping questions within Mineral Resources Landscape can be useful as it can instigate and inspire additional questions in themes not addressed by certain stakeholders.

3. Evaluation of existing sustainability assessment frameworks

The evaluation of sustainability frameworks presented in this study builds off of the research reviewed above in an effort to develop a more comprehensive and effective assessment framework. We explore in detail five current frameworks to find similarities and information gaps that exist. The frameworks are briefly summarized below.

3.1 Selected frameworks for comparison

3.1.1 Global Reporting Initiative—The aforementioned performance-indicator based GRI sustainability reporting framework has three main elements that provide guidance on how and what to report:

1. **The Sustainability Reporting Guidelines:** The guidelines consist of quality and quantity principles (materiality, stakeholder inclusiveness, sustainability context, and completeness) as well as over 130 managerial and performance indicators in several thematic categories (organizational, managerial, economic, environmental, social, human rights, society, and product responsibility issues).
2. **Sector Supplements:** The supplements complement provide additional guidance for a given sector, with sector-specific performance indicators. One of the supplements is the Mining and Metals Sector Supplement, which will be discussed further in the following section.
3. **Indicator Protocols:** The protocols exist for each of the performance indicators contained in the guidelines. They provide definitions and technical and methodological guidance to assist those preparing reports and to ensure consistency in the interpretation of the performance indicators.

The Global Reporting Initiative (GRI) is the most widely adopted framework in the mining sector for sustainability reporting. This is in part due to the facts that ICMM’s Sustainable Development Framework requires companies to use the GRI framework and its Mining and

Metals sector supplement (GRI, 2010) as guidance for sustainability reporting. The GRI reporting framework was first piloted in the late 1990s and is now in its third version called the G3. Promoted by the ICMM, G3's Mining and Metals Sector Supplement (MMSS) has become the standard reporting framework for the mining industry. The GRI database indicates that in 2011, 102 mining companies published sustainability reports, 95% of which used the G3 framework. The actual output of G3 based reports is expected to be higher than this, because many companies do not submit their reports to the GRI database (Fonseca et al., 2014).

G3 is a sustainability assessment framework based on the use of indicator analysis; it employs the triple bottom line approach where comprehensive, well-defined, and specific indicators are evaluated within each of the three sustainability categories (economic, environmental, and social). For example, environmental performance indicators include impacts associated with materials, energy, water, biodiversity, and emissions, effluents, and wastes. G3 has an Application Level process, a procedure that guides companies to self-declare their maturity level in regards to sustainability reporting: expert (A), intermediate (B), or introductory (C), with an optional (A+ B+ or C+) for audited reports (Marimon et al, 2012).

The GRI framework has a significant limitation- a lack of geographical or spatial focus. Because performance is reported at the level of the "organization" instead of "mining sites" or regions, it provides a one size fits all approach, with no consideration of site-specific conditions or properties. GRI guides organizations to aggregate data from all of their facilities/sites into a single report in an effort to promote standardization. However, when indicators are aggregated across geographical areas, the sustainability performance evaluation can become irrelevant and even inaccurate, as it disregards contextual and site-specific disclosures. Another notable limitation is that indicators are evaluated in isolation and the synergies among sustainability components are largely overlooked.

3.1.2 Towards Sustainable Mining—The Mining Association of Canada (MAC) developed an approach to measuring sustainable development in the mining industry in the early 2000s, called Towards Sustainable Mining (TSM). TSM is characterized by an evolving set of guiding principles and 18 performance indicators across six categories (tailings management, energy use and greenhouse gas emissions management, aboriginal and community outreach, crisis management planning, biodiversity conservation management, and safety and health). For each indicator, companies self-assess and assign one of five scores based on the criteria they meet: Excellence and leadership (AAA), integration into management decisions and business functions (AA), systems/processes are developed and implemented (A), procedures exist but are not fully consistent or documented; systems processes planned and being developed (B), no systems in place where activities tend to be reactive and procedures may exist but they are not integrated into policies and management systems (C). In an effort to ensure that reported results represent an accurate account of a company's practices, TSM promotes a checks and balances system implemented through tri-yearly external verification. In 2006, 15 companies reported facility level performance via TSM assessments. In 2013, this number grew to 23 companies (62 facilities) with externally verified results for 7 companies (19 facilities) (MAC, 2014).

It is noted that TSM is a narrower approach with fewer indicators than GRI. With a smaller focus, TSM misses potentially relevant sustainability issues. However, the upside is that the narrow approach provides more reliable and comparable reports. Furthermore, TSM has a clear focus on site-level performance. Therefore, as opposed to GRI, TSM reports contain site-specific data that can be compiled into sector-wide reports.

3.1.3 Azapagic's modified GRI framework—Azapagic (2004) proposed a mining centered, enhanced GRI-based framework. At the time, GRI was in its second-generation phase (known as G2) and had not yet launched sector-specific indicators (i.e. no Mining and Metals Sector Supplement). The framework shares many of the same characteristics of the current GRI G3. However, the Azapagic framework is considered to be more comprehensive in that it employs a larger range of indicators, and more integrative in that the framework includes indicators that link social, environmental, and economic aspects. Despite the wide range of indicators included in the framework, there is no method of aggregating information into an overall index to describe total progress towards sustainable development. Furthermore, as the author recognizes, the exhaustive nature of the framework makes it applicable only to those large-scale mining companies that can afford the time and resources necessary to carry out the assessment (Azapagic, 2004).

