International Journal of Mining Science and Technology 28 (2018) 259–265

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

A new hybrid decision support tool for evaluating the sustainability of mining projects

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ARTICLE INFO

Article history:
Received 9 January 2017
Received in revised form 3 March 2017
Accepted 10 May 2017
Available online 29 July 2017

Keywords:
Sustainable development
Multi-criteria decision analysis
Indicators
Stakeholders
Rare earth elements

ABSTRACT

The integration of sustainable development challenges and opportunities into the decision making process during the design and/or implementation of multi-disciplinary mining projects is generally not supported by decision support systems (DSS). A new hybrid decision support tool, which features an integrated assessment of sustainable development issues as they apply to mining projects, is hereby proposed. The proposed DSS framework, named "Acropolis DSS", can be used to assist involved stakeholders in critical decisions, especially when addressing issues such as stakeholder participation, transparency, and trade-offs. The proposed DSS is based on a multi-criteria decision analysis combined with the multi-attribute utility theory.

1. Introduction

Sustainable development (SD) is the development that "...meets the needs of the present without compromising the ability of future generations to meet their own needs (...). Such equity would be aided by political systems that secure effective citizen participated in decision making and by greater democracy in international decision making...", as stated in the *Report of the World Commission on Environment and Development*, United Nations, in 1999 [1]. Furthermore, a "sustainable path" (SP) towards SD is described as "one that allows every future generation the option of being as well off as its predecessors", as stated in the *Commission on Geosciences, Environment, and Resources*, of the US National Research Council (NRC), in 1994 [2]. In accordance to the European Commission priorities, sustainable development is a fundamental objective of the European Union (EU) under the Lisbon Treaty, stated in *Mainstreaming Sustainable Development into EU Policies: Review of the European Union Strategy for Sustainable Development*, Commission of European Communities, in 2009 [3].

The 2030 Agenda for sustainable development of the United Nations set out 17 sustainable development goals (SDGs) with 169 associated targets [4]. This Agenda is a plan of action for people, prosperity and the planet. All countries and all stakeholders, acting in collaborative partnership, should consider implementing this Agenda. These SDGs and targets will stimulate action over the next 15 years in areas of critical importance for humanity. Quality, accessible, timely and reliable disaggregated data will be needed to help with the measurement of the progress. In accordance to the UN 2030 Agenda, such data is considered a key to decision making for SD. As stated in *Transforming our World, the 2030 Agenda for Sustainable Development,* United Nations, in 2015, the Agenda called upon all private business, from micro-enterprises to cooperatives and multinationals, to apply their creativity and innovation to solving sustainable development challenges.

In addition to these challenges, the extractive industry may be confronted by the unwanted effects of environmental policy mechanisms, energy efficiency issues related to specific operational processes, such as loading and hauling or the environmental effects caused directly by the excavation process, and low carbon issues associated with production, supply chain and operations management perspectives [5–8]. As a result, decision making is becoming a complex process that should utilize logic and inclusive reasoning to make informed decisions based on available information. Decision making is not a straightforward procedure; the right decisions and selection of optimal alternatives are not easy and demand time [9]. When applied to SD, this vital process involves evaluation of a number of outcomes within a social, economic and environmental framework, although many times balancing social, economic, and environmental costs and benefits can be a subjective process. In any case, such assessments should

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http://dx.doi.org/10.1016/j.ijmst.2017.07.001
2095-2686/

eventually promote responsible and sustainable development—a core aim of many international policies [10].

Furthermore, the "Social License to Operate" has become an important prerequisite for the extractive industries, since it helps minimize the business risks related to probable social unrest or opposition stemming from the realization of mining projects. Research has shown that in order to achieve a more socially sustainable mining industry, where social conflict around mining operations is minimized and the public is able to experience the benefits of resource development, both the mining industry and governments need to review their methods of engaging with citizens to build trust in those stakeholder relationships [11]. Society is today sensitive in the case of environmental protection, transparency and means of communication and has adopted a general pro-environmental behavior; this may cover a wide range of initiatives spanning from large mining projects to personal consuming habits. Furthermore, consumers require information that will help them judge the value of environmentally conscious products by themselves and put more emphasis on the transparency of label certification results than the involvement of experts [12].

