In search of a Methodology to assess sustainability for Mining & Mineral sector

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Abstract

Assessing the sustainability of the mining and mineral sector has proved to be a challenge due to its positive and negative externalities arising from it. Sustainability Assessment, which employs tools like Envirnomental Impact Assesment (EIA) and extensions of Input-Output analysis, is one of the many approaches towards this purpose. However due to some inherent limitations these tools have not been able to deliver conclusive results. A major reason for this is the ambiguity that exists in the concepts, principles and criteria of sustainability especially when it is applied to the mining and mineral sector. This paper is an attempt sort out these limitations and ambiguities by building a model based on **fuzzy logic.** *It is an attempt to aid the monitoring of the sector and to enable the estimation of the degree of sustainability of the system under examination and thus, highlight areas which need more monitoring or attention, or need a change of direction to achieve the goal of sustainable development.*

Keywords: *Mining and Mineral Sector; Sustainable Development; Sustainable Assessment; Assessment for Sustainability; Environmental Impact Assessment; Input Output Analysis; Fuzzy Logic; Degree of sustainability.*

"As the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance or relevance becomes mutually exclusive" –**Lofti Zadeh, 1965.**

Introduction

The positive and negative externalities of mining on environment, economy and society stress the need for a standardized framework to initiate and monitor sustainable development of the sector. The focus of this paper is to present an approach for assessing the sustainability of the mining and mineral sector. Firstly it attempts to review the two traditional techniques of assessing sustainability; the *Environmental Impact Assessment* and *extensions of Input-Output Analysis.* It proceeds further to build a tool to assess sustainability of the mining and minerals sector by returning to the fundamental principles, definitions and criteria of sustainable development. The paper finally suggests a methodology for the improvement of current sustainability assessment processes, using *fuzzy logic* computational approach. Its purpose is to bridge the gap between the goal of sustainable development and the barriers faced during its implementation. It enables the estimation of the degree of sustainability of the system under examination and shows stakeholders a way to operate.

The next section gives a brief review of the concept of sustainable development, followed by a section which illustrates sustainability in the context of the mining and mineral sector. It is followed by a critical review of the two basic methodologies of sustainability assessment. The paper concludes by proposing a method which can deal with the ambiguities of sustainability assessment in practice by applying Fuzzy logic.

Sustainable Development

Increased concerns about environmental problems and the failure of relating these to developmental issues led to the establishment of United Nations Commission on Environment and Development (UNCED) in 1983. The tremendous work of this commission under the energetic leadership of Norwegian Prime Minister *Mrs. Harlem Bruntland* resulted in a definition which reads *"development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987)* and development of the concept *'Sustainable Development'*. Since then, sustainable development has evolved into an umbrella ranging from issues relating to environment to those relating to human development *(Dovers and Handmer, 1993)*. The other breakthrough in the evolution of sustainability analysis is the concept of *Triple Bottom Line* (Elkington, 1994), *"the capability of expressing complex relationships between current economic, environmental, and social challenges"*. Even though at present there are defenations galore for sustainable development, there are disagreements about balancing and optimizing these three dimensions at the same time. This makes planning and assessing the progress toward sustainability a complex task. After 20 years of these debates since the Bruntland definition there seems to be a consensus that sustainability assessments ought to (*Gasparatos et al., 2008*):

- Integrate economic, environmental, social and increasingly institutional issues as well as to consider their interdependencies ;
- Consider the consequences of present actions well into the future;
- Acknowledge the existence of uncertainties concerning the result of our present actions and act with a precautionary bias;
- Engage the public;
- Include equity considerations;
- Communicate the results in an appropriate form to the stakeholders.

To make sustainable development more than just a popular description it should be defined precisely and there should be ways to assess and achieve it. As a response, several tools for sustainability assessment have been developed.

The first set of sustainability assessment tools consists of its indicators and indices. *Indicators* translate sustainability issues into quantifiable measures that represent a state of development in a defined region and when indicators are summated it gives an *Index*. Three broad categories of indicators are commonly identified through the lines of triple bottom line approach of sustainability; these are environmental, social and economic indicators. A number of guidelines are found in open literature (for example *Gasparatos et al., 2008*) for aiding the selection of sustainability reporting, but rules of thumb for the selection of indicators for decision making are, fewer in number. Most often, the term sustainability is divided into *"strong"* and *"weak"* sustainability criteria, based on the "capital stock theory" of natural, human and man-made capital (Turner *et al.*, 1994). It deals with the issues of substitutability of these forms of capital. *Sustainability ultimately is an absolute condition which shows weather a country, community, sector or company is sustainable or it is not.*

Sustainability in the Context of Mining &Mineral Sector

Many developing countries like India and China, particularly their mining cites depend on mineral resources. The growth of the mining industry is a critical ingredient in their economic growth, attracting more investments, creating more jobs and relieving poverty. It also generates government revenues, an increase in exports which balances the terms of trade and the level of foreign exchange reserves. Accordingly, it is crucial for a mining city to make sustainable use of its mineral resources.

