WEIGHTING SUSTAINABLE DEVELOMENT INDICATORS (SDIs) FOR SURFACE MINING OPERATIONS USING THE ANALYTICAL HIERARCHY PROCESS (AHP)

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ABSTRACT

Current multi-criteria decision-making methods (MCDM) present valid alternatives for weighting the various criteria while allowing for the participation of different stakeholders. Among those, the Analytical Hierarchy Process (AHP) structures the decision problem in a manner that is easy for the stakeholders to comprehend and allows them to analyze independent sub-problems by structuring the problem in a hierarchy and using pairwise comparisons. This paper presents the application of the Analytical Hierarchy Process to weight the different criteria to measure the sustainability of surface mining operations. Prior to the application of the AHP method, the various criteria were preselected using a preliminary selection method consisting of the identification of criteria from six different sources: governmental regulations; committees and organizations for standardization; management and processes best practices; academically- and scientifically-authored resources; local, regional, national, and international organizations; and industry sector standards and programs. Criteria with different common sources of origin, as well as discretionary project and stakeholder relevance were chosen for the preselected list. The different social, economic, and environmental criteria were classified in ten different areas of excellence to facilitate the application of the weighting method. Therefore, each criterion's final weight is impacted by the criterion's weight itself and the area of excellence's weight obtained in the application of the AHP method. The results of the weighting process assist scientists and practitioners by not only identifying those criteria that stakeholders consider relevant in the sustainability assessment process, but also by expressing the degree to which the criteria should be addressed in order to accomplish the project's and/or organization's sustainability goals.

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1. Introduction

With the emergence of sustainability not only in practice but also as a solid area of research, the assessment of sustainable development integrating its three pillars advances into using scientific and mathematical approaches with the ultimate goal of meeting and balancing the different stakeholder needs. This manuscript presents a framework for utilizing the Analytical Hierarchy Process (AHP) to weight sustainable development indicators (e.g., criteria) for surface mining operations. This multi-criteria decision-making method is part of an integrated approach for sustainability assessment encountered in the Wa-Pa-Su project sustainability rating system (Poveda & Lipsett, 2011a; 2011b).

The basic components of a sustainability assessment methodology involve three distinct stages: (1) identification of sustainable development indicators (SDIs), which answers the question of what to measure; (2) development of metrics, which addresses the challenge of how to measure the SDIs; and (3) application of assessment models (i.e., assessment methodology), which typically uses a scientific approach to deliver a comprehensive valuation that includes an assessment of the diverse impacts, input of stakeholders' views, and application of mathematical models. Instead of abstract and complex assessment tools, the users and stakeholders favor simplistic, flexible, and practical approaches with an expected numeric value as the result. A numeric result of the assessment facilitates not only an understanding of the methodology, but also the internal and external performance benchmarking process. Depending on the methodology, tool, instrument, or process used, the results of the assessment are given in comparative parameters (e.g., time, cost) or simply a value in a numeric scale; however, Munda (2006) states "from the point of view of the management what is really important is the benchmarking exercise and NOT the ranking."

Previous assessments have mainly focused on the environmental criteria instead of integrating the three pillars of sustainability (social, economic and environmental). However, as sustainability is becoming better understood diverse tools, methodologies, processes, and instruments are developing to integrate the social and economic facets, with the aim of achieving a balanced approach to sustainability assessment. Furthermore, while a notorious transition has occurred from environmental regulations to environmental assessment, demonstrating substantial levels of maturation in practice and theory, other pillars of sustainability (i.e., social and economic) face challenges in advancing at the same rate. Nevertheless, sustainability is still in its infant stage, and progress made in the environmental area, which is better understood by stakeholders and the public in general, demonstrates the need for the social and economic pillars to improve. The economics of sustainability tend to be interpreted as how well an organization is doing financially, instead of measuring the economic impacts of its performance, and the social pillar is faced with the major challenge of measuring impacts that are intrinsically subjective.

Several environmental and sustainability assessment tools, instruments, processes, and methodologies have been developed and are continuously evolving to address the stakeholders' needs. The outcome of scientific research in areas of sustainability is poorly understood. Rating systems stand out and have gained attention and credibility, as demonstrated by the vast number of certified projects around the world and by the widely-known advantages of using them (Yudelson, 2008; Issa, Rankin, & Christian, 2009). Green and sustainability rating systems inherently possess a developed scale in which the users are requested to achieve a certain level with the aim of guaranteeing the sustainability of the project and/or organization. Rating systems are developed to meet the needs of specific characteristics, with the aim of categorizing, certifying or acknowledging the project and/or organization as sustainable. Therefore, the SDIs included in the assessment process are selected to reflect the diverse impacts and/or expected performance of projects and/or organizations during their life cycles.

The use of rating systems has rapidly spread in certain industries (e.g., buildings), which has required the development of a number of rating systems for specific projects (e.g., schools, healthcare, homes, commercial, neighborhoods) within the building industry. However, other projects and industries do not possess such rating systems to demonstrate their performance in sustainable development. Among others, Leadership in Energy and Environmental Design (LEED), Comprehensive Assessment System for Built Environment Efficacy (CASBEE), Building Research Establishment Environmental Assessment Method (BREEAM), GBTool, and Green Start lead their local markets and are working to rapidly penetrate markets abroad. Areas of performance (e.g., categories) and criteria are part of most rating systems. A comparison of the performance against a criterion or number of criteria is typically used in the assessment process. However, the distribution of points and weights across the different areas and criteria of the rating system becomes a critical issue in the development process (Trusty, 2008). Criteria take the SDI concept (in a rating system context) a step further by allocating weight through a quantitative multi-criteria analysis (MCA). Each rating system allocates weight to each criteria and category using specific methodology to then obtain a weighted summation (e.g., final score) by the addition of every criterion's weight if the project or task has met a pre-established requirement. A company and/or project is categorized, certified, or acknowledged as sustainable based on the number of points or parameters accomplished in a pre-determined rating scale. Therefore, stakeholder engagement and participation is essential not only during the implementation of the rating system, but also in the development phase of the assessment tool (i.e., the criteria weighting process), as it translates into efficient decision-making and sustainability assessment processes. Stakeholder participation increases the credibility factor and facilitates implementation and penetration into the market. Weighting the categories and criteria requires considering the application of multi-criteria decision methods (MCDM). Stakeholders are faced with the challenge of evaluating the relevance of distinctive categories (e.g., management, water, materials, and air) and social, economic, and environmental criteria.

2. Development, Usage and Weighting of Sustainable Development Indicators (SDIs)

In 1987, the Brundtland Commission—formally known as the World Commission on Environment and Development (WCED)—changed the way industry does business by introducing a formal definition of sustainability. Since then, the international community—including governments, scientists, politicians, sociologists, engineers, and economists—has come together in an effort to link the plans, policies, and programs (PPP) of sustainable development at a macro level, with the goals and objectives at the organizational and project levels. The development and implementation of SDIs have contributed to close the gap; however, the identification and measurement of SDIs is in permanent evolution.