The tools that can potentially contribute to the assessment of SD and support decision making have been divided into three main categories: (1) indicators and indices, (2) product related assessment, and (3) integrated assessment [13]. Typically, such indicators can be non-integrated (e.g., environmental pressure indicators), regional flow indicators (e.g., based on an input/output analysis) or integrated (e.g., representative of a well-being index). The second category includes product related tools that focus on flows in connection with production and consumption of goods and services. Finally, the third category of tools is used for supporting decisions related to a policy or a project in a specific region. A decision support system (DSS) is defined as a software based tool assisting in the decision-making process by interacting with both internal and external users and databases, while utilizing standardized or specific algorithms for problem solving [14,15]. Multi-criteria decision-making (MCDM) "deals with a general class of problems that involves multiple attributes, objectives and goals" [15,16]. This paper proposes a new hybrid DSS tool which is based on an integrated indicators-based SD assessment process for supporting decision making in mining projects. The developed DSS tool combines baseline indicators, i.e., evaluated before starting up a project, and indicators evaluated during project implementation and after project completion. The tool considers local, regional, country, and international conditions during these three distinct time frames. For example, project stakeholders can compare the economic activity in an area before starting up a project to the economic levels achieved during project implementation as well as after the project has been completed. Thus, any advantages and disadvantages with respect to SD principles can be easily outlined. In addition, this work integrates the proposed DSS with the sustainable development framework presented and discussed in previous works [17,18].

This paper is organized as follows: the background section reviews and discusses different DSSs that have been proposed in a sustainable development context as applied to the energy sector, the extractive industries and some industrial systems that have an environmental component; sustainable manufacturing, which is an emerging discipline, is not discussed here. Subsequently, the developed DSS model, which incorporates different SD indicators as applied to mining projects with respect to sustainable development challenges and opportunities, is presented. The proposed system, named "Acropolis DSS", can be used to assist involved stakeholders in critical decisions, especially when issues such as stakeholder participation, transparency and trade-offs are addressed. The proposed DSS is based on a multi-criteria decision analysis (MCDA) combined with the multi-attribute utility theory (MAUT). Multi-criteria decision analysis methods have been developed to support decision makers in their unique and personal decision process; MCDA is a discipline of operations research that encompasses mathematics, management, informatics, psychology, social science and economics [19]. The multi-attribute utility theory is based on the main hypothesis that every decision maker tries to optimize, consciously or implicitly, a function which aggregates all their points of view [19]. In MAUT, the decision maker's preferences can be represented by a function, called the utility function [20]. This function is not necessarily known at the beginning of the decision process, so the decision maker needs to construct it first. Finally, the conclusions of this study are presented and future research initiatives are discussed.

2. Background

The concept of applying a DSS with respect to SD principles in technical projects is not new. In this section, several such systems are evaluated as published in the international literature. However, none of these systems has been directly applied to mining projects.

Two such models, which address stakeholder input, have been recently proposed. The first one developed a DSS based on MCDA to promote community involvement in the case of mining projects [21]. The MCDA which was used to assess the most relevant factors for stakeholder strategy evaluation, includes perspectives upon which new alternatives might be developed, and assesses these alternatives based on multiple economic and social criteria. The preference function assigned to each criterion illustrates how each stakeholder changes his/her preference with the difference in performance level for two alternatives. A multi-criteria preference index was created by the weighted average of the corresponding preference functions for each criterion utilizing the weighting factors assigned previously by each stakeholder to every criterion. Although the model is based on the three SD pillars (social, economic, environmental) it is only focused on the preliminary stage of mining projects and does not cover the mining stage and the stage following the completion of a mining project. The model follows the "people-first" approach to support the involvement of local communities before a mining project is initiated and especially at the design stage. Also, the model does not intend to incorporate the criteria and indicators utilized into the broader SD policy context i.e., the achievement of the United Nations SDGs as they were stated at the UN 2030 Agenda for sustainable development [4].