3.1.4 Innovation and technology driven sustainability performance management framework (ITSPM)—The innovation and technology driven sustainability performance management framework (ITSPM) was developed specifically for the mining sector by Basu and Kumar (2004). ITSPM is a conceptual framework with three broad pillars of performance (environmental, social, and economic) and three foundation areas (multi-stakeholder governance, technology, and innovation). The framework does not yet specify types or quantity of indicators but rather discusses indicator development through a combined 'top-down' (expert driven) and 'bottom up' (stakeholder scoped) approach. The authors envision indicators divided into two major performance groups (1) health and safety and (2) economic feasibility with the hope to integrate social, environmental, and economic spheres. However, a detailed coverage of sustainability indicators was beyond the scope of Basu and Kumar (2004), and they have not since been defined. ITSPM does have some significant components; it's distinguished from other framework designs by its emphasis on innovation and technology in terms of design and engineering at the site level to improve sustainability performance.

3.1.5 Seven Questions of Sustainability (7QS)—The Seven Questions of Sustainability (7QS) was produced by the Mining, Minerals and Sustainable Development research project's North American branch as an integrated and future oriented framework to assess the contributions of mineral projects to sustainability (MMSD, 2002). The seven components of the framework each pose a question as a means of assessing the net contribution to sustainability of a mining or mineral project over the long term, either positive or negative. The seven themes are (1) engagement; (2) people; (3) environment; (4) economy; (5) traditional and non-market activities; (6) institutional arrangements and governance; (7) synthesis and continual learning. Using 7QS, decision makers define answers to each of the seven questions. Indicators are case specific, where quantity and

types are decided upon to best answer the seven questions. In this way, 7QS recognizes that when applying the framework, values come into play and there may not be one correct answer. As knowledge evolves and values change, answers to the questions can be refined, eliminated, or replaced to reflect changes. Because of this value-dependency characteristic, the question of who is involved in the assessment is important. The framework leaves it to stakeholders to determine specifics such as indicator quantity and type, degree of public participation, criteria for comparing impacts, third-party audit, etc. It is designed to provide guidance throughout the projects entire lifecycle and for operations of all sizes.

The 7QS framework has had one application so far; the Tahltan Mining Symposium held during April, 2003. The Tahltan lands are located in the drainage area of the Stikine River and its tributaries in the Northwest corner of British Columbia. Gold mining and exploration in this area dates back to 1861. The symposium brought together a total of 38 contributors; 28 Tahltan people, 9 individuals from industry and government, and a facilitator from the Mining/Mineral Team of the International Institute for Sustainable Development. The committee's goals were to review the relationship between the Tahltan people, their land, and the mining industry and to build a strategy to guide the relationship in the future. Guided by the Seven Questions of Sustainability, the result of the symposium was the 'Out of Respect' report in which participants considered past, present, and potential future conditions for the Tahltan people and their land in the years to come. The IISD Mining/Minerals Team is pursuing additional opportunities to test the framework in mining and other sectors (IISD, 2003).

3.2 Framework assessment approach

We employ an evaluation matrix similar to that proposed by Fonseca et al. (2013). However, we add seven new evaluation characteristics: (1) external verification; (2) stakeholder involvement/community involvement; (3) research translation/common language; (4) public access to information; (5) decision making context; (6) economic valuation of resources; (7) disclosure of assumptions, uncertainties, and indicators not evaluated). In addition, we employ the five characteristics used by Fonseca (temporal orientation; geographic focus; comprehensiveness; integration; scale and scope considerations). Definitions and rationale for prior and newly proposed evaluation characteristics are described in Tables 2 and 3, respectively.

We analyze how each of the five sustainability frameworks fulfill all eight of the BellagioSTAMP principles (Table 4). The Bellagio principles are used in this evaluation because they have been tested, updated, and repeatedly endorsed by many experts in the field (Fonseca et al., 2014). They help realize the full potential of sustainability assessments through considerations of four aspects, including (1) content - questions that should be answered in assessments, (2) process - the way in which assessments should be carried out, (3) scope - range of assessments across the dimensions of time and geography, (4) impact - the way to maximize the impact of assessments on the public and policy-makers. BellagioSTAMP is intended to inform the totality of the sustainability assessment process, specifically with regards to the choice and design of indicators and how they are interpreted and communicated. The principles can serve to guide any group - community bodies,

academics, non-governmental organizations, corporations, governments and international institutions- in the assessment of societal progress, consideration of policy options, or in advocating for change (IISD and OECD, 2010). Our analysis differs from Fonseca et al. (2014) in that we employ all eight of the principles. As the International Institute for Sustainable Development (IISD) states, the principles are inter-related and are intended to be used as a complete set.

Using similarities and gaps as a starting point, we determine a comprehensive set of important characteristics for a desirable and effective sustainability assessment framework. There are evaluated in terms of the BellagioSTAMP principles described above. Finally, we evaluate each proposed component to determine its feasibility for use, i.e. how easily and readily it can be implemented.

3.3 Synopsis and analysis of existing frameworks

The results of the comprehensive evaluation of the five frameworks are presented in Table 5. Researchers and experts in mining sustainability have proposed the five frameworks evaluated in this work. Therefore, it is not surprising that the evaluation highlights a significant amount of similarity among the frameworks, as shown in Table 6. What is quite striking and noteworthy is that there are significant gaps in each framework's fulfillment of certain characteristics, indicated by a white space in the table, where a BellagioSTAMP Principle is not fulfilled.

3.3.1 Temporal orientation—The third Bellagio Principle, Adequate Scope, specifies that a sustainability framework must define a time horizon that captures both short and long term effects. Evaluating the temporal orientation of the five frameworks, we see that three of the frameworks (TSM, Azapagic's, and ITS-PM) evaluate a mining company's performance on an annual basis. The 'annual snapshot assessment' partially fulfills the eighth Bellagio Principle, Continuity and Capacity, in that it considers repeated yearly measurement. The GRI and 7QS frameworks, however, fulfill both the eighth principle and third principle, being that they are 'comprehensive' with regards to temporal orientation. The GRI framework guides users to report on information gathered from the current reporting period (e.g. one year) and at least two previous periods, as well as future targets, where they have been established, for the short and medium term (GRI, 2010). Adopting a more sophisticated treatment of time, 7QS guides institutional arrangements and governance to be in place to ensure that operation consequences can be addressed throughout the full lifecycle of the mine, including post closure. Furthermore, included in 'Question Seven: Overall Integrated Assessment and Continuous learning', the 7QS framework emphasizes the importance of not only looking at the 'once only snapshot', but also for periodic reassessment. They state that this will ensure that trends over time are identified and factored into the decision making process (MMSD, 2002).