The United Nations (UN) describes the functions of SDIs as leading to better decisions and more effective actions by simplifying, clarifying, and making aggregated information available to policy-makers (United Nations [UN], 2007). Key performance indicators (KPIs) for sustainability known as SDIs have largely been used to demonstrate the performance of implemented PPP in a diverse range of organizations and industries. The SDIs or KPIs for sustainability evaluate social, economic, and environmental performance of projects and/or organizations. In 1992, Agenda 21 was adopted after the United Nations Conference on Sustainable Development and Environment to guide programs and actions designed to achieve environmentally sound and sustainable development (ESSD) at global, regional, and local levels (Harger & Meyer, 1996). Therefore, measuring and assessing the results of implementing ESSD indicators (e.g., SDIs or KPIs for sustainability) has become relevant to define the effectiveness of the PPP. Moreover, benchmarking performance requires the development of metrics and the definition of a scale against which results can be measured, verified, compared, and correlated. However, no benchmarking process can take place unless a common set of SDIs are used to measure the sustainability of similar projects and/or organizations within an industry sector. Consequently, the design and development of SDIs, including the definition of the final assessment set of indicators and their metrics, are activities in which success is measured by the effective engagement and participation of the different stakeholders.

An SDI measures the performance of a specific subject, and is not to be used in isolation when assessing sustainability as a whole due to its multi-disciplinary nature. Therefore, different SDIs are developed not only representing the different facets of sustainability, (e.g., social, economic, and environmental) but also addressing the different stakeholders' needs of an explicit organization, project, or industry sector. At the macro level, benchmarking performance and progress of developing and developed countries, and comparing the status of whole countries in terms of a specific aspect, are two areas of proven usefulness of SDIs' implementation in addition to measuring the effectiveness of PPP. At the organizational and project level, the linkage with macro-level goals and objectives represents a major obstacle. Additionally, SDIs development faces two major hurdles that are still under international debate among scientists: which indicators should be included in the assessment of sustainability (i.e., What should be measured?), and how those indicators should be measured (i.e., Which metrics are to be used?). Since the set of

SDIs to be included in the assessment is proven to define the success of the process, guidelines and considerations for assisting with the design of SDIs have been developed (Gibson, Hassan, Holtz, Tansey, & Whitelaw, 2010; Harger & Meyer, 1996; Hart, 1999; International Institute of Sustainable Development [IISD], 2012; Taylor, 2006; United Nations [UN], 2007). Furthermore, simplification and practicability are the main reasons behind the appeal for the design and use of a sole indicator (i.e., a composite indicator [CI]) to assess sustainability (Gasparatos, El-Haram, & Horner, 2008). However, data aggregation into a sole indicator implies compensability and substitutability between criteria (Munda & Nardo, 2005). Even though these disadvantages are hardly compatible with the vision of sustainability (Gasparatos et al. 2008; Neumayer, 2003), multi-criteria decision methods (MCDM) allow an alternative and viable perspective to aggregate the criteria into a CI using techniques such as Electre (Figueira, Greco, Roy, & Slowinski, 2010).

3. The Wa-Pa-Su Rating System: Structure and SDIs for Surface Mining Operations

The applicability of the AHP, a multi-criteria decision-making method, is demonstrated in the development of the Wa-Pa-Su project sustainability rating system—a verification process to assist demonstrating compliance in sustainable development performance during project life cycle through the implementation of enhanced strategies to mitigate environmental, social, health, and economic impacts (Poveda & Lipsett, 2011a,b). The AHP is a fundamental pillar in an integrated approach for a new methodology for sustainability assessment for long-term projects. The Wa-Pa-Su project sustainability rating system assessment methodology is integrated for three distinct areas of knowledge. These areas are (1) sustainable development theory and fundamentals are the basis for the development of the rating system, since the aim is to find a balanced path to the social, economic, and environmental needs; (2) the multi-criteria decision-making analysis (MDMA) allows for the engagement and participation of stakeholders during the decision-making process of the design and implementation of the criteria weighting system; and (3) the continual performance improvement immersed in the assessment methodology assists organizations and/or projects in improving performance over time.

Poveda and Lipsett (2011a) describe the necessity for developing a methodology for the assessment of sustainability, which fills the existing gaps in industrial projects with an emphasis in the oil sands developments. The integrated assessment methodology, initially conceived with oil sands projects in mind, evolved into a methodology with characteristics of applicability to other long-term projects. The Wa-Pa-Su project sustainability rating system with application to oil sands operations consists of ten (10) subdivisions, ten (10) areas of excellence within each subdivision, and a number of criteria within each area of excellence (Poveda & Lipsett, 2011b).

Aligned with the project’s life cycle, the Wa-Pa-Su project sustainability ratings system contains the subdivisions of project integration; provisional housing/buildings; permanent housing/buildings; roads; oil transportation and storage; mining process; in-situ process; upgrading and refining; shutdown and reclamation; and CO_2, SO_x and other greenhouse gas mitigation, capture, and storage. The applicability of the AHP methodology described in this manuscript focuses on the surface mining process which, in the case of Canadian oil sands projects, occurs for bitumen located within 75 m of the surface. The surface mining sub-division includes the mining itself and other related processes to recover the bitumen by removal of overburden from an oil sands deposit (Poveda & Lipsett, 2011b). The pre-selected SDIs for the surface mining operations in oil sands projects are identified in six (6) potential sources, and grouped in three (3) areas known as group originators of SDIs. The group of indicators agreed upon through consensus by public or governmental representatives includes governmental regulations as well as committees and organizations for standardization; academically- and scientifically-authored resources as well as management and processes best practices grouped into the academic and practitioners identified indicators group; and the organizationally-established indicators group including local, regional, national, and international organizations and surface mining industry standards and programs. Table 1 illustrates the pre-selected SDIs or KPIs for sustainable development in each area of excellence for the surface mining operation in the oil sands projects. The design of the different areas of excellence is based on three distinctive facets of the projects: the resources involved in project development, stakeholder expectations, and potential environmental, economic, and social impact.