The second model was proposed by Poplawska et al. who created a DSS utilizing fuzzy logic in order to assess and categorize stakeholders involved in an SD process in a set of groups [22]. In order to categorize the stakeholders in groups, their importance was evaluated by indicating the exact degree of membership to a particular interest group. The fuzzy set theory allows intermediate degrees of membership between elements in a given set. Membership is defined based on criteria which are selected from a list of attributes and is assessed by the decision maker. Thus, by calculating fuzzy scores for every stakeholder, the model provides the ranking of stakeholders. The authors utilized this DSS in order to construct the profile of key extractive sector stakeholders and measure their salience in a corporate social responsibility context.

Similar systems that have been fully or partially applied to the extractive industries include a DSS model developed by Hunt et al. which was based on MCDA and combines two other tools: a decision rationale and a probabilistic forecasting tool [23]. The DSS was applied to the energy sector in order to determine the recommended sources of electricity generation in different locations in the United Kingdom, paying attention to water consumption and water purification using hybrid power and desalination plants.

Table 1
Description of DSSmodels.

Reference	Method	Applied technique	Sector
Hunt et al. [23]	MCDA	Weighted sum model	Energy
Poplawska et al. [22]	Optimization	Fuzzy logic–Weighted sum model	Extraction industry
Erzurumlu and Erzurumlu [21]	MCDA	Preference ranking organization	Extraction industry
Ruiz et al. [26]	MCDA	Fuzzy logic–Analytical hierarchy process–GIS platform	Planning & Design
Mattiussi et al. [15]	Optimization	Multi-objective multi-attribute mathematical model–Analytical hierarchy process	Planning & Design
Paraskevas et al. [25]	LCA	Mathematical programming	Sustainable manufacturing

For the MCDA tool, the weighted sum model was utilized based on Fishburn [24]. The decision rational tool was based on the methodology of issue based information systems (IBIS). For the probabilistic part of the DSS, a time series methodology involving the mean absolute deviation (the average difference between the data and the forecast) in order to create a range of predicted values and their probabilities, was used. This was done because the researchers claimed that a decision taken today may not be the recommended decision in a month's time, and the ability to anticipate changes or analyze risks is a key to empowering people to make better decisions in the future.

Mattiussi et al. created an energy supply DSS for sustainable plant design and production. The authors used multi-objective and multi-attribute decision-making modeling together with impact assessment of the emission outputs [15]. The proposed model consisted of three major decision-making steps: (1) problem classification/definition, (2) alternative generation/evaluation, and (3) alternatives negotiation/selection and action determination. In the first step, the environmental impact assessment was used in order to evaluate the total EIP emissions' inventory and impacts. In the second step, a multi-objective mathematical model, including economic and environmental objectives in a Pareto-frontier, was utilized to evaluate different scenarios of combined heating and power plants (internal combustion engine, gas turbine, micro-turbines and fuel cells) and two types of photovoltaic plants. In the third step, the model utilized a multi-attribute method (Analytic Hierarchy Process) for selecting the best alternative among the Pareto-frontier efficient solutions. The model was applied to a case study of an Eco-Industrial Park located in Perth, Western Australia.

Paraskevas et al. developed an environmental assessment tool aiming to support decision making related to the sustainable management of metal resources during secondary aluminum production. This tool aimed to the minimization of material downcycling and maximization of scrap usage [25]. The DSS was based on Life Cycle Assessment tool as described by the *14040 Environmental Management-Life Cycle Assessment-Principles and Framework*, International Organization of Standardization, in 2006. The DSS aimed to facilitate environmental impact calculations, express material, dilution and quality losses during aluminum recycling in LCA studies, and determine from an environmental point of view the optimal metal inputs for the aluminum recycling process. The model considered the composition of the metal inputs and the desired target aluminum specifications and also took into account the material input/output interconnections, focusing on the contamination of the scrap streams by the residuals that pose a great challenge in aluminum recycling.