3.3.2 Geographic scope—The GRI (and Azapagic's modified GRI framework) are organizational-centered evaluations. In an effort to promote standardization, GRI guides organizations to report their performance across the organization, which may have sites of different scales and in various locations. This approach has a significant drawback, as it

disregards contextual (location-specific) issues. For example, a large, global company is likely to have facilities in many locations, with different geographical and ecological conditions and political, social, and economic contexts. When indicators are aggregated across geographical sites, the sustainability performance evaluation can become irrelevant and even inaccurate. The other three frameworks (TSM, ITS-PM and 7QS) report on the site level, carrying more detailed and quantifiable location-specific data so that operational sites can improve their internal performance. Reporting on the site level fulfills the third BellagioSTAMP Principle, Adequate Scope, reporting on a geographic scope starting at the local level, and building to global.

3.3.3 Types and quantity of indicators—All five of the sustainability assessment frameworks are based on the use of indicator analysis to characterize the impacts of mining and materials production activities. However, only GRI, TSM, and Azapagic's framework provide comprehensive, well-defined, and specific indicators to be evaluated and therefore fulfill the fourth BellagioSTAMP Principle, Framework and Indicators. For example, the GRI framework presents over 150 indicators across the three sustainability categories, economic, environmental, and social. Azapagic's framework expands on the indicators listed in for GRI and is more comprehensive as it enforces reporting on all 140 indicators, whereas GRI encourages companies to report on the most 'material' indicators. This means that a GRI G3.1 report is not expected to address all of the indicators, but instead those that are considered 'core' indicators, determined by the companies consulted stakeholders. TSM provides a more concise list, with a set of 18 indicators across six categories. A narrow approach promotes more reliable and comparable reports but has the potential to miss potentially relevant sustainability issues.

3.3.4 Integration between sustainability categories—Integrated indicators have been proposed only in Azapagic's framework, as the GRI G3.1 has not yet identified a standardized set of integrated performance indicators. Azapagic presents examples (not a standardized list) of integrated indicators and specifies that further development is necessary. Azapagic argues "Firstly, integration reduces the number of indicators to a smaller more manageable number of performance measures, thus better facilitating the decision making process. Secondly, sustainable development is a holistic concept and ideally we should strive to consider all three pillars of sustainability simultaneously" (Azapagic, 2004). An example is the integrated indicator 'energy consumption per mass of product sold', which addresses the interplay between the environmental and economic productivity of the mineral extraction process. Azapagic's integrated indicators fulfill BellagioSTAMP Principle 2, Essential Considerations. Integrated indicators recognize the interactions between sustainability components, acknowledge synergies/tradeoffs, and identify how activities may have impacts across boundaries.

3.3.5 Scale effects—Scale effects come into play in terms of the size of a mining facility and related production processes. This characteristic is important for BellagioSTAMP Principle 3, Adequate Scope. None of the frameworks include scale in their sustainability assessments. Azapagic mentions issues related to scale through the acknowledgement that the proposed framework is focused more for large scale mining

companies that can afford the time and resources necessary to carry out the exhaustive nature of her assessment (Azapagic, 2004).

3.3.6 External verification—Third party verification has been a proposed solution to the problem of misleading claims, ambiguity, inaccuracy, or incompleteness with regards to sustainability reporting (ICMM, 2014). The TSM framework is the most established with regards to this characteristic. TSM incorporates external verification directly into their program, promoting a system of checks and balances in an effort to build an accurate characterization of each facilities management systems and performance. In this framework, a company's self-assessments are externally evaluated every three years by a trained verifier, who is an experienced auditor independent of the company. In the year of external verification, the company's CEO (or most senior executive) submits a letter to the Mining Association of Canada (MAC), confirming that external verification has been conducted in accordance with the Terms of Reference for Verification Service Providers. The final step of the process is the Community of Interest (COI) Panel Post-Verification Review. Each year, MAC'S independent COI Advisory Panel selects two companies to appear before it to present and discuss their TSM results. During these consultations, the Panel tests to see whether and how facilities are improving their performance, and explores any challenges and the steps being taken to address them (MAC, 2014). The use of external verification falls into the fifth BellagioSTAMP principle, which emphasizes the need to assess the progress towards sustainable development by disclosing all data sources and methods.

It should be noted that ICMM member companies who are required to report using the GRI's Mining and Metals Sector Supplement are also required to obtain independent third party assurance to review and assess the quality of their sustainability reports. However, the GRI framework itself, separate from ICMM, only 'recommends' external assurance in their Mining and Metals Sector Supplement to enhance the credibility of reports. They mention a variety of approaches that can be used to implement external assurance including professional assurance providers, stakeholder panels, or other external groups or individuals. With the broad description that it should be conducted by competent groups or individuals external to the organization, external verification may employ groups or individuals that follow professional standards for assurance, or they may involve approaches that follow systematic, documented, and evidence-based processes but are not governed by a specific standard (GRI, 2010). The GRI states that information describing the methods used for external assurance should be disclosed in the report.

The 7QS framework briefly mentions this characteristic, in its first theme entitled Engagement. In the reporting and verification category, they note that there should be appropriate systems of reporting and verification in place. However, no further description of how verification processes should be carried out is provided (MMSD, 2002).