Table 1
Pre-selected SDIs for surface mining operation in oil sands projects

Project & Environmental Management Excellence - PEME	**Site & Soil Resource Excellence - SSRE**
- Strategic Environmental Assessment (SEA) - Environmental Impact Assessment (EIA) - Cumulative Environmental Impact Assessment (As per cumulative impact threshold requirements for Alberta Oil Sands) - Social Impact Assessment (SIA) - Economic Impact Assessment (EIA) - Biophysical Impact Assessment (BIA) - Project Lifecycle Assessment (PLA) - Environmental Protection Management Plan - Environmental Risk Management Plan - Emergency Response Management Plan - Water Management Plan - Solid Waste Management Plan - Erosion and Sediment Control Plan - Hazard Management Plan (includes assessments, inspections and procedures) - Safety Management Plan (includes safety training, reporting and prevention of incidents) - Environmental Management Systems - Sustainable Public Procurement Strategies - Regulatory Compliance (approvals, licenses, and permits) - Independent Verified Auditing and Reporting Plans	- Mining effluents[1]: monitoring, control & reduction - Biological monitoring studies and reports - Overburden Management - Implementation and monitoring of structures to prevent erosion and soil runoff - Re-used excavation material - Proportion of non-previously developed land used - Proportion of protected land used - Total waste extracted (non-saleable, including overburden) - Percentage of resource extracted relative to the total amount of the permitted reserves of that resource - Tree harvest management - Deforestation
Water Resource Excellence - WRE	**Atmosphere & Air Resource Excellence - AARE**
- Mining effluents[1]: monitoring, control, & reduction - Water supply & consumption - Usage of recycled water & wastewater management - Ground water resources: protection & monitoring - Muskeg drainage: monitoring & control - Control of formation dewatering - Seepage prevention (from ponds, pits and landfills) - Construction of water management systems and structures - Acid drainage: monitoring & control - Aquatic life protection & monitoring	- GHGs[2]: monitoring, control, & reduction - Fugitive emissions: monitoring, control, & reduction - Dust control - Noise & vibration management
Natural & Artificial Lighting Excellence - NALE	**Energy Resource Excellence - ERE**
- Luminosity control and regulatory compliance	- Internal production of energy consumed (renewable energy use) - Consumption of primary energy (natural gas, LPG, petrol, and other fuels) - Consumption of secondary energy (electricity and heat)

Resources & Materials Excellence - RME	Innovation in Design & Operations Excellence - IDOE
- Usage of chemical substances - Hazardous material management, storage and disposal - Improvement in machine application efficiency - Machines material re-use - Waste management (reduce, reuse and recycle of non-renewable resources) - Distance of materials suppliers	- Investment in innovation - Clean technology innovations: testing and implementation of new technologies
Infrastructure & Buildings Excellence - IBE	**Education, Research, & Community Excellence - ERCE**
- Ecological footprint - Mining location within or proximal to water bodies - Proximity of mining operations and mining material processing and tailing ponds - Monitoring and protection of wildlife - Monitoring and protection of vegetation - Area of habitat created/destroyed (area disturbed by oil sands development) - Affected animal and vegetal species - Monitoring and protection of biodiversity and habitat (includes biological studies and reports) - Tailings ponds location and impacts study - Reduction of land area used for tailings ponds operations - Total area of permitted developments - Total land area newly opened for extraction activities (including area for overburden storage and tailings) - Transportation distance of customers, business travel, workforce, and community for fly-in and fly-out operations - Communication & transportation facilities	- Investment in research - Workforce awareness training programs (safety, and environmental, social, economic, and health impacts) - Community awareness programs - Community and stakeholder consultation and involvement - Poverty alleviation of affected areas - Wealth distribution - Contribution to social development of communities & participation in regional co-operative efforts - Contribution to economic and institutional development of communities - Employment, unemployment and underemployment rates - Contribution to GDP - Expenditure on environmental protection - Ethical investment - Percentage of employees that are stakeholders in the company - Ratio of lowest wage to national legal minimum - Health, pension and other benefits and redundancy packages provided to employees as percentage of total employment cost - Expenditure on health and safety - Inflation rate - Internal return ratio - Environmental liabilities - Return of investment - Payback period
Infrastructure & Buildings Excellence - IBE	**Education, Research, & Community Excellence - ERCE**
	- Investment in employee training and education - Lost-time injuries - Lost-time injuries frequency - Women/men employment ratio - Percentage of ethnic minorities employed relative to the total number of employees - Work satisfaction - Housing provision for workforce - Housing development for local communities - Projects acceptability - Female-to-male wage ratio - Net migration rate to projects areas - Number of direct and indirect employees - Net employment creation - Percentage of hours of training - Employee turnover - Fatalities at work - Total number of health and safety complaints from local communities - Percentage of employees sourced from local communities relative to the total number of employees - On-going health monitoring (workers and local communities) - Health care management/first aid facilities - Number of local suppliers relative to the total number of suppliers - Number of local contractors relative to the total number of contractors

[1] Mining effluents include: arsenic, cooper, cyanide, lead, nickel, zinc, total suspended solids, radium, pH
[2] GHGs include: sulphur dioxide (SO2), ozone (O3), nitrogen Dioxide (NO2), particular matter (PM2.5), carbon monoxide (CO), oxides of nitrogen (NOx), volatile organic compounds (VOCs), hydrogen sulphide (H2S).

4. Multi-Criteria Decision-Making Methods and the Analytical Hierarchy Process

The multi-criteria decision analysis and methods (MCDA, MCDM) have evolved rapidly, and their applicability has been proven in a variety of areas, including education, transport, economy and finance, supply chain, wastewater and urban sanitation, and ecology. Today, thousands of manuscripts and dozens of books have been devoted to this area of knowledge, and this section presents a brief description of the existing MCDM and the context for the AHP in the MCDA environment.

Structuring and solving decision and planning problems with multiple criteria is the focus of MCDM and MCDA studies and research. MCDM problems can be divided into three categories: problems of multi-criteria choice, problems of multi-criteria ranking, and problems of multi-criteria sorting (Vassilev, Genova, & Vassileva, 2005). Independent of the problem or set of problems to solve, there is an additional component that defines the success of the decision-making process. The decision maker (DM) provides additional information in order to select the preferred alternative(s), and provides input based on his/her preferences based on the goals sought to accomplish. With the aim of providing the most feasible solution, several methods have been developed to solve multi-criteria problems and these can be grouped in three distinctive classes. The first class is the multi-attribute utility theory (MAUT) method which gives the decision-maker (DM) the ability to quantify the desirability of a series of alternatives in which a certain level of uncertainty and risk are considered. The AHP weighting method (Saaty, 1994) and its most recent extension, the ANP (analytic network process); the UTA method (Beuthe & Scannella, 2001); the value tradeoff method (Keeney & Raiffa, 1993); the direct weighting method (Von Winterfeldt & Edwards, 1986); and the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) method (BanaeCosta & Chagas, 2004) are among the most common in the multi-attribute utility theory methods group. The second class is the outranking methods and these have been developed based on the assumption that there is limited comparability among the alternatives, and in most of the outranking methods, it is assumed that the DM is unable to differentiate among the four binary relations (i.e., the indifference I [reflexive and symmetric], the weak preference Q [irreflexive and antisymmetric], the strict preference P [irreflexive and anti-symmetric], and the incomparability R [irreflexive and symmetric]) used to compare two alternatives. The main examples of this second group are the PROMETHEE methods (Brans & Mareschal, 1994), the ELECTRE methods (Roy, 1996), and the TACTIC methods (Vansnick, 1986). The PROMETHEE methods include PROMETHEE I (partial ranking), II (complete ranking), III (ranking based on intervals), IV (continuous case), V (MCDA including segmentation constrains or MCDA under constraints), and VI (representation of the human brain). The ELECTRE methods (Roy, 1996) include ELECTRE I (choice, crisp S relation), IS (choice, valued S relation), II (ranking, crisp S relation), III (ranking, valued S relation), IV (ranking, valued S relation and no weights on criteria), and TRI (sorting, value S relation), in which crisp S means a yes/no relation (either outranks or not) and value S means that a credibility degree for the outranking is computed in the interval [0,1]. The TACTIC method (Vansnick, 1986) is similar to ELECTRE I, but yields a global preference relation instead of a choice set. Like ELECTRE I, the TACTIC method consists of three main steps: preference modeling, aggregation, and exploitation. The TACTIC method is fairly close to the (weighted) Condorcet method. The third class of the Non-classical MCDA approaches requires distinguishing between internal and external uncertainties. Internal uncertainties relate to DM values and judgments, while external uncertainties refer to imperfect knowledge concerning consequences of actions (Figueira, Greco, & Ehrgott, 2005). Figueira et al.