Ruiz et al. developed a spatial DSS based on a geographic information system (GIS) platform for planning sustainable industrial areas [26]. The system was applied to a district of 646.2 km^2 located in Cantabria (Northern Spain). The model was based on the previous work by Fernandez and Ruiz which included more than two hundred SD variables [27]. The new model used fewer variables (75) that were selected through various meetings and group discussions with the stakeholders involved. First, the evaluation and selection of suitable geographical areas was conducted. Then, the defined variables were evaluated according to criteria and reference values using fuzzy logic functions that normalize the results between 0 and 1. The weighting factors of the criteria were obtained using the analytical hierarchy process. The GIS platform allowed the development of digital maps for existing areas that can be evaluated, while the different zones can be distinguished according to their suitability for the siting of potential industrial areas. Table 1 presents a summary of the above mentioned models.

Despite the aforementioned research efforts into the SD-DSS field, to the best of our knowledge, there is currently a lack of a complete DSS framework, tool or method that can be used to approach the sustainability concepts in a holistic manner, as these have been described and recommended by the UN 2030 Agenda for sustainable development [4].

To fulfill this gap, this paper proposes a state-of-the-art DSS which allows decision makers to evaluate multiple options that may offer alternate solutions in "Go-No-Go" situations. The proposed DSS is based on the MCDM theory and is dynamic in that it allows flexibility for decision makers and stakeholders, depending on the project being evaluated.

3. Methodology

As already mentioned, the "Acropolis DSS" presented in this paper is based on a MCDA and on the MAUT. The DSS was constructed in Microsoft Excel™ 2013 environment and its core is based on criteria and indicators in order to assist decision makers/stakeholders to better assess the impact of a mining project from the sustainability point of view. The proposed DSS was then integrated into a state-of-the art sustainable development framework (SDF) (Fig. 1) which was previously developed by Kamenopoulos et al. [18].

In summary, the recommended SDF includes five SD pillars (economy, society, environment, technology and geopolitics), three controlling/limiting factors (policy, governance and stakeholders), and a number of output quantities (indicators) to be used in

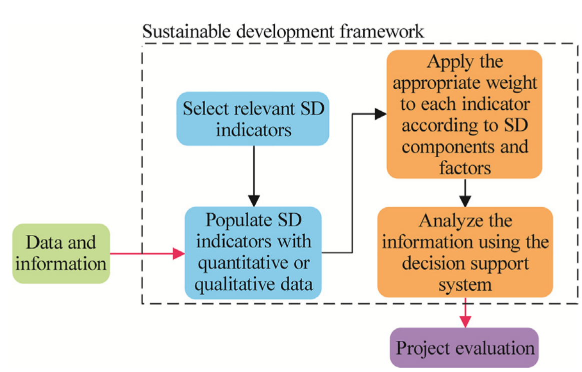

Fig. 1. Integration of the proposed DSS into the recommended sustainable development framework [18].

decision making. Using the recommended SDF facilitates addressing the unique and specific challenges present in mining projects [18,28–30].

Sustainability assessment, from the point of view of multi-criteria analysis, has the following characteristics: multiple stakeholders, with distinctive objectives and preferences; a decision context of quantitative and qualitative aspects; and multiple alternatives with different positive or negative impacts accruing to different stakeholders [17,18]. From the SD point of view, some of the main questions that the decision makers may face when working with project evaluation are:

(1) What are the appropriate processes to be used in order to assess the project?
(2) What are the criteria that should be used and what are their corresponding weighting factors?
(3) Which process should be used to allow different stakeholders to trade-off, negotiate or bargain?
(4) Is this process clear and transparent?
(5) Should a nominated project be completely rejected or can it be re-considered or even approved under a number of modifications? Which are these modifications?
(6) Should any specific level of index/indicators for approval or rejection be established?
(7) How sensitive should the final solution be to specific stakeholder preferences?
(8) Are there provisions that can be implemented to continuously monitor the project throughout its life cycle (before, during and after the project) in a reliable manner?
(9) How should the assessment of multiple projects be handled?

