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Proposal of an indicator-based sustainability assessment framework for the mining sector of APEC economies

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ABSTRACT

The mining sector faces some of the most difficult sustainability challenges of any industrial sector. The mining sector is remarkably significant to the development of the Asia-Pacific Economic Cooperation (APEC) region, because the majority of global trade and investment in this region depends on this sector. Therefore, the assessment of mining sector sustainability at national and global scales in APEC economies is an important task. So far, however, mining sector sustainability assessment frameworks have only been developed at small scales, such as companies and cities. In this study, therefore, it is proposed an indicator-based sustainability assessment framework (iSAF) to assess mining sector sustainability at national and global scales. In this framework, fuzzy logic was utilized to adequately deal with the uncertainty and vagueness of human expressions. The conventional fuzzy scales were suitably modified in the proposed framework to facilitate confident decision-making by the relevant stakeholders. In order to avoid repeatedly conducting the judgment until the acceptable consistency was obtained, iSAF implemented an innovative theory to deal with unacceptable consistencies in judgment. The proposed iSAF was applied to the mining sector of APEC economies using data from the APEC 2010 Project. As for the results, three important criteria including economic, environmental, and social criteria and twenty significant indicators were appropriately selected to cover the actual situation in the sector. The results showed that iSAF was a suitable framework for preventing uncertainty and vagueness in decision-making. iSAF was found to provide crucial support to decision-makers, not only in identifying and structuring the main components contributing to sustainability, but also in pointing out the factors in which significant investment should be made to effectively improve sustainability.

1. Introduction

Sustainable development has been defined as a process that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Described by Moles et al. (2008), sustainability is “an inspirational future situation” and sustainable development is “the process by which we move from the present status quo towards this future situation”. Put simply, economic development for a better standard of living is the main goal of human well-being, but ensuring those activities are not harmful to social and environmental conditions is also extremely important for sustainable development. This concept has become one of the critical global issues for humankind.

The mining sector has been facing some of the most difficult sustainability challenges of any industrial sector (Azapagic, 2004). Although beneficial to socio-economic development, mining activities have caused many adverse effects on social and environmental conditions. In a previous study, we comprehensively reviewed existing research regarding the main contributions of the mining sector to economic development and its undesirable impacts on environmental and social conditions (Bui et al., 2011). The challenges for governments, mining enterprises, and communities are (i) how to balance

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socio-economic benefits and socio-environmental conditions (Worrall et al., 2009); and (ii) how to provide useful information to support decision makers in determining which actions should or should not be taken to effectively improve the sustainability of the mining sector (Haberl et al., 2004).

In order to provide appropriate answers for these questions, mining sector sustainability assessment frameworks have been developed at company and city scales (Singh et al., 2007; Yaylacı and Düzgün, 2016), using Analytical Hierarchy Process (AHP), a popular and powerful Multi-Criteria Decision Making (MCDM) approach. MCDM is considered to be the best method for sustainability assessment (Boggia and Cortina, 2010; Liu, 2007; Shmelev and Labajos-Rodrigues, 2009) using modern tools to help decision makers optimize solutions for sustainable development in the mining industry (Govindan, 2015; Erzurumlu and Erzurumlu, 2015). Specifically, AHP can help decision makers to cope with multifaceted and unstructured problems such as sustainability (Yu, 2002). The assessment frameworks have been developed using indicators, because the indicators can provide information how the company contributes to sustainability (Azapagic and Perdan, 2000). Indicators should be easy to measure, cost effective, accommodate changing conditions, scientifically sound, and based on functional ecological relationships (Worrall et al., 2009). In this way, indicators can provide information for policy makers and aid in decision-making (Niemeijer and de Groot, 2008). Therefore, the indicator-based approach is acknowledged as a useful tool in communicating "simplified, concise and scientifically reliable information on problems of sustainable development" (Haberl et al., 2004).

Most previous studies using AHP approach to evaluate sustainability within mining companies are normally carried out for specific mining products, such as coal and steel (Singh et al., 2007; Si et al., 2010; Yazdi, 2014). Table 1 summarizes the objectives, criteria, and sustainability indicators from a sample of these studies. In these studies, the basic principles are general conditions for achieving sustainability, which may be seen as the ultimate goal. Hence, sustainability is formulated as a general objective to be achieved. The goal may be reviewed as the three fundamental pillars of sustainability including environmental, social, and economic criteria while indicators provide measures of change in the criteria over time. The number of indicators and the selected indicators depend on the specific interests and the certain objectives of each study. So that an indicator's significance can be extended beyond what is actually measured to larger phenomena of interest.