(2005) describes four broad approaches for dealing with external uncertainties: "multi-attribute utility theory and some extensions; stochastic dominance concepts, primarily in the context of pairwise comparisons of alternatives; the use of surrogate risk measures such as additional decision criteria; and the integration of MCDA and scenario planning." Additionally, some hybrid methods have been developed. The fuzzy set theory has been used for choice, ranking, and sorting problems in the MCDA, taking several different approaches (e.g., fuzzy-PROMETHEE). PROMETHEE-GAIA uses the visual interactive module GAIA to provide graphical representation support to the PROMETHEE methodology, and procedures such as PROMETHEE-GDSS (group decision support system) have been developed based on the PROMETHEE-GAIA to provide additional decision aid to a group of decision-makers. In addition to these three classes of MCDM, another area of consideration in decision-making is the use of systems support or software systems which provide support to researchers and/or practitioners (e.g., DM) in different areas/steps of the decision-making process. Vassilev et al. (2005) classified the developed systems supporting the solution of multi-criteria analysis and multi-criteria optimization problems into three groups: commercial, research or teaching, and experimental. The authors also divide the software systems supporting the solution of multi-criteria analysis problems into two classes: software systems with a general purpose and problem-oriented software systems.

The AHP was originally developed by Saaty (1977, 1980, 1982, 1990), and it is not only flexible, but also one of the most easily-implemented multi-attribute utility theory (MAUT) methods (Anselin, Meire, & Anselin 1989). The AHP technique describes a problem using a hierarchy, which in its simplest case has three levels, and applies a measurement scale to obtain vectors of normalized weights or priorities using pairwise comparisons. Bouyssou, Marchant, Pirlot, Tsoukias, and Vincke (2006) describe the main characteristic of the AHP method; "the evaluation model is structured in a hierarchical way, the same assessment technique is used at each node of the hierarchy, and the assessment of the "children" nodes of a common "parent" node is based on pairwise comparisons". The top-level node in the hierarchy represents the main objective of the DM, and is the result of the aggregation of the analysis of the alternatives in the second level node. As there are alternatives in each node and nodes can split as many times as there are alternatives, the number of levels in the hierarchy depends on the initial analysis of the problem and how the decision problem has been structured. Saaty (2008) describes the organized way for generating priorities in four steps as follows: (1) problem definition and knowledge sought, (2) structure the decision hierarchy in which the top is the goal of the decision then intermediate and lowest levels, (3) build the set of pairwise comparison matrices, then use each element in the upper level to compare the element in the level immediately below with respect to it, and (4) use the priorities from the comparisons to weight the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighted values and obtain its overall or global priority. Continue this process of weighting and adding until the final priorities of the alternatives in the bottom-most level are obtained. Furthermore, the process of assigning weights or scores to each of the "children" (i.e., alternative) nodes of a "parent" node (except for the bottom nodes) can be summarized as follows: (1) the participants (e.g., DM, client, stakeholders) are asked to compare the alternatives (e.g., criteria, indicators) in a pairwise comparison in terms of their relative importance and using a conventional semantic scale; (2) the qualitative assessments given by the participants are quantified (i.e., quantitative interpretation), resulting in an n x n pairwise comparison matrix; and (3) using the pairwise comparison matrix, a score or weight w_i is obtained to then be computed as the eigenvector corresponding to the maximum eigenvalue of the matrix, and they are normalized to add up to 1.

5. Setting the Weighting Process, SDIs Ranking, and the Decision-Makers

The AHP methodology assists scientists and practitioners in the decision-making process of weighting a series of criteria that are, for the most part, implicitly subjective. The assessment of sustainability implies the involvement of social, economic, and environmental aspects as minimum requirements mandated by the triple bottom line. However, other scholars include additional areas such as policy, culture, and values, while others combine two or more pillars of sustainability using multi-facet or multi-attribute indicators (e.g., socio-economic indicators). Although some areas of sustainability are fairly well-developed and understood (e.g., environmental), others are still in the infant stage (e.g., social) and, at this point, involve a great degree of subjectivity (Poveda & Lipsett 2013a).

Even though the graphic representation of sustainability in which three equally-sized circles intersect each other implies the balance and equality of the pillars, the indicators within each pillar are to be proportionally weighted. Since the number of indicators and the areas of assessment vary, a preliminary classification of the indicators is recommended. The process can group the indicators using the different pillars of sustainability, areas of a project, pre-determined areas of excellence, or any other classification, with the condition that stakeholders are preliminarily debriefed, as they need to understand what brings those indicators together (i.e., characteristics commonality). To demonstrate the applicability of the AHP methodology in the weighting of SDIs for surface mining operations, the SDIs have been classified in ten (10) different areas of excellence. These areas address the different aspects of surface mining operations that not only concern the various stakeholders but also align with the fundamentals and theory of sustainability. Additionally, the weighting process mandates the prompt and effective engagement and involvement of the stakeholders that are directly impacted or impact the functionality and/or development of an organization or project. The number of indicators in each pillar and the identification and classification of stakeholders are two areas in which scholars, scientists, and practitioners have not reached common ground. However, stakeholders are recognized as critical components in the success of the decision-making and sustainability assessment processes.

Surface mining projects are unique in many ways. Not only are impacts on the environment rapidly noted by local communities, but economic benefits are also tangible on local and national levels. Therefore, stakeholders become rapidly knowledgeable regarding how the projects directly affect them. Even though the identification and classification of stakeholders is still an area for development, experience and the "learning-as-you-go" process have resulted in the identification of a number of stakeholders for the surface mining projects for the Canadian oil sands operations/projects. Owner companies, EPC (engineering, procurement, and construction) companies, contractors, suppliers, logistics providers, government/regulators, local communities, local business, aboriginal communities, NGOs (non-governmental organizations), scientists and researchers, media (television, press, radio), industry and community associations, and financiers are some of those interested parties that may be actively or passively engaged in the development of the projects. Development does not imply the approval of the projects or giving the social license to operate. The Canadian oil sands are a good example of surface mining operations due to (1) the large reserves or resources exploited, (2) the comparatively stringent set of regulations, and (3) the large number of stakeholders engaged in the process, among other valid reasons.