The MCDA is a technique which supports decision makers when they need to compare different alternatives and decide which one should be selected. The MCDA is diachronically used in many different fields and sectors including sustainable development [31–35]. The MCDA incorporates mathematics, management, informatics, psychology, social science and economics [19]. One of the basic attributes of the MCDA is the participation of stakeholders at the decision making through the negotiation process (trade-offs) [36]. This attribute has made the MCDA a very attractive analytical tool to support decision making processes. In addition, the MCDA integrates unique and personal decision making practices of individual decision makers [19].

The MAUT was created by Keeney and Raiffa [20]. In the MAUT, the preferences of the decision makers are described by a utility function, which expresses the level of preference that a decision maker has on a set of alternatives. The alternatives are compared under specific criteria (attributes). Every criterion has its own weighting factor. The most common MAUT method is the additive model which is represented by the following equation [19].

$$V_j = \sum w_i p_{ij} \tag{1}$$

where V_j is the aggregate score of the jth alternative; p_{ij} is the score of the jth alternative on the ith criterion; and w_i is the weighting of ith criterion.

A basic constraint of MAUT dictates that the sum of all criteria weighting factors should be equal to one as shown by Eq. (2).

$$\sum w_i = 1 \tag{2}$$

The relevant importance of each criterion is expressed by its own weighting factor under the preference of the decision makers. The Simple Multi-Attribute Rating Technique (SMART) is a technique which calculates the criteria weighting factors; the technique was developed in 1977 and improved in 1994 [37,38]. SMART calculates the weighting factors in two phases: during the first phase, the decision-makers are asked to rank the criteria according to their own preferences, from the most to the least important. In the second phase, a number of points (typically 10), is allocated to the least important criterion. Subsequently, 10 additional points (i.e., a total of 20 points) are allocated to the second least important criterion and so forth until all criteria have been allocated with points accordingly. To normalize the total score and comply with the constraint of Eq. (2), the points allocated to each criterion are divided by the total number of allocated points [35].

In the case of the recommended SDF, the selection of criteria and indicators was based on available literature, taking into consideration the particularities of specific projects as well as the indicators listed by the World Bank [17,39–43].

Weighting factors are assigned not only to the criteria but to the sustainable development pillars as well. This is due to the fact that each SD pillar may have a different relative importance for each stakeholder. The SMART technique was modified for the calculation of the weighting factors: initially, the weighting factors of SD pillars, and then, the weighting factors of the criteria (indicators) were calculated. Eqs. (1) and (2) were modified as shown by Eqs. (3)–(5) to fully correspond to the additional weighting factor calculations:

$$V_j = \sum b_k w_i p_{ij} \tag{3}$$

where V_j is the aggregate score of the jth alternative; p_{ij} is the score of the jth alternative on the ith criterion; w_i is the weighting factor of ith criterion; and b_k is the weighting factor of kth pillar;

The constraints are:

$$\sum w_i = 1 \tag{4}$$

$$\sum b_k = 1 \tag{5}$$

Actually, parameter V_j represents the total score of sustainable paths for the mining project. Thus, the total scores of four sustainable paths were calculated: the total score of the ideal sustainable path (SPI), the total score of the sustainable path before project start (SPB), the total score of the sustainable path during project implementation (SPD), and the total score of the sustainable path after project end (SPA).

The ideal sustainable path represents the optimum level of sustainable development and was defined through trade-offs between stakeholders. The stakeholders need to decide through negotiations about the ideal (desired) value of indicators. Fig. 2 describes the process of decision making. In all stages of this process, the stakeholders have the ability to trade-off. In addition, stakeholders have the ability to continuously monitor the sustainable path during project implementation. When a project is evaluated from the SD point of view, it should be categorized based on the magnitude of its potential environmental, social, economic, technological and (geo) political impacts. Such ranking is based on the categorization process described in Fig. 2.