Specifically, in the Asia-Pacific Economic Cooperation (APEC) region, the mining sector is remarkably significant to development, because the majority of global trade and investment here depends on the mining sector. APEC has a series of global mining industrial leaders including Russia, Australia, China, Peru, Indonesia, Canada, and the United States. Minimizing the possible adverse environmental impacts along with a focus on socio-economic conditions is thus important to ensure the sustainable development of APEC. Thus, there is a need to develop sustainability assessment frameworks for the mining sector of APEC economies that are at national and global scales. To date, however, there have been no studies dealing with the development of sustainability indicators for the mining sector at large scales including national and global scales. There are also no studies regarding sustainability assessment frameworks for the mining sector as a whole, as opposed to a specific mining product. Furthermore, most previous studies utilized the AHP approach, in which the comparison judgments were based on crisp numbers. The conventional AHP approach is criticized for its limited ability to capture vagueness, which is due to its dependence on crisp numbers. It is difficult to extract precise data pertaining to measurement factors because human preferences normally include a degree of uncertainty and it is unrealistic to expect that decision-makers have either complete information or a full understanding of all aspects of the problem (Boender et al., 1989; Nurmi, 1981). Consequently, the AHP's numerical comparison scale does not effectively reflect human thoughts (Levary, 1998; Ribeiro, 1996; Zimmermann, 1987). Besides, dealing with the unacceptable consistencies that may arise in AHP comparison judgments, the method normally used was to repeatedly conduct the judgments until the acceptable consistency is obtained (Saaty, 2000; Shen et al., 2015). Repeatedly conducting judgments is time-consuming and unfeasible. Therefore, there is a need to develop a sustainability assessment framework for the mining sector at large scales using the indicator-based approach, considering vagueness and consistent judgments.

In order to evaluate the sustainability for the mining sector of APEC economies, in this study, an indicator-based sustainability assessment framework (iSAF) for the mining sector at global and national scales is proposed. We utilized some unique data from the project, "Balancing competing demands of mining community and environment to achieve sustainable development in mining sector", financially supported by APEC during 2009–2011 (hereinafter referred to as the APEC 2010 Project). In this assessment framework, indicators were used to provide the information on how the sector contributes to sustainability. The first objective of iSAF is to identify the main components (criteria and indicators) contributing to the sustainability improvement using AHP approach. Sustainability, the final goal of the development process, is placed at the highest level; criteria, the main aspects of the sustainability concept and target interests are placed at the second level; and finally, sustainability indicators are placed at the lowest level of the framework. The second objective of iSAF is to evaluate and prioritize the contributions of the criteria and indicators to sustainability improvement. To achieve this, a classical AHP extension, the fuzzy AHP approach, was utilized with a suitably modified conventional scale to facilitate confident decision-making by the relevant stakeholders. Besides, iSAF implemented an innovative theory to deal with unacceptable consistencies in judgment.

2. Methodology

2.1. The AHP and fuzzy AHP

Developed by Saaty and Vargas (1987), the main advantage of the AHP is to decompose a decision problem into a hierarchy of more easily comprehensible sub-problems, each of which can be analyzed independently. Then, such sub-problems are expanded into their behavior elements. In the AHP, the performance ratings and the weights of the attributes result from a series of pairwise comparison judgments between two attributes at the same level of the hierarchy, which are given in crisp numbers from 1 to 9. With the strong foundations in mathematics, psychology and philosophy, the AHP has been successfully applied in a wide range of multidisciplinary areas in both public and private sectors worldwide since its creation in the 1980s (Ho, 2008; Wong and Li, 2008). However, crisp numbers have limitations in dealing with uncertainties of human preferences because this numerical comparison scale does not effectively reflect human thought (Levary, 1998). Extending the concept of the AHP to the fuzzy environment is thus necessary to solve the MCDM problems with uncertain data, resulting in a fuzzy AHP.

In order to deal with the vagueness of human thoughts, Zadeh (1965) introduced the fuzzy theory, which was oriented to the rationality of uncertainty. Following on from Zadeh (1965), there were a number of studies suggesting that fuzzy numbers could be used to effectively handle the uncertainties of subjective evaluations affecting sustainability management processes (Zhou et al., 2014; Li et al., 2010). The combination of fuzzy theory and the AHP approach, called fuzzy AHP, is an extension of classical AHP. While there have been a massive number of fuzzy AHP applications to various multi-sided fields including economic, environmental, social, and sustainability issues (Biju et al., 2015; Calabrese et al., 2013, 2016; R.H. Chen et al., 2015a, J.F. Chen et al., 2015b; Kahraman, 2008; Larimian et al., 2013; Rajak and Vinodh, 2015; Torfi et al., 2010; and so on), there have been

Table 1
Sustainability assessment framework for the mining sector at company and city scales.