Mining and Mineral sector faces some of the most difficult sustainability challenges because of the dichotomy embedded in it. At one extreme, it produces substantial wealth from the land and on the other it disturbs environment and community life associated with it. This stresses the need for a proper assessment of the sector, but the present definitions and methods of assessing sustainability fails to make it possible. Crowson (1998), states that *"if a mine is considered from an aspect of resource exhaustion only, then no operation is sustainable"*. Mining is not a sustainable industry if we view through the lens of *strong sustainability* instead; through ***weak sustainability*** the economic benefits created by mining can be sustained indefinitely through appropriate investment in education, health care, infrastructure and other activities that can create well being even after mining ceases (Solow-Hartwick criteria, Solow (1974), Hartwick (1977)). From the literature, definitions and methodologies available for sustainability assessment imply that the entire concept of sustainability, its definition and criteria requires profound revisions for it to be applicable to mining and minerals sector. There were attempts to define sustainable development more specifically to the mining and minerals sector. Ecologically Sustainable Development Working Group on Mining of Australia (1991) has defined sustainable development for the mining sector as: *"...ensuring that the mineral raw materials needs of society are met, without compromising the ability either of future societies to meet their needs"*. Natural Resources Canada in their web site has defined sustainable development for the mining sector as:*"...finding, extracting, producing, adding-value to, using, re-using, recycling and, when necessary, disposing of mineral and metal products in the most efficient, competitive and environmentally responsible manner and maintaining or improving environmental quality for present and future generations."* Another definition which is applicable in the context of mining is the definition by Parkin's (1989) *"The rate at which we can exploit natural resources or exhaustible resources"*.

Major studies in the area of mines & minerals sustainable development were Global Mining Initiative(2002) , Canadian Minerals and Metals Initiative(2003) , works of European Industrial Minerals Association(1993-2008) , sustainability indicators proposed by World Business Council for Sustainable Development(WBCSD,2006), The reporting standards suggested by Global Reporting Initiative(GRI,2002), The report created by WBSCD with the International Institute for Environment and Development called Mining, Minerals and Sustainable Development (MMSD)(IIED,2002), GRI Mining and Metals Sector supplement (GRI,2005) and various sets of matrices produced by academic researchers like A. Asapagic (2004), J.Yu et al.(2004), etc.

Methodologies of Sustainable Assessment

This section reviews two major methodologies for sustainability assessment proposed to satisfy the demands of sustainable development. It critiques the approaches in the context of their applicability to mining and as tools for decision making.

a) Environmental Impact Assessment

'Environmental Impact Assessment' (EIA) is a tool for decision-making, used to identify and evaluate the probable environmental impacts of a proposed development (Glasson *et al.*, 1999). EIA was originated in the United States, with the National Environmental Policy Act of 1969, now it is applied in almost all major countries of the world. An effective EIA provides potential to identify the impacts of the project at the pre-implementation stage and can develop strategies to mitigate them, hence contributing to sustainable development (Glasson *et al.*, 1999). The potential of EIA is widely recognized (Rio Decl. Princ. 17) state three fundamental purposes of the EIA process *"an aid to decision-making, an aid to the formulation of the development actions, and an instrument for sustainable development"*. More over *Agenda 21* recognizes EIA as an essential tool for ensuring sustainable development through the integration of environmental and socioeconomic considerations. Although sustainability is considered as the principal aim of EIA, it is viewed as less successful in achieving sustainability goals (Caldwell, 1993).The reasons which limit EIA form its purpose can be discussed through the following points:

1) Sustainable development is a very complex concept that involves interactions between the environment and socio economic activity and it is doubtful if EIA is able to capture it. While applying weak sustainability, which is important in the mining and mineral sector it requires an integrated assessment, so that the environmental factors may be weighed against the social and economic ones (George 1999), It is doubtful if whether EIA is able to do this.