3.3.7 Public access to information—The GRI G3.1 and TSM frameworks suggest that sustainability reports should be made publicly accessible, and the 7QS requires it. Facilities participating in TSM are increasingly making reports publicly available. In 2006, 49 facilities publicly reported performance, and in 2013 this number grew to 62 facilities (MAC, 2014). In line with the fifth BellagioSTAMP Principle, Transparency, companies

who release public reports reinforce a consistent process to collect reliable data and information regarding sustainability performance. However, although TSM is shifting towards more transparency, only 19 of the 62 facilities making their reports publicly available also externally verified their results (MAC, 2014). It is important to note that if reports are not done properly (and verified), making them publicly available could perhaps be a disservice to the community.

3.3.8 Stakeholder/community involvement—Stakeholder/community involvement falls into the seventh BellagioSTAMP Principle, Broad Participation, by reflecting views of the public and providing a means for active leadership. While the GRI framework overlooks this characteristic, the other four frameworks recognize the value of stakeholder/community involvement in some capacity, mostly in regards to outreach. Azapagic lists stakeholder involvement as an indicator category; ITS-PM emphasizes a multi-stakeholder process to achieve good governance; and 7QS measures the effectiveness of the stakeholder engagement process via periodic satisfaction surveys. TSM devotes one of its seven guiding principles to this topic; included in the guiding principle of aboriginal and community outreach are four indicators: (1) community of interest identification, (2) effective community of interest engagement and dialogue, (3) community of interest response mechanism and (4) reporting. TSM encourages facilities to identify the affected community and demonstrate that they are actively engaged in meaningful dialogue. This includes providing information to the community in a timely manner and having the community complete periodic reviews of the engagement process to promote continual improvement. The interest response indicator seeks to ensure that facilities have processes in place to receive feedback from their communities of interest and ensure that they consider and respond to community complaints and concerns. Facilities will receive a grade of ‘A’ for this indicator if they demonstrate that they have incorporated community input into the decision making process. The fourth indicator, reporting, requires that formal systems be in place to report on concerns raised by the community. The inclusion of stakeholder involvement/community involvement (through stakeholder and community outreach) in most of the frameworks denotes that there is a consensus among framework developers that it is important. However, so far frameworks have focused only on outreach. Frameworks may be improved upon by redefining the idea of stakeholder/community involvement from ‘outreach’ to ‘participation’, through initiatives such as publicly involved monitoring programs.

3.3.9 Research translation/common language—Public availability of sustainability reports is only effective if reports use language that makes the information relevant and accessible to all parties. Not only is it important for reports to be completed and verified by a 3rd party but they must be ‘translated’. The sixth BellagioSTAMP Principle, Effective Communication, states that clear and plain language should be used in order to present information in a fair and objective way. In doing so, this will build trust and attract the broadest possible audience while minimizing the risk of misuse. Specifically, GRI G3.1 outlines that reports should avoid technical terms, jargon, and acronyms and necessary explanations should be included in a glossary (GRI, 2010). The TSM framework includes a specific indicator entitled ‘effective community of interest engagement dialogue’ with the

purpose to ensure that communities are informed of the facility's activities and performance and that the facility understands the viewpoints of the community. To ensure that communications are written in a language that is clear and understandable to all parties involved, facility staff is trained on Aboriginal consultation requirements. Furthermore, they are required to provide information to the community of interest in a timely manner (MAC, 2014). The 7QS framework addresses that integration and synthesis of ideas and common language is an issue when bringing theory to practice, but does not explicitly define requirements for effective communication practices (MMSD, 2002).

3.3.10 Decision-making context—The decision-making context characteristic falls into the second BellagioSTAMP Principle, Essential Considerations. Sustainability reports should be dynamic with current trends and drivers of change, carried out through the decision making process. Azapagic's framework and the 7QS framework both discuss decision-making. Azapagic presents the idea of multi-objective decision-making, a technique where all perspectives are brought to the table and valuation is done after all objectives have been identified and analyzed. She argues that this method can be applied to a wider range of decision-making processes. In situations of multiple decision makers with conflicting interests, the technique can help resolve disputes by providing different alternative solutions. When decision makers understand tradeoffs, they can more easily understand the interests of other parties and compromise (Azapagic and Perdan, 2000).

7QS suggests the idea of developing a 'structured collaborative decision-making process' in the "Next steps: Pilot testing and ongoing collaboration" part of their framework. They suggest a multi-party decision making approach called the multiple accounts analysis (MAA). MAA is a facilitated process that aims to describe major issues of concern, weigh their significance and, when alternatives are to be considered, collectively come to an optimal set of actions. MAA provides a basis for assessment through: (1) the exchange of information; and (2) expression and definition of concerns, interests and values. They do not specifically state what stakeholders are usually present, but indicate that if it is correctly carried out, it is a transparent process that addresses, discusses, and includes all interests and values. However, they note that the key for application of any "structured collaborative decision-making process" is maintenance of the process integrity through collaborative design of the ground rules and subsequent implementation involving all implicated communities of interest. Therefore, the 7QS framework promotes stakeholder inclusion in the decision-making process. They recognize that over the past several decades, market driven decision-making has not always led to satisfactory results in terms of human and ecological implications (MAC, 2014).

3.3.11 Economic valuation of resources—The importance of ecosystems to human society is multifaceted (ecological, sociocultural and economic), but expressing the value of ecosystem services in monetary units can be a valuable tool to raise awareness and communicate the (relative) importance of ecosystems and biodiversity to policy makers and decision makers. This characteristic has not yet been incorporated into four of the sustainability assessment frameworks. However, the 7QS framework touches upon the idea of using accounting tools to assess implications in terms of ecosystem costs, benefits, and

risks. Incorporating economic valuation of resources into a framework would fulfill the second BellagioSTAMP principle, in that is a method to evaluate tradeoffs and synergies between sustainability categories. Research on economic valuation of ecosystem services dates back to the early 1960s but it received wide attention with the publication of Costanza et al. (1997), thus generating interest and a steady growth in the number of articles and reports on the subject of monetary valuation of natural resources, ecosystem services, and biodiversity (Groot et al., 2012).