6. The Hierarchy

In the AHP, the relative value of surface mining operations' sustainability is viewed as the main objective, which is obtained by way of a combination of a number of criteria (i.e., areas of excellence), each with their own relative importance, relevance, weight, or priority with respect to their influence to the overall objective. These three levels are linked together in a hierarchical structure, as shown in Figure 1, where the top level is the objective and the next level consists of the different criteria (i.e., areas of excellence). In our application of the AHP methodology, we consider ten (10) areas of excellence: project & environmental management excellence (PEME); site & soil resource excellence (SSRE); water resource excellence (WRE); atmosphere & air resource excellence (AARE); natural & artificial lighting excellence (NALE); energy resource excellence (ERE); resources & materials excellence (RME); innovation in design & operations excellence (IDOE); infrastructure & buildings excellence (IBE); and education, research, & community excellence (ERCE). Additional criteria can be considered in other sustainability assessment rating systems, which must be conceptualized during the development phase of the assessment tool, with the aim of having a level of consistency in order to benchmark performance between projects and/or organizations. Poveda and Lipsett (2011b) explain each criterion (i.e., area of excellence), and that the main objective for each of them is to apply fundamentals and principles, as well as the latest advances and technologies, with the aim of targeting a level of excellence in performance. Additionally, the criteria (i.e., areas of excellence) take three aspects into consideration: resources involved in project development; stakeholders' expectations; and potential environmental, economic, social, health, and other impacts.

The next level in the hierarchy materializes once each criterion (i.e., area of excellence) is considered as a cluster, to which a certain number of indicators contribute. The number of indicators may vary in each criterion, and each one of the indicators has its own weight, relevance, importance, or priority with respect to the particular criterion (i.e., area of excellence). In our application, the number of indicators in each criterion varies. Those indicators reflect the different pillars of sustainability (i.e., social, economic, and environmental) or can be the combination of two or three of the pillars, which are being called multi-facet or multi-attribute indicators. Additionally, the classification of indicators considers when and where a set of activities occurs within the surface mining operations (Poveda & Lipsett, 2011b).

7. Measurement Scale

The fundamentals of the measurement scale utilized in the AHP method have not changed since the methodology was introduced by Thomas L. Saaty in the 1970s (Saaty, 1977). However, a comparison of the different tables presenting the measurement scale notes slight modifications of how the scale is interpreted, and/or conceptual additions that have been introduced and observed in different publications throughout the years (Saaty 1977, 1980, 1982, 1990, 1994, 2008). Though those differences may be semantic interpretations, the stakeholders must be presented with a consistent and clear measurement scale with the aim of obtaining optimum results. In the application of the AHP methodology in the weighting process of sustainability indicators for surface mining operations, the measurement scale used is represented in Table 2. While the measurement scale adopted for this application considers the principles of the AHP methodology, the information presented considers the different measurement scales introduced throughout the years. Furthermore, the measurement scale illustrates a descriptive and detailed compilation of how the information must be presented to the decision-makers (i.e., stakeholders) during the process of weighting the indicators.

The measurement scale developed and detailed by Saaty throughout the years addresses the hierarchical structure of the problem by assisting decision-makers in setting the weights or priorities for each criteria and indicators. It reflects the relative strength of each element at a level in the hierarchy with respect to other elements considered in the weighting process at different levels and between each other. In our application, the weights or priorities of criteria (i.e., areas of excellence) and indicators (i.e., sustainable development indicators [social, economic, environmental, and multi-attribute/facet]) are calculated to then be integrated in the calculations for sustainability assessment developed in the Wa-Pa-Su project sustainability rating system (Poveda & Lipsett, 2011a,b). This serves as an integrated approach for sustainable development of long-term projects (i.e., projects having a life cycle that exceeds a 2-year period [which includes only the execution phase] from start to finish [e.g., mining, industrial, oil & gas, energy]). The measurement scale consists of nine points. Anselin et al. (1989) indicate that nine points are chosen because psychologists have concluded that nine objects are the most that an individual can simultaneously compare and consistently rank. The scale ranges from 1, which indicates an equal importance between elements to 9, which refers to an absolute importance of one element over another. Additionally, the pair values of 2, 4, 6, and 8 indicate intermediate values between two adjacent judgments, and some compromise is needed.

The construction of pairwise matrices and their values within are assisted by the measurement scale which indicates the level of strength or dominance that an indicator or criterion has over others when they are compared pairwise. Consequently, sets of