A project's environmental, social, economic, technological and (geo) political due diligence may be considered proportionate to its the nature, scale and stage of the project, and to the level of potential impacts. The following sustainable development indices can then be determined:

$$\text{“ACROPOLIS 1”} = 100(\text{SPA} - \text{SPI})/|\text{SPI}| \tag{6}$$

$$\text{“ACROPOLIS 2”} = 100(\text{SPA} - \text{SPB})/|\text{SPB}| \tag{7}$$

$$\text{“ACROPOLIS 3”} = 100(\text{SPA} - \text{SPD})/|\text{SPD}| \tag{8}$$

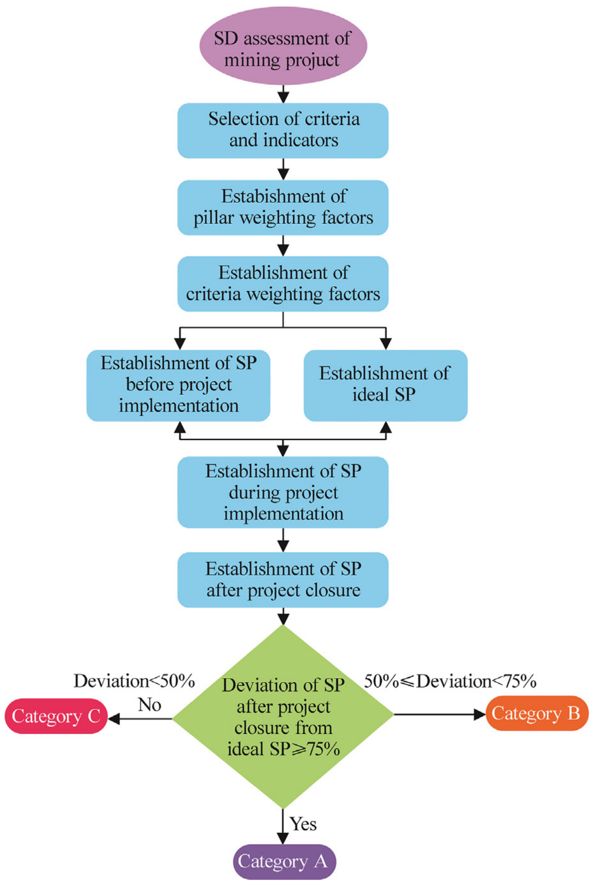

Fig. 2. "Go-No-Go" decision making process for project assessment from the sustainable development point of view.

For the purposes of this paper, and based on previous work [17,18], three project categories have been arbitrarily selected as follows:

(1) Category A ("green code"): projects with "Acropolis 1" index ≥ 75%. This means that the "total score of the sustainable path after project end" is at least 75% of the "total score of the ideal sustainable path". In that case, the project has a considerable positive impact in all SD pillars and, thus, it may be evaluated as "Go".
(2) Category B ("orange code"): projects with 50% ≤ "ACROPOLIS 1" index < 75%. Negligible modifications should be proposed to minimize, mitigate and offset minor negative impacts. The project has the potential to be re-assessed.
(3) Category C ("red code"): projects with "Acropolis 1" index < 50%. These projects may have significant environmental, social, economic, technological and geopolitical negative impacts that cannot be currently accepted. Critical changes and modifications are needed before re-evaluation. This evaluation should lead to a "No Go" decision.