An example of evaluation and modeling of ecosystem service loss is shown in a case study in the Mentougou district of Beijing, China (Li et al., 2011). With over a century of historic coal mining, the region has existing ecological and environmental problems affecting the sustainable development of the region. The authors carry out an evaluation of economic value and its ecological and environmental effect of coal resource exploitation in an effort to provide a scientific basis for the optimization of ecosystem services. The authors consider various effects within three key elements: (1) Solid waste - loss due to coal waste and treatment and loss due to lands occupied by coal wastes (2) Geological environment and coal mining sinks - loss of farmlands, loss of water resources, loss of abandoned land in mining area, loss of migration, and (3) Soil, biology and landscape - loss of soil and water. Losses are calculated with four methods, including: the Market Value Method, Opportunity Cost Method, Shadow Project Method, and Restoration Cost Method. They compare the total monetary values associated with the loss of ecosystem services caused by coal mining to the calculated economic value of coal mining in the region. Based on these results, they conclude that the ecological and environmental losses resulting from coal mining is far greater than the direct economic benefits.

3.3.12 Disclosure of assumptions, uncertainties, and indicators not evaluated—Disclosing assumptions, uncertainties, and indicators not evaluated falls under the fifth BellagioSTAMP Principle, Transparency. The GRI G.3 is the only framework that includes disclosure, when talking about maximizing report value. This includes explaining methods and assumptions, with reliable evidence to support assumptions. However, there is no mention of disclosing uncertainties, nor indicators not evaluated (GRI, 2010).

4. Where should sustainability assessment go from here-development of an enhanced framework

The above analysis highlights the commonalties amongst the five sustainability assessment frameworks, as well as makes clear the components that are lacking (Table 6). As a means to improve the methods and quality of sustainability assessment and reporting in the mining industry, we have synthesized the concepts and themes and identified 5 ideal components of an enhanced sustainability framework (Table 7). The components are Foundation, Focus, Breadth, Quality Assurance, and Relevance, and are described below.

4.1 Component 1: Foundation

The Foundation component of the framework provides a comprehensive model of sustainability through the integration of the three pillars: economic, environmental, and

social. Azapagic's framework suggests integrated indicators as a method to relate the three spheres. The water-energy nexus is a hot topic in sustainability literature currently, and by definition presents an integrative analysis of how the two elements interact. The Department of Energy presents an integrated strategy for addressing challenges across the water-energy nexus through the use of six pillars (DOE, 2014):

1. Optimize the freshwater efficiency of energy production, electricity generation, and end use systems
2. Optimize the energy efficiency of water management, treatment, distribution, and end use systems
3. Enhance the reliability and resilience of energy and water systems
4. Increase safe and productive use of nontraditional water sources
5. Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts
6. Exploit productive synergies among water and energy systems

To enhance integration efforts and aid in the development of a standard list of integrated indicators, this concept of the water-energy nexus could be brought into mining assessment as a method to further integration. The water-energy nexus can serve as a starting point in the development of the water-energy-environment nexus, a model that would provide a more complete assessment of sustainability in the mining industry.

The second part of the Foundation component is active stakeholder/community involvement. The evaluated frameworks focus only on outreach with regards to stakeholder/community involvement. Implementation of this component may be improved upon by redefining the idea of stakeholder/community involvement from 'outreach' to 'engagement', specifically through initiatives such as public monitoring programs. Citizen science projects facilitate a collaborative partnership between scientists and non-scientists in which authentic data are collected, shared, and analyzed (Bonney et al, 2009). Community members living in proximity to a contaminated site are typically interested to learn more about the site, as environmental and health impacts are directly related to their lives (Ramirez-Andreotta et al., 2015). Community members often identify exposure zones or areas in need of more monitoring. Projects that invite community members to participate in scientific research in their local environment provide opportunities for them to improve their scientific literacy while promoting awareness of local environmental issues. Citizen science can enhance the understanding of a given phenomenon and the social and cultural dynamics of the community to improve the health and wellbeing of community members. Concomitantly, their participation as partners can promote transparency and communication among the mine personnel and community members, and lead to community-initiated projects that can reduced deleterious impacts on environmental health (Ramirez-Andreotta et al., 2013, 2014).

The third part of the Foundation component is requiring that sustainability reports calculate and report on the economic value of impacts to ecosystem services and human health. This addition is a means to integrate the spheres of sustainability. Expressing the value of ecosystem services in monetary units can be an integrative tool to raise awareness and

communicate the significance of ecosystems and biodiversity. Economic valuation of ecosystem services can be completed using a tool such as InVest (Integrated Valuation of Ecosystem Services and Tradeoffs). InVest is a suite of ecosystem service models developed by the Natural Capital Project to help local, regional and national decision-makers incorporate ecosystem services into a range of policy and planning contexts for terrestrial, freshwater, and marine ecosystems. It includes spatial planning, strategic environmental assessments and environmental impact assessments (Wang et al., 2010). Similarly, economic valuation of health impacts can show the costs of diseases and illnesses associated with mining. Including this in reports would be an avenue for mining companies to demonstrate the extent of health-related cost savings accrued through their sustainability practices, as well as benchmark their improvements and initiatives set to reduce associated health impacts. The World Health Organization outlines the Health and Environmental Linkages Initiative (HELI), in which the HELI economic valuation toolkit is seen as an avenue for health issues to receive adequate consideration in policy (WHO, 2015).