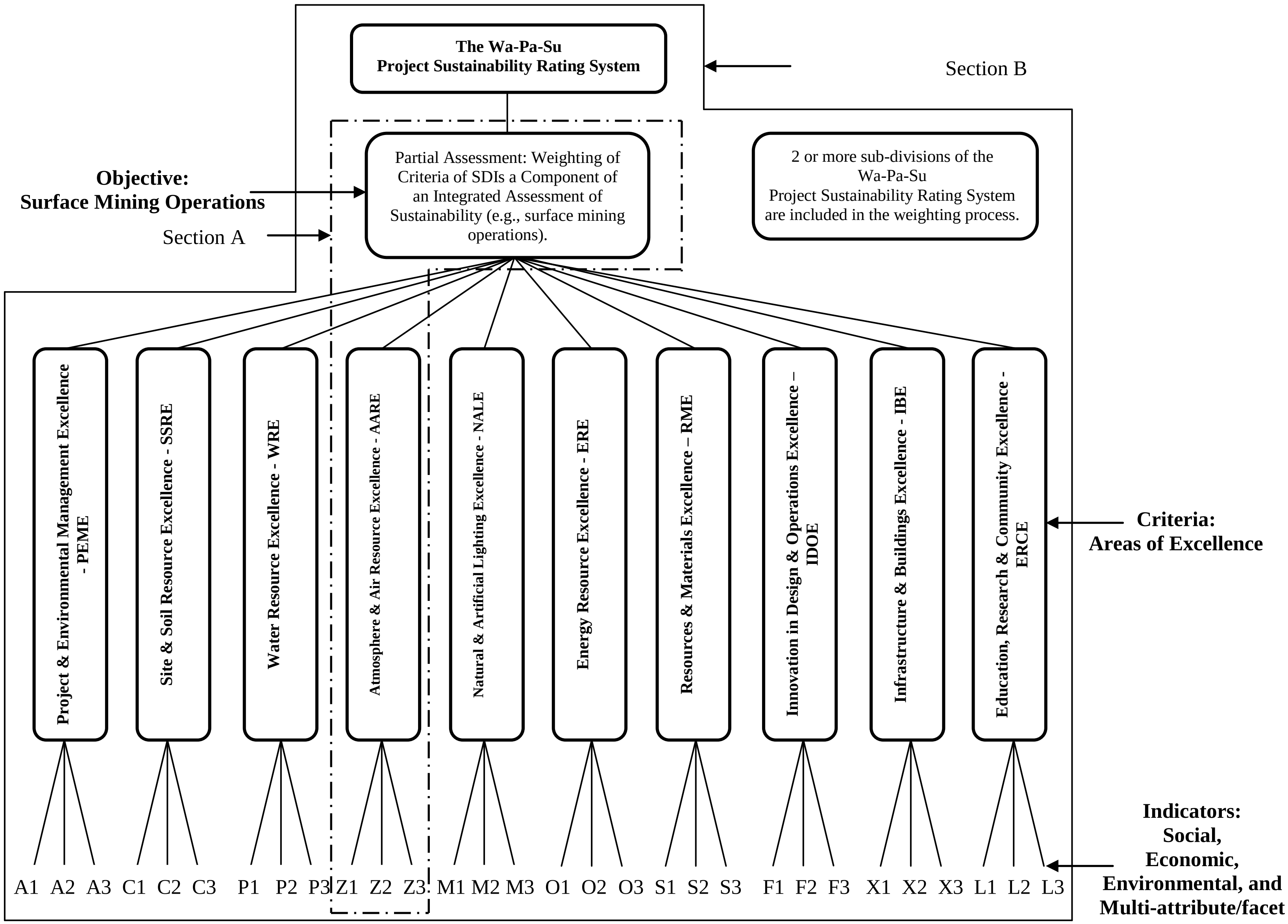

Figure 1. Hierarchy structure of the evaluation for sustainability of surface mining operations (Section A) or the overall oil sands projects (Section B) which may include two or more sub-divisions. The AHP method is used as partial assessment in the weighting of criteria of SDIs as a component of an integrated assessment of sustainability in the Wa-Pa-Su Project Sustainability Rating System (Poveda and Lipsett 2011a, b).

pairwise comparisons are the result of simultaneous rankings broken down. Consistency in the use of the measurement scale is required within the same pairwise comparison matrix and among different matrices in the event the study requires more than one matrix. However, the construction of a matrix of pairwise comparisons does not impose strong requirements of consistency (Anselin et al., 1989).

Table 2
The fundamental scale according to Saaty (1977, 1980, 1982, 1990, 1994, 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective7
2	Weak or slight	
3	Moderate importance of one over another	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Where; 2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities
Reciprocals	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

8. Pairwise Comparison Matrices

Pairwise comparison matrices are used to determine the relative importance of a series of elements in terms of each criterion. When an element is compared with itself, the value of the weight becomes 1. The structure followed in this paper consists of a number of elements, M, and a series of criteria, N. N criteria are the same elements M, when forming the pairwise comparison matrix certain element M becomes a N criteria (e.g. $M_1 = N_1$). Since elements can be evaluated in terms of the different criteria, the relative importance or weight of each element can be calculated as well. In the pairwise comparison matrices, a_{ij} represents the relative importance or weight of an element over a criteria where, i=1,2,3,……M and j=1,2,3,…..N. Therefore, the core of the typical problem to be solved using the AHP methodology to weight the alternatives (criteria) can be represented by the following pairwise comparison matrix:

	Alternative						**Alternative/Criteria Absolute Weights**
Criteria	M_1	M_2	M_3	M_4	……..	M_M	
N_1	a_{11}	a_{12}	a_{13}	a_{14}	……..	a_{1M}	w_1
N_2	a_{21}	a_{22}	a_{23}	a_{24}	……..	a_{2M}	w_2
N_3	a_{31}	a_{32}	a_{33}	a_{34}	……..	a_{3M}	w_3
N_4	a_{41}	a_{42}	a_{43}	a_{44}	……..	a_{4M}	w_4
.	.	.	.	.		.	.
.	.	.	.	.		.	.
.	.	.	.	.		.	.
N_N	a_{N1}	a_{N2}	a_{N3}	a_{N4}		a_{NM}	w_{NM}

Where;

$M_1 = N_1$,	$a_{11} = w_{N1}/w_{M1}$	$w_1 = w_{N1} = w_{M1}$
$M_2 = N_2$,	$a_{21} = w_{N2}/w_{M1}$	$w_2 = w_{N2} = w_{M2}$
$M_3 = N_3$,	$a_{31} = w_{N3}/w_{M1}$	$w_3 = w_{N3} = w_{M3}$
$M_4 = N_4$,	$a_{41} = w_{N4}/w_{M1}$	$w_4 = w_{N4} = w_{M4}$
: :	: :	: : :
$M_M = N_N$	$a_{21} = w_{N2}/w_{M1}$, *etc*	$w_{NM} = w_{NN} = w_{MM}$

The first pairwise comparison compares the different criteria (i.e., areas of excellence) in a 10 x 10 matrix which includes the following elements: project & environmental management excellence (PEME); site & soil resource excellence (SSRE); water resource excellence (WRE); atmosphere & air resource excellence (AARE); natural & artificial lighting excellence (NALE); energy resource excellence (ERE); resources & materials excellence (RME); innovation in design & operations excellence (IDOE); infrastructure & buildings excellence (IBE); and education, research, & community excellence (ERCE). In the assessment process (pairwise comparison), the decision-maker is free to evaluate the relative importance of each alternative/criterion over others. Finding the largest eigenvalue and associated eigenvector, the absolute value of each weight can be calculated from the relative pairwise weights. In detail, if n criteria have known relative weights/importance of w_1, w_2, …w_n, then the comparison of the relative importance of criterion i to criterion j gives a value of N(i, j) = M (i, j) = w_i / w_j for the element (i, j) in the pairwise comparison matrix N or M (M = N but M is called alternative and N criteria when forming the pairwise comparison matrices). Additionally, alternative/criteria N(j, i) = M (j, i) = w_j / w_i which justified the use of reciprocals in Table 2. To build the matrix, the alternative and criteria are compared pairwise to then estimate the weight attached to each alternative/criteria using the eigenvector associated with the largest eigenvalue. In this application of the AHP method, there is no pre-established consistency or mathematical sense in implying that N(i, j) x N (j, k) = N(i, k) or that an alternative/criterion follows a semantic relationship with its degree of importance. Therefore, alternative/criterion i is not more important than j, and neither is alternative/criteria j higher than k, or i ranked lower than k. As the value for inconsistency increases, it is expected to find a greater eigenvalue (above n). Therefore, the pairwise comparisons have a poorer representation by the eigenvector. Finally, the values for w_1, w_2, …w_n, can be found by calculating the geometric mean of each matrix row and then normalizing by dividing each number by its total. These represent the corresponding value of importance given to each alternative/criterion.

