MCDM applications in Sustainability Assessment & Reclamation Practices of Mining Industry

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Abstract – ***Sustainability can be achieved by incorporating the social, economic and environmental aspect in the business. Several sustainability frameworks are used to quantify the contributions of an industry. This article provides an introductory view of total sustainability in mining. Sustainability frameworks and performance indicators used in the mining industry are introduced. Sustainability offers a high-level complexity in its integrated assessment and accounting. Hence, this study asserts in need of multi-criteria decision making (MCDM) and then introduces the MCDM techniques. A study was performed to determine the weights of selected governing parameters of mine reclamation. The application of AHP in the case of selection of best alternative for land reclamation has been presented.***

Keywords— Sustainability in Mining, MCDM, AHP

1. Introduction

The satisfaction of human needs and aspirations is the major objective of development. Development involves a progressive transformation of economy and society. Sustainable development (SD) was defined in 1987 by the World Commission on Environment and Development (WCED) as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. Sustainable development is not a fixed state of harmony, but rather a process of change in which the actions (viz., exploitation of resources, the direction of investments, the orientation of technological development, and institutional change) are made consistent with future as well as present needs [1].

If needs are to be met on a sustainable basis the Earth's natural resource base must be conserved and enhanced. Thus, there is a need of integrating economic activity with environmental integrity, social concerns, and effective governance systems. The total sustainability of human actions or business on this planet has been broadly addressed by representing all concerns under the social, environmental and economic aspects. These three aspects are termed and form the Triple Bottom Line (TBL) attributes (or the Three Pillars) of sustainability.

Based on notions of SD, there has been a transformation in the business and companies to incorporate sustainability development agenda. However, the steps taken by the companies require assessment of achievement of sustainability goals. All information under the TBL must in the form of being accountable, understandable, easy to analyse, interpret and draw conclusions. Besides, it is important for the information to be objective, quantitative as well qualitative, reliable, accurate and following a set of predetermined uniform code. It was in this direction that the initial frameworks of sustainability were formulated. These frameworks indentified a list of crucial sustainable development indicators (SDI).

The Commission of The European Communities posited the concept of corporate social responsibility (CSR) and identified ways to build a partnership for the development of a European framework for the promotion of socially responsible initiatives in the sustainable business [2]. In 2002 the Global Reporting Initiative (GRI) published the Sustainability Reporting Guidelines [3], which aids the practice of measuring, disclosing, and being accountable to internal and external stakeholders for organizational performance towards the goal of sustainable development.

2. Sustainability In Mining Sector

There is a considerable degree of environmental impact associated with most exploration, mining, and mineral processing, and negative impacts can be spread over large areas. Building up from the initial GRI framework, many research contributions were made to place mining sector specific indicators of sustainability development. Under the International Council on Mining and Metals (ICMM), the Mining, Minerals and Sustainable Development (MMSD) framework identified the key sustainable development principles in the context of mineral sector. In the context of mining and metals industry, GRI framed the guidelines for sustainability reporting. GRI identified the performance indicators under economic, environmental and social aspects for the mining industry and laid emphasis on gathering reliable data for comparing mining organizations [4]. Some research work towards addressing sustainability include work by Lins (2007), Hilson (2003), Ripmeester (2003), Shields (2003), Turner (2003), Saini (2016).

3. SUSTAINABILITY FRAMEWORK IN MINING

Five sustainability frameworks generally used by the mining companies have been compared, viz., Global Reporting Initiative (GRI) and the Toward Sustainable Mining (TSM), Seven questions to sustainability (7QS), Innovation and technology driven sustainability performance management framework (ITSPM) and Adisa Azapagic's framework [11].