4.2 Component 2: Focus

The Focus component of the Enhanced Sustainability Framework ensures that the data collected and reported by companies is done so in a meaningful and organized fashion. The comprehensive assessment approach requires companies to collect annual data, compile it with previous years data, analyze current trends, and forecast future trends. This component should be completed on a schedule of every five years to ensure that data will routinely be assimilated and evaluated for consideration during decision-making. The assessment will be specific to mining site, requiring that data collected and reported will be carried out at each site separately. This component can be best implemented through the development of a “warehouse” of assessment impacts, or a central data-reporting repository for the complete lifecycle of the mine. This idea is in line with the lifecycle assessment methodology (LCA), which was initially developed in 1972 to limit the energy used in manufacturing processes (Yellishetty et al., 2009). LCA has since been applied to the mineral and metal sector to analyze potential environmental impacts of a product or process over its entire life cycle, from raw material acquisition to ultimate disposal. In the past decade, increased use of LCA to evaluate mining impacts has advanced scientific knowledge through the development of life cycle inventory databases. Requiring this inventory component in sustainability would be a direct method for storage of sustainability assessment information, in which data would be available for easy access to analyze for trends as well as to compare across mining sites and companies.

4.3 Component 3: Breadth

The Breadth component of the Enhanced Sustainability Framework requires specific and explicitly defined performance indicators within the three sustainability categories (economic, environmental, and social) as well as integrated indicators. The quantity of required indicators should remain concise so that operations of all scales can afford the necessary time and the resources to carry out the assessment. The Enhanced Sustainability Framework has two tiers of indicators. The first is a small, standardized set of core required indicators allowing for the comparison of information from different mining sites and companies. The second tier of indicators provides a list of site-specific indicators, to be

selected based on specific properties of a site. The second tier of indicators gives flexibility to reporting, as well as additional site-specific information that can serve to inform decisions. Development of specific tier one and tier two indicators is beyond the scope of the present study.

4.4 Component 4: Quality Assurance

The Quality Assurance component requires routine 3rd party verification and audits of reports. This can be carried out similarly to the TSM framework, where the company's self-assessments are evaluated every three years by a trained verifier, who is an experienced auditor independent of the company. This component also requires reports to contain full disclosure of information regarding assumptions, uncertainties, and indicators not evaluated. This will maximize report value and can be simply implemented as a required appendix to sustainability reports. Lastly, this component states that reports must be publicly available and written in a language that makes the information relevant and accessible to all parties.

4.5 Component 5: Relevance

The Relevance component gives a basis for which the information included in reports can be applied for decision-making and other purposes. The Enhanced Sustainability framework provides a well defined and 'clear from the start' method to using reported information to inform decisions. This can be carried out most efficiently by identifying the relevant stakeholders and decision makers in the early stages of the mine's lifecycle as well as having a structured process of how all parties concerns will be heard and addressed.

5. Conclusion

Mining and mineral extraction is essential to support current living standards. The past few decades have brought forth an awareness and understanding of the impacts associated with mining, specifically related to the impairment of ecosystem services and impacts on human health. As a result, sustainability assessment and reporting has become commonplace in the industry. To date, there is no agreement on the best approach to assess mining sustainability.

A variety of sustainability frameworks have been proposed to guide the mining industry in conducting sustainability assessments. Five of the most relevant frameworks were selected for comparison in this analysis, the Global Reporting Initiative (GRI), Towards Sustainable Mining (TSM), Azapagic's modified GRI framework, Innovation and technology driven sustainability performance management framework (ITSPM) and the Seven Questions of Sustainability (7QS). Results show that there are many commonalities amongst the five, as well as some disparities. In addition, relevant components are missing from all five.

An enhanced framework was created to provide a more holistic, comprehensive approach for sustainability assessment and reporting. The proposed framework has five components that build from and encompass the twelve evaluation characteristics used in the analysis. The components include Foundation, Focus, Breadth, Quality Assurance, and Relevance. The Foundation component of the framework provides a comprehensive model of sustainability through the integration of the three pillars: economic, environmental, and social. It includes promotion of stakeholder/community involvement and economic evaluation of ecosystem

services and human-health impacts. The Focus component of the Enhanced Sustainability Framework ensures that the reporting of data collected by companies is done so in a meaningful and organized fashion, and that it is implemented through a compressive assessment approach that is specific to each individual mining site. The Breadth of the framework states that performance indicators will be explicitly defined and that the quantity of required indicators (tier one) should remain concise. Tier two indicators provide a means for flexibility, where site-specific conditions can be reflected in sustainability reports. The Quality Assurance component maximizes report value through verification, full disclosure, and public availability. And finally, the Relevance component gives a basis for which the information included in reports can be applied, specifically with regards to decision making.

Given that the GRI is the predominant approach currently in use, the concepts and suggestions provided from the current study may be best implemented by using them to enhance the GRI. It is anticipated that their application will improve methods of sustainability assessment by producing reports that are more consistent and comparable. Ultimately, it is anticipated that incorporating these enhancements will enhance sustainable mining practices, and as a result reduce deleterious impacts to ecosystem services and improve the well-being of mining-affected communities.

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Table 1.

The ICMM's sustainable development principles.

Principle 1	Implement and maintain ethical business practices and sound systems of corporate governance
Principle 2	Integrate sustainable development considerations within the corporate decision-making process.
Principle 3	Uphold fundamental human rights and respect cultures, customs and values in dealings with employees and others who are affected by our activities.
Principle 4	Implement risk management strategies based on valid data and sound science.
Principle 5	Seek continual improvement of our health and safety performance.
Principle 6	Seek continual improvement of our environmental performance.
Principle 7	Contribute to conservation of biodiversity and integrated approaches to land use planning.
Principle 8	Facilitate and encourage responsible product design, use, re-use, recycling and disposal of our products.
Principle 9	Contribute to the social, economic and institutional development of the communities in which we operate.
Principle 10	Implement effective and transparent engagement, communication and independently verified reporting arrangements with our stakeholders.

Table 2.

Definitions of evaluation characteristics adopted from previous studies and their rationale for use.