Indices "Acropolis 2" and "Acropolis 3" may be utilized by stakeholders as complementary to monitor decision supporting tools. The process that the stakeholders utilize to assign weighting factors for the pillars and criteria (indicators) has five stages:

- In the first stage, the stakeholders rank the pillars in terms of their importance from 1 to 5, by assigning an "1" value to the pillar that is most important, and a "5" to the least important.
- In the second stage, a fixed number of 10-points are automatically assigned to the least important pillar (pillar ranked as "5"). Then 2 × 10 points are assigned to the second least important (pillar ranked as "4") and so on. During the third stage, the pillar scores are normalized to one in order to obtain the final pillar weighting factors. The scores are normalized by dividing the points assigned to each pillar by the total number of allocated points.
- In the fourth stage, the average pillar weighting factors are calculated for all pillars: the sum of each pillar weighting factor is divided by the number of stakeholders.
- In the fifth and final stage, the same process is repeated for the establishment of the weighting factors for indicators. The only difference is that during this process the stakeholders rank the indicators in terms of their importance from 1 to 10 by assigning a "1" to the indicator that is most important, and a "10" to the least important indicator.

During this process, there are three available levels (opportunities) for trade-offs between stakeholders. At the first level, the stakeholders need to agree on the type of the impact (positive or negative) of each criterion (indicator). At the second level of trade-offs, the stakeholders have the chance to modify their initial preferences on the weighting factor for each pillar. At the third level of trade-offs, the stakeholders have the opportunity to modify their preferences for the weighting factor of each indicator.

After this process, the stakeholders need to agree on the establishment of the current sustainable path by providing the actual current values of indicators (values before the mining project starts). After that the stakeholders need to agree on the establishment of the ideal sustainable path by providing ideal (expected) values of the indicators. During these two processes the stakeholders have another opportunity for trade-offs (fourth level of trade-offs): the stakeholders actually decide mutually which are the desired sustainable paths. Finally, the Acropolis 1, 2, and, 3 indices are calculated.

As it was previously mentioned, the UN's official definition of sustainable development prerequisites the conditions of "...effective citizen participation in decision making and by greater democracy in international decision making...". The proposed "Acropolis DSS", through its five stages of assigning weighting factors to pillars and its four trade-off levels, provides several degrees of freedom to stakeholders for "effective citizen participation". Therefore, the likelihood of companies to gain and retain the "Social License to Operate" is assessed. This is not a "white collars-cost" oriented tool. It is rather a "value" oriented tool, where stakeholders are encouraged to incorporate and directly or indirectly express their "value" for the stake of the project.

Furthermore, the proposed "Acropolis DSS" provides the ability to quantify and measure the US NRC's term of "sustainable path" which was described in the *Commission on Geosciences, Environment, and Resources*, of the US National Research Council (NRC), in 1994 [2] as "...one that allows every future generation the option of being as well off as its predecessors...". As a result, it provides a meaningful quantitative interrelation and interconnection between the SD pillars. Additionally, it provides the ability to measure other essential SD pillars such as: geopolitics and technology. These SD pillars, although not recommended by the UN, they are considered extremely important in today's globalized business environment.

The proposed "Acropolis DSS" framework is in a prototype stage. At this stage there are not sufficient actual data available from existing projects to support a sensitivity or parametric analysis. However, if this system is accepted and utilized as a decision making support system, a parametric analysis should be conducted to study its performance by allowing specific parameters to obtain

Table 2
Arguments for and against the implementation of the proposed "Acropolis DSS".

For	Against
It provides the stakeholders with the opportunity for transparent, free decision making and democratic negotiations	No sufficient data yet available for testing/prototype stage
It quantifies and measures the US NRC's term of "sustainable path" which was described as "...one that allows every future generation the option of being as well off as its predecessors..."	No sufficient data yet available for testing/prototype stage
It complies with the UN's SD prerequisite for "...effective citizen participation in decision making and by greater democracy in international decision making..."	No sufficient data yet available for testing/prototype stage
It contributes in gaining and retaining "Social License to Operate"	No sufficient data yet available for testing/prototype stage
It is a "value" oriented tool: stakeholders are encouraged to incorporate and directly or indirectly express their "value" on the stake of the project	No sufficient data yet available for testing/prototype stage
It is designed to support all three stages of a project: before, during and after project's termination	No sufficient data yet available for testing/prototype stage
If modified, it may include any number of SD pillars	It was built for five SD pillars; Need modifications/prototype stage
If modified, it may include unlimited number of stakeholders	It was built for five stakeholders; Need modifications/prototype stage
If modified, it may include unlimited number of indicators	It was built for 10 indicators per each pillar; Need modifications/prototype stage.
If modified, it could also incorporate financial indicators	Not designed to assess projects from their financial/economic value
It incorporates qualitative and quantitative indicators	No sufficient data yet available for testing/prototype stage
If modified, it may be applicable in any project, not necessarily in mining sector	Need modifications/prototype stage
Utilizing parametric analysis the stakeholders may be provided with additional useful information	No sufficient data yet available/prototype stage