The sustainability assessment by these frameworks involves considering the various indicators in isolation. The many trade-offs and synergies among sustainability dimensions are largely overlooked in the frameworks. The indicators cannot be aggregated into an overall index indicative of ''sustainable development''. The sustainability has been assessed by using the non-integrated indicators, more so on a planetary scale. Today, mining companies genuinely interested in understanding their potential contributions to sustainability have no other choice but to adopt a combination of existing assessment frameworks. This does not reveal an overall sense of sustainability, but fragmented information.

For the mining sector, there is high complexity of addressing TBL especially at local scale. Research into the performance indicators of sustainability suggests innumerable alternatives to be assessed, compared, both in qualitative and quantitative measures, besides the difficulty of handling varying dimensions. Such case of variability and complexity has been effectively handled using the multi-criteria decision making (MCDM) models.

4. MCDM IN MINING SECTOR

Multi-Criteria Decision Analysis/Making (MCDA/MCDM) is a process that allows one to make decisions in the presence of multiple, potentially conflicting criteria. MCDM methods have different underlying assumptions, information requirements, analysis models, and decision rules that are designed for solving a certain class of decision making problems. MCDM is concerned with structuring and solving decision and planning problems involving multiple criteria. The decision matrix and preference information are the main input data utilized to solve the decision problem. There is no longer a unique optimal solution to an MCDM problem but comprises of the set of non-dominated solutions. MCDM techniques perform the evaluation of explicitly known alternative solutions or can help in arriving at an alternative solution by solving a mathematical model. Mathematical techniques include vector maximization, interactive programming, value function analysis, fuzzy set analysis, and multi-objective optimization.

Some of the dominant methods applied in mining sector include Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Data envelopment analysis (DEP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Fuzzy-TOPSIS.

5. MCDM APPLICATIONS IN MINING

Coal mining activities lead to environmental changes. A study was conducted on assessing the environmental impacts due to mining in Jharia coal field [10]. The results assert that the parameters that are the most affected due to mining are air, water, soil, agricultural land, vegetation and, topography. Analytical Hierarchy Process (AHP) has been used for prioritizing of these parameters. Upon analysis, air has been found to be the most affected followed by water, soil, vegetation, agriculture and topography.

A study was conducted to provide a comprehensive framework for green supply chain practices and its introduction in the Ghana mining industry [16]. The framework separates the practices into six major factors groupings including Green Information Technology and Systems, Strategic Suppliers Partnership, Operations and Logistics Integration, Internal Environmental Management, Eco-Innovation Practices, and End-of-Life Practices. These factors were separated into 30 sub-practices. The framework was applied using two-stage MCDM methodology that comprised of rough set theory and fuzzy-TOPSIS model.

The TBL was represented by 63 elements for sustainability analysis in the Indian mining industry [12]. These elements were categorized under 18 sub-criteria (level-three criteria). Out of these 63 elements, 17 were found to fall under the "soft" category and 46 under the "hard" category. AHP was deployed to identify the relative importance of various criteria, sub-criteria, and attributes that are critical for the effectiveness of GSCM implementation in the Indian mining industry. The AHP results indicate that all of these 63 elements do not have equal impact on GSCM effectiveness. The empirical study also indicates the degree of influence of "soft" and "hard" criteria on GSCM implementation. The study explores that Indian mining industries give less emphasis to "soft" factors (human resource factors), whereas a significant number of researchers conclude that human resources—being the executers of any program—decides its success; hence, it should be given significant weightage.

A study developed a measure for sustainability of exploration phase of mining in Finland [13]. Data Envelopment Analysis (DEA) is used to combining economic, ecological and social variables with DEA to produce one index for every exploration site studied. This index, between zero (0) and one (1) is called sustainability score of the given exploration site. It takes into account six variables affecting the sustainability of exploration phase of mining. These results reflect the fact that some exploration sites are more effective in the sense of sustainability.

Performance Evaluation of coal enterprises based on the energy conservation and reduction of pollutant emissions has been performed by gray correlation degree (GRD)-TOPSIS technique [14]. Three coal enterprises are evaluated on the basis of activities towards energy efficiency and reduction of emissions.