Characteristic	Definition	Rationale for use
Temporal orientation	A framework uses an 'annual snapshot assessment' if it assesses data in the past year. A framework is a 'comprehensive assessment' if it collects annual data, compiles it with previous years data, and analyzes trends and predicts future trends.	Modified from Ness et al. (2007) and Fonseca et al. (2013) where a framework is defined as 'retrospective' if it looks back in time and a framework is defined as 'prospective' if it is forward looking (or forecasting).
Geographic scope	A framework that promotes an 'organizational based' assessment aggregates data from all mining sites. A site framework with a scope that is 'specific to mining site' designates that assessments should be conducted at each site separately.	Adopted from Hacking and Guthrie (2008) and Fonseca et al.(2013).
Types and quantity of indicators	The framework defines types and quantity of sustainability indicators to be used in the assessment.	Adopted from Hacking and Guthrie (2008), Ness et al. (2007), and Fonseca et al.(2013).
Integrations between sustainability categories	The framework evaluates relationships, trade-offs and synergies among social, economic, and environmental impacts.	Adopted from Hacking and Guthrie (2008), Ness et al. (2007), and Fonseca et al.(2013).
Scale effects	The degree to which the framework considers the size of a mining facility and related production processes.	Adopted from Hacking and Guthrie (2008) and Fonseca et al.(2013).

Table 3.

Definitions of evaluation characteristics newly added for this work and their rationale for use.

Characteristic	Definition	Rationale for use
External Verification	The framework states that a third party will verify and audit sustainability reports.	To avoid the potential for misleading claims, ambiguity, inaccuracy or incompleteness with regards to sustainability reporting (Emel et al, 2012).
Public access to information	The framework states that sustainability reports will be made available and easily accessible to the public.	Releasing public reports enforces transparency and reinforces a consistent process to collect reliable data and information regarding sustainability performance.
Stakeholder/community involvement	The framework provides avenues to enhance participation and buy-in from relevant stakeholders and the affected community.	Reports should reflect the views of the all stakeholders (including the public) and frameworks should provide active means of leadership for stakeholders, so that the view points of all parties can be considered in the decision making process.
Research translation/common language	The framework states that sustainability reports will be written in clear and understandable language.	Public availability of sustainability reports is only effective if reports use language that makes the information relevant and accessible to all parties.
Decision making context	The framework describes how sustainability reports will be used to inform the decision making process.	Information in sustainability reports is useful for assessing trends and can be the drivers of change through decision making process. A well defined decision making process will ease a situation with multiple decision makers with varying conflicts of interest.
Economic valuation of resources	The framework states that sustainability reports will calculate the monetary value of ecosystem services.	Economic valuation of resources can be a useful tool in communicating the relative value of ecosystems and biodiversity to policy makers and decision makers.
Disclosure of assumptions, uncertainties, and indicators not evaluated	The framework states that a disclosure of assumptions, uncertainties, and indicators not evaluated will be included in sustainability reports.	To increase transparency and maximize report value.

Table 4.

BellagioSTAMP Principles (source: IISD and OECD (2010))

Principles	Description
1. Guiding Vision	Assessing progress towards sustainable development is guided by the goal to deliver well-being within the capacity of the biosphere to sustain it for future generations
2. Essential Considerations	Sustainability Assessments consider: The underlying social, economic and environmental system as a whole and the interactions among its components; The adequacy of governance mechanisms; Dynamics of current trends and drivers of change and their interactions; Risks, uncertainties, and activities that can have an impact across boundaries; Implications for decision making, including trade-offs and synergies
3. Adequate Scope	Sustainability Assessments adopt: Appropriate time horizon to capture both short and long-term effects of current policy decisions and human activities; Appropriate geographical scope ranging from local to global
4. Framework and indicators	Sustainability Assessments are based on: A conceptual framework that identifies the domains that core indicators have to cover; The most recent and reliable data, projections and models to infer trends and build scenarios; Standardized measurement methods, wherever possible, in the interest of comparability; Comparison of indicator values with targets and benchmarks, where possible
5. Transparency	The assessment of progress towards sustainable development: Ensures the data, indicators and results of the assessment are accessible to the public; Explains the choices, assumptions and uncertainties determining the results of the assessment; Discloses data sources and methods; Discloses all sources of funding and potential conflicts of interest
6. Effective Communication	In the interest of effective communication, to attract the broadest possible audience and to minimize the risk of misuse, Sustainability Assessments: Use clear and plain language; Present information in a fair and objective way, that helps to build trust; Use innovative visual tools and graphics to aid interpretation and tell a story; Make data available in as much detail as reliable and practical
7. Broad Participation	To strengthen their legitimacy and relevance, sustainability assessments should: Find appropriate ways to reflect the views of the public, while providing active leadership; Engage early on with users of the assessment so that it best fits their needs
8. Continuity and Capacity	Assessments of progress towards sustainable development require: Repeated measurement; Responsiveness to change; Investment to develop and maintain adequate capacity; Continuous learning and improvement

Table 5.

Comparative analysis of five mining sustainability frameworks with similarities highlighted in terms of fulfillment of the eight BellegiaoSTAMP principles, color-coded in the key below.