extreme values. For example, if a "Go-No-Go" decision is to be reached for a project, important questions such as the following would be asked:

(1) What would be the influence of a pillar's and/or indicator's weighting factor on the "Go-No-Go" decision making indices?
(2) How would the SP properties change using trade-offs between stakeholders, while maintaining the same total score for the "Go-No-Go" decision making index ("Acropolis 1" $\geq$ 75%)? What tradeoffs should be made in order to double the "GDP per Capita" but maintain the "Acropolis 1" index above 75%? Alternatively, the stakeholders may need to tradeoff and clarify how much they have to modify the SP properties to reduce by half the "Level of Unemployment".
(3) How much an indicator may change in order to reach a 1% increase of the "AcropoliS 1" index?"
(4) If an indicator increases by 1000 units, by what percentage would the "Acropolis 1" index be changed?"

The proposed DSS in its prototype version was designed to include the preferences of five stakeholder groups. It can be easily modified to include a greater number of stakeholders. In the same manner, the proposed DSS was initially designed to support decisions for the five most important SD pillars in order to adapt with the recommended sustainable development framework for rare earth element mining projects; it can be easily modified to include any number of SD pillars. The proposed DSS was designed to incorporate ten SD quantitative and qualitative indicators; however, it can be modified to incorporate a different number of SD qualitative and quantitative indicators [18].

It should be noted that the proposed DSS was not designed to assess mining projects from their financial or economic value, however it can be modified to also incorporate financial indicators and support the assessment of project costs [44]. Finally, the proposed DSS was designed to support all three stages of a project: before the project starts, during project implementation and after the project terminates. Table 2 describes the arguments for and against the implementation of the proposed "Acropolis DSS".

4. Conclusions

The 2030 Agenda for sustainable development of the United Nations set out 17 SDGs that require creativity and innovation to meet SD challenges. So far, a number of DSS models have been applied in several SD concepts utilizing different methodologies and techniques. This paper proposes a state-of-the-art DSS ("Acropolis DSS") which can assist decision makers and stakeholders to evaluate a project and make "Go-No-Go" decisions from the SD point of view. This work integrates the proposed all-purpose DSS into a recommended SDF. The presented DSS is based on MCDA and MAUT, and provides the ability to approach the sustainability concepts of "citizen participation", and "greater transparency" in decision making in a holistic quantified manner, as described and recommended in earlier years by the United Nations. In addition, the proposed DSS provides the ability to trace, quantify and measure the concept of "sustainable path", as defined by the U.S National Research Council.

The innovation of the proposed DSS is evident when considering the following:

(1) It provides stakeholders with the opportunity for transparent, free decision making and open negotiations within several stages of weighting factor calculations and numerous levels of trade-offs as this is required by the definition of sustainable development. These conditions may increase the likelihood of companies to gain and retain the Social License to Operate.
(2) It is designed to properly combine quantified indicators before the implementation of a project and forms the baseline for an SD evaluation during the implementation of any mining project as well as after its end.

The proposed DSS is still in a prototype form, but sets the stage for what needs to be considered when mining projects stall due to a number of conflicts. It is clear that further research is necessary towards the goal of a uniformly accepted DSS for the design and implementation of mining projects under the principles of sustainable development. The authors will continue to develop the proposed DSS and test its applicability to different projects.

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