The Ultimate Pit Limit (UPL) design is an important step in open pit mining. The objective function for UPL determination is usually maximization of profit (economic aspect) that satisfies the mine owners and shareholders. TOPSIS method is used to develop a model for integrating the TBL into the design process of UPL in a copper mine. This TOPSIS model based on SD concepts lead to a larger pit than traditional method of profit optimization.

6. AHP METHOD FOR RECLAMATION PRACTICE IN MINING

The *Analytic Hierarchy Process (AHP)* is due to *Saaty* and quite often is referred to as the *Saaty method*. It is popular and widely used, in decision making and in a wide range of applications. Decision situations to which the AHP can be applied include [16]:

- Choice – The selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.
- Ranking – Putting a set of alternatives in order from most to least desirable
- Prioritization – Determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them
- Resource allocation – Apportioning resources among a set of alternatives
- Benchmarking – Comparing the processes in one's own organization with those of other best-of-breed organizations
- Quality management – Dealing with the multidimensional aspects of quality and quality improvement
- Conflict resolution – Settling disputes between parties with apparently incompatible goals or positions

The AHP process involves three phases –
Phase-1 Conversion of the decision problem into a structural hierarchy
Phase-2 Collection of data and development of judgmental matrix
Phase-3 Determination of priorities by computation of normalized weights

The relative values (from 1 to 9) of a set of attributes are provided by the experts using the Saaty Scale [17].

Table 1: The fundamental scale of absolute numbers, Saaty Scale

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement 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 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
Reciprocals of above	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*	

This may be performed by considering four different standpoints: the benefits (*B*), that the decision brings, the opportunities (*O*) it creates, the costs (*C*) that it incurs and the risks (*R*) that it might have to face (or BOCR). The relative importance of attributes is converted to determining judgment matrices, through the procedure of matrix calculations, Eigen value computations and determination of consistency ratio. This ensures in checking the consistency of the evaluations made by the decision maker.

Besides this, AHP can be modified, e.g. the fuzzy AHP, to provide freedom to the experts to express their judgments through natural languages.

7. CASE STUDY IN MINING INDUSTRY

Reclamation practices involve revitalizing the degraded lands and bringing it back to its original or better state, especially with the view to make it amenable for a future end-use. In most cases, the mining lands are returned in the form of agricultural land, forest land, plantation, and water reservoirs.

The engineer faces the task of ascertaining the land regeneration options and then weighing them for their applicability under the changing site conditions. To select the most suitable option among reclamation projects, a multi-criteria decision-making process is developed. The AHP method is applied to analyze select governing criteria for determining the best possible alternative method of reclamation. In this study, it was attempted to use the AHP tool and determine the characteristic Weightage and hierarchy of the selected criteria. The criteria selected for the assessment of reclamation practice are - Dump characteristics, Climate, Topography, Soil Management, Ground Water, Soil Toxicity, Soil Limiting Factors. Applying the tool, the assessment resulted in the following weight distribution.

Dump characteristics	0.337
Climate	0.132
Topography	0.066
Soil Management	0.138
Ground Water	0.112
Soil Toxity	0.112
Soil Limiting factors	0.102

The above analysis was performed using inputs from five independent coal mining executives. The pairwise comparison matrices were developed and the weights given by the five decision makers were averaged. Eigen vector computations yields a consistency index within 0.1.

Based on the above analysis, it can be visualized that the dump characteristics plays a major role in the decision making towards the selection of a particular mining reclamation method. Also, it is observed that soil management in conjunction with ground water shall provide an enhanced contribution towards the final selection of the method.

Conclusion

The GRI framework provides basic guidelines of reporting the sustainability in mining industry. AHP tool helps in assessing the sustainability. This tool has been extended in its use towards the decision making in the mine reclamation studies. It has been observed from this study that the complexity offered by large number of criteria in the process of decision making can be handled by using MCDM.

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