2) The weakness of EIA to be a sustainability tool is seen in its nature itself. It is a project-by-project approach whereas sustainability assessment is that of industry- society-wide decisions (Becker and Jahn 1999); i.e. EIA is a pre project analysis whereas sustainability assessment is a post project analysis;

3) The ambiguities present in the definitions of sustainability makes an EIA practitioner unclear about what to do and how to attain sustainability;

4) The two or more EIA accepted projects when combined together in an area can be a threat to the sustainability if carrying capacity is not considered;

5) EIA is only a path towards sustainability but we have to check by taking the path whether we have attained the goal or not;

6) The gap in expectations and reality makes the implementation of EIA for the sustainability assessment doubtful;

7) Much research has been done on the theoretical opportunities for EIA to achieve sustainability, but there is little empirical research on whether EIA achieves this aim in practice (Cashmore *et al.*, 2004);

8) EIA is applied at the time when a project is implemented. It cannot give a picture of what happened to the project (post project) and how it is performing and contributing to the sustainable development ;

9) New additions to the project are not captured by the EIA;

10) There is no perfect or universal method of developing an EIA which is region, sector specific;

11) The sustainability assessment for mining and mineral sector needs a mix of subjective and objective approach. The existing methods of EIA are not able to

effectively handle subjective expressions of societal, group, and individual values and opinions.

The problems discussed above thwart the achievement of sustainable development through EIA. Lots of practitioners, researchers and observers agree that EIA, a 20 year tool for environmental management is not living up to its full potential (Mudge., 1993) EIA reports and documents are used to obtain project approvals, but EIA has now transformed to a management tool for achieving acceptable forms of environmentally sound development; at best it is proves nothing more than a permit to move a project ahead.

b) Input Output Analysis

Input output analysis provides a theoretical framework for studying the socio economic and environmental linkages. Earlier its application was limited only to national income accounting, structural economics and regional economics. Now it has extended its wings to other human activities as well. It has now evolved as a major tool used for sustainability assessment. The methods of input output analysis used for this purpose can be grouped under a) *Physical Input-Output models*, which present input and output material, flows for each sector of an economic system in physical units. The foundation of these models which mainly focuses on ecological-economic systems was first made by Kneese *et al.* (1970) which are called as *material balance approach*. b) *Monetary Input-Output models* which are used to represent connections between the sectors of an economic system.

The major breakthrough studies which came out from input output analysis in relation to the environment and sustainability are; Cumberland extended inter-industry model (1966), Isard (1972)/Daly (1968) models, The Leontief abatement model (1970), Ayres-Kneese Model (1969) and the Environmental Input-Output – Life-Cycle Assessment models of Stone (1961, 1966).The most relevant and important one, is the Environmental Input-Output Life Cycle Assessment (Hendrickson et al., 2006). Although the input-output analysis offers one of the most robust and appropriate methodologies to undertake sustainable assessments, it also has also some serious drawbacks which limits its applicability for the sustainability assessment in mining and mineral sector. Some of them are the following:

1) Input-output analysis is a data hungry methodology, it needs enormous quantity of data that has to be obtained from several agents; Data availability appears to be one of the main obstacles in applying input-output analysis to policy problems on a low regional scale;
2) The data requirements of input output analysis makes it too expensive to analyze sustainability as the environment, economic and social interactions are difficult to model quantitatively. These difficulties of the data requirements forces the analyst to make data adjustments which are always prone to errors;
3) The assumptions of the input-output analysis without which it can't work includes the major limitations of it for analyzing sustainability ; the fixed proportions of inputs, the static analysis, ignoring the effects of scale economies and of technological progress, static and linear, homogeneity (each sector produces a single product) , single technology in the production process are serious threats for analyzing sustainability;
4) No matter which set of metrics is used to assess the sustainability of a production

system or sector, an intrinsic difficulty arises from Arrow's Theorem (MacKay, 1984) which points out that it is not possible to rank, unequivocally, quantities which have more than one dimension. But the socio-economic system is embedded in a much broader natural system which makes the sustainability assessment impractical using an input output analysis ;

5) The life-cycle analysis which is used for the sustainability assessment in the input output analysis domain relies on a data collection can which can lead to "double-counting" of resource use because the further down the supply chain, the harder it is to apportion the correct resource use to the product under investigation and the harder it is to track interactions between the contributing suppliers.