The second set of pairwise comparison is integrated with alternatives/criteria at the 3rd level. In Figure 1, the third level consists of the indicators in each criterion (i.e., area of excellence). The number of alternatives/criteria in each pairwise comparison matrix varies as follows: PEME with 19 SDIs, SSRE with 11 SDIs, WRE with 11 SDIs, AARE with 4 SDIs, NALE with 1 SDI, ERE with 3 SDIs, RME with 6 SDIs, IDOE with 2 SDIs, IBE with 14 SDIs, and ERCE with 44 SDIs.

The identification, pre-selection, and classification methodology of SDIs for surface mining operations was assisted by six different sources grouped in three areas: indicators agreed upon by public or governmental representatives through consensus, indicators identified by academics and practitioners, and indicators established by organizations. Although the assessment of sustainability and SDIs are still areas in an infant stage, the measurement methodology of criteria for surface mining operations was developed based on the continual performance improvement (CPI) methodology (Poveda & Lipsett, 2013b). The weighting of SDIs can be assisted by using a variety of approaches including the AHP methodology used in this application. Therefore, the weighting of the alternative/criteria in each pairwise comparison matrix follows the same parameters used in the 10 x 10 matrix to weight the criteria (i.e., areas of excellence) at level two (node two) in the hierarchy, with the aim of consistency in the weighting process of each alternative/criteria in each level (node) of the system (hierarchy). Each pairwise comparison matrix at level three (indicators [i.e., social, economic, environmental, and multi-attribute/facet]) is an independent sub-system. The final weight of the each indicator is impacted by the results of what integrates the 10 x 10 pairwise comparison matrix at level two (node two) in which the criteria (i.e., areas of excellence) have been weighted; therefore, the level of relevance or importance to each sub-system (pairwise comparison in level three [indicators level]) must be calculated considering the weight of each criteria (area of excellence).

9. Expected Results and Contributions

The expected results can be presented in the two scenarios represented in Figure 1: (1) partial assessment for the overall sustainability performance of the oil sands projects, in which the weighting of criteria of SDIs for surface mining operations is a component for the assessment of the project (Section A); and (2) overall assessment for sustainability performance of the oil sands projects in which ten (10) sub-divisions represented a component for the assessment of the projects (Section B). In Figure 2, the same hierarchy structure as in Figure 1 Sections A & B is presented, but with the respective criteria and indicators showing the priority weights. To obtain the resulting overall weight for each indicator (SDIs) in Case A of Figure 2 (surface mining operations as an isolated system in the overall sustainability assessment of the oil sands projects), the priority weights have to be multiplied by the weight of the respective criterion (i.e., area of excellence). For example,

$$SDI1' = SDI1 \times SDI = 0.175 \times 0.325 = 0.056$$

The overall weights must sum to the respective weight of each indicator as noted in Figure 2 for the examples illustrated (e.g., SDI = 0.056 + 0.080 + 0.142 + 0.047 = 0.325), while the sum of weights of all indicators must sum to the unit (one [1]) (e.g., Objective [surface mining operations] = 0.115 + 0.051 + 0.145 + 0.325 + 0.055 +0.105 + 0.085 + 0.025 + 0.038 + 0.056 = 1). Similarly, the calculations can be done in Case B of Figure 2 (surface mining operations as one of the ten (10) sub-divisions included in the Wa-Pa-Su Project Sustainability Rating System to measure the sustainability of the oil sands projects) (Poveda & Lipsett 2011a,b). The priority weights also have to be multiplied by the weight of the respective criterion (i.e., area of excellence). However, since the surface mining operation is another sub-division in the system (objectives), an additional step must be included to calculate the weight of each sub-division to then be multiplied by the weight of the respective criterion (i.e., area of excellence). Therefore, the weight of a particular indicator with reference to the overall system can be calculated as:

$$SDI1' = SDI1 \text{ x } SDI \text{ x } SDI_{objective} = 0.175 \text{ x } 0.325 \text{ x } 0.345 = 0.020$$

In Case B of Figure 2, the overall weight of the objective must sum to the unit (one [1]), while the overall weights of the criteria must add to the weight of a particular objective, and the overall weight of the indicators must sum to the respective total of the multiplication of the weight of the objective by the weight of the indicators (e.g., SDI = 0.020 + 0.027 + 0.049 + 0.016 = 0.112 in which 0.112 = 0.345 x 0.325).

Previously, in order to submit the different SDIs to a weighting process supported by a multi-criteria decision-making (MCDM) methodology, the critical task in sustainability assessment has referred to the identification and design of metrics, which assists decision-makers in addressing the questions of what to measure and how to measure the SDIs, respectively. Moreover, decision-makers (stakeholders) are faced with a cost-benefit paradigm of implementing a series of SDIs to demonstrate a certain level of sustainability performance while addressing the stakeholders' needs. Despite the fact that there is a series of beneficial factors behind the applicability and usefulness of SDIs, there are also certain costs to be considered (Poveda & Lipsett, 2013a). The next query(s) in the decision-maker's mind involves the level of relevance or importance of each SDI. The application of the AHP method assists in addressing questions such as (1) should all the SDIs be weighted equally? (2) should the SDIs user expend the same level of resources for each indicator to address the impact (social, economic, environmental) that they represent?, and (3) is each indicator equally important for each group of stakeholders? Although finding universally-accepted responses is not the main aim in the application of the AHP method, the different groups of stakeholders have an opportunity to be heard and express their individual needs through an effective engagement and participatory process that leads to the assessment of the weight of each of the indicators (SDIs), criteria (i.e., areas of excellence), and/or objectives (i.e., sub-divisions). Furthermore, the AHP method, like other multi-criteria decision-making methodologies, helps the decision-makers face the complex problem of evaluating multiple conflicting and subjective SDIs.