Characteristics	GRI	TSM	Azapaigic's	ITS-PM	70
Description	The most frequently used framework in the mining sector for sustainability reporting	Developed by the Mining Association of Canada (MAC) in the early 2000s. Used by Canadian mining companies	A proposed, modified, and more comprehensive version of the GRI framework, suitable for large scale mining and larger organizations	A proposed conceptual framework that identifies the need for a multistakeholder process in performance management to to develop relevant performance indicators	A int of lif
Temporal orientation	Comprehensive assessment	Annual snapshot assessment	Annual snapshot assessment	Annual snapshot assessment	Co
Geographic scope	Organizational-centered	Specific to mining	Organizational-centered	Specific to mining site	Sp
Types and quantity of indicators	Quantity of indicators	23 indicators across 6 protocols	132 indicators across the economic, environmental, and social categories	Indicators are not defined, but cover social, environmental, and economic categories	No se
Integrations between sustainability categories	Not included	Not included	Integrated indicators suggested	Not included	No
Scale effects	Not included	Not included	Not included	Not included	No
External verification	Recommended but not specifically defined	Every 3 years, verifier reviews the company's self assessment	Not included	Not included	M sp
Public access to information	Reports are publicly available	Reports are publicly available	Not included	Not included	Re as pu
Stakeholder/community involvement	Not included	Encourages to have facilities to establish formal systems to report on concerns raised by the community	Stakeholder involvement is listed as an indicator category	Emphasizes a multistakeholder process for performance management	Co go vi
Research translation/common language	Reports should avoid technical terms, jargon, and acronyms that are likely unfamiliar to stakeholders, and should include explanations where necessary in a glossary	Includes an indicator entitled 'effective community of interest engagement dialogue'	Not included	Not included	Ac an co iss to
Decision making context	Not included	Not included	Multiobjective decision-making	Not included	Pr im ma
Economic valuation of resources	Not included	Not included	Not included	Not included	To ac the of be
Disclosure of assumptions, uncertainties, and indicators not evaluated	Limited	Not included	Not included	Not included	No

Table 6.

Summary of similarities, differences, and missing elements for the mining sustainability frameworks.

Characteristics	Similarities and differences		Missing elements
Temporal orientation	Three frameworks use the 'annual snapshot assessment', in which data is assessed on a past year basis.	Vs. Two frameworks are a 'comprehensive assessment', in which data is added to previous years data to reveal trends and predict future scenarios.	
Geographic scope	Two frameworks use an organizational-centered approach to reporting, wherein data from all mining sites are aggregated into one report.	Vs. Three frameworks use a mining site reporting approach, where each site reports its data separately.	
Types and quantity of indicators	Three frameworks provide comprehensive, well-defined, and specific indicators. The types and number of indicators varies from a comprehensive list to a smaller, more concise list.	Vs. Two frameworks are based on indicator analysis as an evaluation method, however they do not provide a defined list of such indicators.	
Integrations between sustainability categories	One framework proposes integrated indicators.	Vs. Four frameworks do not include integrated indicators.	
Scale effects			None of the frameworks include scale in their sustainability assessments.
External verification	One framework requires that every three years a verifier reviews the companies self assessment.	Vs. Two frameworks mention or recommend external verification (do not require it) and two frameworks do not include external verification.	
Public access to information	Three frameworks require that reports are publicly available	Vs. Two frameworks do not mention public availability of reports.	
Stakeholder/community involvement	Four frameworks recognize the value of stakeholder involvement/community involvement in some capacity, mostly in regards to outreach.	Vs. One framework overlooks stakeholder/ community involvement	None of the frameworks use active participation for stakeholder/ community involvement.
Research translation/common language	Three frameworks specify that reports should be written in language that makes the information relevant and accessible to all parties.	Vs. Two frameworks do not mention research translation/common language.	
Decision making context	Two frameworks discuss decision making.	Vs. Three frameworks do not mention decision making.	
Economic valuation of resources	One framework touches upon the idea of using accounting tools to assess implications in terms of ecosystem costs, benefits, and risks.	Vs. Four frameworks do not mention economic valuation of resources.	
Disclosure of assumptions, uncertainties, and indicators not evaluated	One framework includes disclosure with regards to explaining methods and assumptions.	Vs. Four frameworks do not include disclosure of assumptions, uncertainties, and indicators not evaluated.	None of the frameworks mention disclosing uncertainties, nor indicators not evaluated.

Table 7.

Components of an enhanced framework for assessing mining sustainability.

Ideal Components	Definition of Ideal Components
Component 1: <i>Foundation</i> <ul style="list-style-type: none"> Integrations between sustainability categories Economic valuation of resources Stakeholder/community involvement 	<p>The <i>Foundation</i> of the framework provides a comprehensive model of sustainability through the integration of the three pillars (economic, environmental, and social) by:</p> <ul style="list-style-type: none"> (1) Defining and requiring integrated indicators in sustainability reports. (2) Requiring stakeholder/community involvement through outreach and active participation (3) Requiring that the economic value of ecosystem services and health impacts be calculated and reported.
Component 2: <i>Focus</i> <ul style="list-style-type: none"> Temporal orientation Geographic scope 	<p>The <i>Focus</i> of the framework includes:</p> <ul style="list-style-type: none"> (1) A comprehensive assessment that requires collecting annual data, compiling it with previous years data, and analyzing trends and forecasting future trends. (2) An assessment that is specific to the mining site, which requires that data collection and reporting be completed at each site separately.
Component 3: <i>Breadth</i> <ul style="list-style-type: none"> Types and quantity of indicators Scale effects 	<p>The <i>Breadth</i> of the framework encompasses:</p> <ul style="list-style-type: none"> (1) Performance indicators will be specific and explicitly defined. (2) The quantity of indicators should remain concise so that operations of all scales can afford the necessary time and resources to carry out the assessment.
Component 4: <i>Quality Assurance</i> <ul style="list-style-type: none"> External verification Public access to information Disclosure of assumptions, uncertainties, and indicators not evaluated Research translation/common language 	<p>The framework incorporates <i>Quality Assurance</i> by:</p> <ul style="list-style-type: none"> (1) Requiring 3rd party verification and routine audits of reports. (2) Requiring that reports will have full disclosure of information regarding assumptions, uncertainties, and indicators not evaluated. (3) Requiring that reports are publically available and written in language that makes the information relevant and accessible to all parties.
Component 5: <i>Relevance</i> <ul style="list-style-type: none"> Decision making context 	<p>The <i>Relevance</i> of the framework is the basis of why sustainability reports are important. It explains how the information included in reports can be applied through:</p> <ul style="list-style-type: none"> (1) Providing a well defined and 'clear from the start' method for using reported information to inform decisions.