Leontief (1955) who propounded the input output analysis, himself has observed some limitations of it; his observations include the concern that it needs voluminous, laboriously compiled collection of statistical data, It is difficult for an input output analysis to capture price changes as it deals with physical output of manufactured goods; It depends on indirect estimating procedures, which if not done correctly yields absurd, the time required for obtaining the data is highly relevant. It is perfectly possible that, if the two types of information were of the same vintage, we would prefer the matrix, but that, since the matrix takes a long time to produce, it may be better to use the less pertinent but more rapidly available types of data. Leontief concludes that while several measures can be proposed to overcome the limitation of Input-Output analysis they would invariably destroy its most attractive property, i.e. its simplicity.

The limitation of the above methods stresses the need for a new method which can address some of these limitations. One such approach could be the application of fuzzy logic, as it takes into account the subjectivities associated with concepts relating to sustainability.

Applying Fuzzy logic to the Assessment for Sustainability

The concept of sustainability and methods for assessing it, specifically for the mining and minerals sector are difficult to define or measure. *Fuzzy logic,* due to its capability to emulate skilled humans and its systematic approach which handles vague situations makes it apt for sustainability assessment of Mining & Mineral Sector. It is fair to say that some clear measures, or at least, indicators of sustainability exist, but a methodology which can use these indicators according to the context and region still has to be developed. Referring to the Bruntland report, Bartelmus (1994) says "what is needed now is to replace dramatization and rhetoric with scientific measurements, synthesized into statistics and indicators that provide a comprehensive picture of sustainability or non sustainability of current human activities". Using fuzzy logic it is possible to make aggregation of judgments with respect to goals and to rank the decision alternatives according to the aggregated judgments (Zimmermann, 1967). A systematic method based on a reliable scientific methodology, which combines multidimensional components and uncertainty assessment, is needed. Such a method should be flexible in the sense that one can add or remove indicators to achieve a better assessment of a system according to the context.

The Concept

Methods based on fuzzy logic were introduced by *Lofti Zadeh* (1965); his pioneering article gave a new way of presenting non probabilistic uncertainties via fuzzy sets. Zadeh created mathematical theories and tools to quantify linguistic concepts, words that have meaning but are inherently imprecise, vague or fuzzy. Each fuzzy set is defined by a membership function that is used to calculate the grade of membership and these sets are rigorously manipulated using the tools of fuzzy logic. Membership functions are different from ordinary sets; an ordinary set is a set with a crisp boundary in that an element can either *'be' or 'not be'* a member of that set. A fuzzy membership set instead is a transition from *'belonging to'* to *'not belonging to'*; the degree of membership is characterized by membership function. The linguistic database is the heart of a fuzzy model. The expert knowledge, which is assumed to be given as a number of *'if- then'* rules, is stored in a fuzzy rule base. These rules are subsequently given a precise mathematical meaning through user supplied definitions and at the end defuzzification methods converts' fuzzy numbers into crisp values. This method Fuzzy logic which can be used for assessing sustainable development can be technically classified under the broad head of multi-objective, multi-criteria decision making under conditions of uncertainty. Multi-criteria Decision Analysis (MCDA) is defined by Belton & Stewart (2002) as: *"an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter"*.

The Context

The following features of fuzzy logic derived from review of literature justifies the use of fuzzy logic to the sustainability assessment of mining and mineral sector

- Fuzzy logic has the ability to deal with complex and polymorphous concepts which contain ambiguities and are not amenable to a straight forward quantification;
- It provides the mathematical tool to handle ambiguous concepts and reasoning and finally gives concrete answers (crisp as they are called) to problems with subjectivity (*Andriantiatsaholiniaina. et al., 2001*);
- It captures the factors or concepts(values or opinions) which are left out or which are impossible to quantify if a traditional approach towards sustainability assessment were adopted, such as EIA, Extensions of Input Output analysis, Cost Benefit analysis , stochastic methods or algebraic formulas;
- It uses linguistic variables, and thus can perform computation with words.(Zadeh 1978);
- In the area of human thought fuzzy logic performs successfully (Zadeh, 1978);
- It helps to make models for carrying out intelligent information processing of thinking, judgments, evaluation and decisions(Asai, 1995);
- Accommodates stochastic variability in attributes without the knowledge of their probability distributions, making it superior to the existing stochastic and nonstochastic methods for assessing sustainability that (Tony Parato, 2007)

It can be concluded that a methodology using fuzzy logic offers important advantages in overcoming at least three of the inherent difficulties in modeling sustainability:

1) *The problem of non commensurate units*: Effectively handled through the use of linguistic variables used in fuzzy logic methodology ;
2) *Information that is vague or imprecise:* Can be included if information is

modeled as a fuzzy set

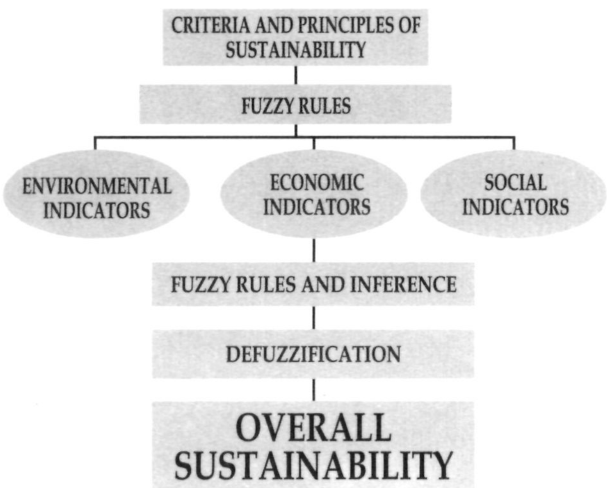
3) *The interrelationships between the dimensions and criteria of sustainability:* Can be incorporated into a model by means of fuzzy rule base.

When dealing with sustainability indicators, an essential step is the definition of sustainability standards and as a consequence, the concept of distance from the sustainability standards has to be dealt with. This is a typical example of a fuzzy concept (Zadeh, 1965). Economic assessments are usually represented using a monetary scale whereas environmental assessments are measured in physical units. Sustainability assessments in addition to these monetary and physical units stress on the qualitative units also. Therefore, a model for assessing sustainability must be able to combine quantitative variables, measured in both monetary and physical units, with qualitative variables. The method of Fuzzy Logic includes tools for transforming or normalizing all of the decision variables to a similar scale before making any assessment.

Application

A method of sustainability assessment using fuzzy logic for the mining and mineral sector can be schematically represented as follows:-

Figure 1: The Schematic Representation of the Proposed Method



From the basic principles, criteria of sustainability development and fuzzy reasoning methods, the sustainability indicators of the area where the assessment for sustainability has to be done are developed. The categories of economic, social and environmental subsystems are maintained. Based on the relevant principles and criteria of sustainability normalized values are derived for each indicator. The overall sustainability is then a function of the individual subsystem's *integrity* (the degree to which each sustainability variable fulfills criteria and principles of sustainability). This function will be a combination of rules derived from expert knowledge, the rules being then an expression of the role of interdependencies among the factors of sustainability. There are many ways to qualitatively express fuzzy rules by choosing a specific mathematical representation of the AND, OR and IF-THEN connectives (Tsourveloudis and Phillips, 1998).

Values of indicators would be obtained through various secondary sources as well as primary data collection. Qualitative data would be obtained through knowledge acquisition methodologies like interviews, questionnaires, Delphi method etc (Zadeh, 1973). They are then normalized to obtain a common scale to allow aggregation and to facilitate fuzzy computations.

The fuzzy integrated judgment is based on fuzzy mapping and maximizing the membership degree. The judgment consists of creating a series of fuzzy sets, a fuzzy judgment matrix and conducting a multi hierarchical fuzzy integrated judgment. The degree of membership and weight are determined by Delphi method. Memberships for an indicator given by the experts are then summed to yield a degree of membership after normalizing. Defuzzification is the final operation that converts membership grades into a single crisp value.

This model provides a flexible framework for defining sustainability as a function of a number of variables and at the same time it gives the mathematical machinery to compute numerical values of sustainability and overall sustainability (in percentages) as an end result. The method presented here provides an instrument that enables the interaction between the representations (indicators) and their interrelationships. The method also allows transparency in the definition of weights. It may contribute to the democratization of decisions, as an instrument that equips non specialized social agents to better understand reality.

Conclusion

Sustainability assessment in the mining and minerals sector is difficult to accomplish using the present methodologies. It not only does need a proper analysis of the concepts, principles and criteria, it also demands a methodology which can analyze the ambiguities and can include expert opinion explicitly in the formulation. The model proposed here, using a fuzzy judgment model appears to be capable of incorporating these requirements. Using fuzzy logic the ambiguities, arising from sustainability assessments in the mining and minerals sector is systematically taken care of and the human intelligence (the decisions of experts) is also factored into the assessment. The value obtained gives the overall degree of sustainability of the area under study. The net output from the proposed methodology is a 'crisp number, which assigns value in percentage terms of the extent of the sustainability of the mining activity. Moreover a clear indication is made available of areas (whether social, economic or environmental) that need to be paid attention to improve the overall degree of sustainability in the region.

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