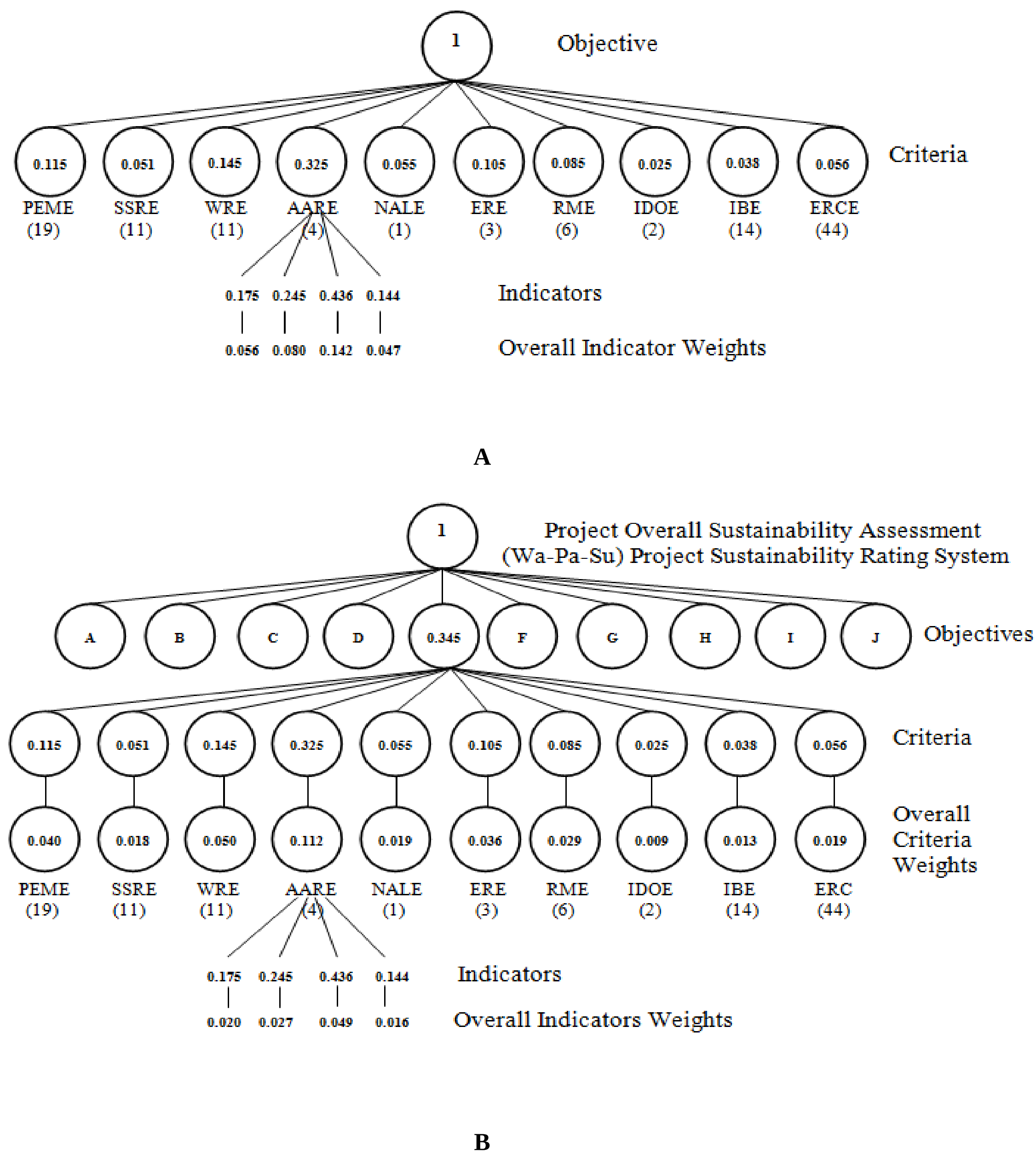

Figure 2. Hierarchical structure of the evaluation process of the two hypothetical applications of the AHP methodology to weight SDIs to measure the surface mining operation and oil sands projects sustainability

Decision-makers face the challenge of multiple choices in their routine operations or among their list of activities. Therefore, they usually prefer simplistic, rapid, and applicable methodologies to find answers to their queries. The AHP methodology is similar to using the common sense decision-making approach. Consequently, decision-makers easily understand the approach applied in this methodology. Simplicity in the SDIs assessment becomes a strategic element from the stakeholder's standpoint. In surface mining operations, the different stakeholders vary with respect to their level of education, experience, and seniority level (management position), among other impacting factors in the assessment process. Additionally, the results (weights) of applying the AHP method can be easily communicated and understood by the different decision-making groups. Bahurmoz (2003) noted that using AHP in group settings leads to better communication, clearer understanding, and consensus among members of the decision-making group. Therefore, a greater commitment to choosing the alternative is expected.

10. Discussion and Future Research

In addition to the various challenges decision-makers encounter during the projects conception, planning, execution, and closing phases, the different stakeholders—who often become decision-makers—are facing the pressure of obtaining the "social license" to operate with the aim of smoothly executing and delivering their projects. Different industries are exchanging the well-known mentality of "business as usual" for proactive approaches to address the stakeholders' needs. Implementing more environmentally-friendly practices has been not enough. Therefore, organizations are including social and economic performance indicators to demonstrate their commitment to the triple bottom line often addressed in the fundamentals of sustainable development. The number or selection of SDIs for a determined kind of project or industry is still under debate, not only among stakeholders but also within the international scientific community. While selecting specific SDIs for a project, organization, or industry seems to be the preference, the main challenge in applying such criteria lies in the area of benchmarking sustainable development performance. Surface mining operations and the mining industry encounter similar difficulties when determining how to answer not only questions such as [1] what to measure and [2] how to measure the selected set of SDIs, but also in finding the level of importance (weight) of each SDI. The application of the AHP method, the design of its hierarchy, and the development of the pairwise comparisons required in the methodology assume that questions 1 and 2 have been satisfactorily answered and universally accepted. Nevertheless, multi-criteria decision-making (MCDM) methodologies may offer new perspectives, not only in the weighting, but also in the selection and design of metrics for SIDs.

While applying the AHP methodology offers a clear representation of the different groups of decision-makers regarding the level of importance of the various SDIs, criteria (i.e., areas of excellence), and objectives (i.e., sub-divisions), future research must address the validation of the findings (overall indicators' weights) and areas such as the level of importance or relevance of the different decision-makers (stakeholders), independency of pairwise comparison matrices, and the influence of SDIs among each other. The validation of the findings refers to comparing the values (weights) obtained after applying the AHP methodology with scientific evidence. The weight of an indicator measuring main environmental impacts is expected to be higher than other indicators reflecting have lesser impact, which can be measured through various scientific parameters (e.g., GHG emissions, energy consumption). The weight of each SDI is not only determined by decision-makers (stakeholders) based on the fact that they represent the three pillars of sustainability (social, economic, and environmental), other factors should be investigated to calculate the final overall indicators' weights; the SDIs' weighting should include the weights of each stakeholder group (e.g., Is the input of a politician and a small business representative equality weighted?); the decision-maker's seniority level (e.g., Is the input of a CEO and a junior manager equally weighted?); and the decision-maker's relevance represented in a combination of years of experience, position, and seniority in a determined position (e.g., Is the input of a Junior Project Manager with 10 years of experience and a Senior Superintendent with 30 years of experience equally weighted?).

Finally, pairwise comparison matrices and SDIs have been treated as independent bodies and the outcomes have been read as such. Future research should question such independency and/or find the interconnection between the different matrices and among the various SDIs in each matrix. For example, an indicator representing the water resources excellence (WRE) area of excellence may be closely linked to another indicator representing the energy resource excellence (ERE) area of excellence. Understanding such dynamism may result in addressing the subjectivity often encountered among SDIs and the metrics used to measure them.

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