Previous study	Main objective	Product/ Scale	Selected Criterion	Sustainability indicator
Krajnc and Glavic (2005)	To design a sustainable development framework by AHP	a widely diversified product portfolio)/Company	Economic performance	6 indicators: sales operating profit, investment capital expenditures, net earnings, research and development costs, and number of employees;
			Environmental performance	22 indicators: greenhouse gas emissions, emission of heavy metal into surface water, waste, energy consumption, production mass, and so on.
			Social performance	10 indicators: number of occupational accidents, number of accidents during typical production activities, number of accidents while walking or moving around, number of complaints from neighbors, number of complaints due to noise, number of complaints due to dust, number of complaints due to odor, number of improvement measures initiated.
Singh et al. (2007)	To offer a logical and representative way of structuring the decision problem and deriving priorities for sustainability performance of the steel plant by AHP	Steel/ Company	Economic performance	5 indicators: gross margin, net profit, average capital employed, total income, and investment in new processes and products.
			Environmental performance	15 indicators: particulate matter stack emission load, solid waste, energy consumption, raw material and water consumptions, carbon dioxide emission, power consumption, percentage green cover of total plant area, specific hazardous waste generation, specific heavy metals discharge load, and average noise level in the periphery of plant.
			Society performance	12 indicators: fatal accidents, employees trained, expenditure on peripheral development, employee satisfaction, quality of life, employment generation, non-discrimination, diversity and opportunity, child, forced labor and human rights issues, concern for local communities, and customer health and safety.
			Organizational governance	12 indicators: Leadership, Strategic planning and resource management; Cost competitiveness; Management tools; Innovation and knowledge management; Technology and Investment; Human resource management; Order generation, market development and customer satisfaction; Materials management; Research and development; Process management; Information technology
			Technical aspect	14 indicators: Coke rate; BF productivity; Labor productivity; Export tonnage ratio; Defects; Special grades production (%) of saleable steel; New product development (% of saleable steel); Market performance (% increase in domestic share with previous year); Customer satisfaction index; Savings through suggestions and QC projects; Cost reduction; Equipment availability; Order compliance; No. of complaints
Yazdi (2014)	To propose a general framework for sustainability assessment by AHP	Steel/ Company	Economic performance	4 indicators: production value of crude steel and total, product sales, raw material costs and fixed wages
			Environmental performance	7 indicators: CO_2 emissions, water supply for operation, water effluents, COD effluent, chemical substances, by-product recycling into resources, investments in environment facilities
			Social performance	5 indicators: injury cases, fatality cases, lost-time injury frequency rate, training hours, and number of female workers
Si et al. (2010)	To evaluate the environmental sustainable capability by AHP	Coal/ Regional	Economic aspect	3 indicators: per capita GDP, increase in rate of GDP and rate of recovery.
			Environmental situation	10 indicators: the damage or pollution by coal mining such as coal gangue, coal ash, TSP, SO_2, NO_x, pH of river, DO, COD, SS, noise, pH of soil and heavy metals in soil.
			Resource protection	4 indicators: reuse of subsidence surface, recycle of waste, annual forestation, and coverage of green belt.
Boggia and Cortina (2010)	To assess sustainability of a certain area by MCDM	public policy/ municipality level	Socioeconomic indicators	9 indicators: Population density; Unemployment rate; Women's unemployment rate; Work-related accident; Index of higher education; Index of tourist attraction; Index of demographic dependence; Active businesses; Available income

(continued on next page)

Table 1 (*continued*)

Previous study	Main objective	Product/ Scale	Selected Criterion	Sustainability indicator
			Environmental indicators	9 indicators: CO2 emissions; Artificial surface areas; Fragmentation index; Electric power use; Waste separation; Drinking water use; Total potential loads; Certified firms; Certified public institutions;
Yaylacı and Düzgün (2016)	To assess sustainability of the mining sector plans by AHP	Coal/ project- and strategic-level	Economic aspect	6 indicators regarding production amount of sellable products; Produced goods or services; land acquisition cost; Recovery of reserve; The number of families need to change their traditional source of income; the number of local families benefiting from the mining sector;
			Environmental aspect	12 indicators regarding resource left; land area needed to be rehabilitated; forest damaged; Amount of land disturbed due to mining operations; Total area of permitted development; Total land area newly opened for extraction activities; newly opened land area; The number of sites on environmentally protected or sensitive areas; Loss of arable land; Amount of land consumption; Area change from greenfield to brownfield; Total waste extracted
			Social aspect	6 indicators regarding resettlement of communities; number of households resettled; number of archaeological sites affected; vehicle accessibility negatively affected by settlements; new land acquisition; local population thinking/ observing the mining sector as a potential source of conflicts at the local level in terms of environmental issues.

comparatively few studies combining AHP and fuzzy integrated judgment applied to sustainability assessment of mineral resources (Su et al., 2010).

The fuzzy AHP evaluations introduced by Chang (1996), which uses triangular fuzzy numbers (TFNs) for the pairwise comparison scale and the extent analysis method for the synthetic extent values of pairwise comparisons, has been used in a large number of diverse applications due to the simplicity of its implementation (Kahraman, 2008). This is, because, among the various shapes of fuzzy numbers, TFNs are the most popular (Ali et al., 2012; Gao et al., 2012) due to (i) the simplicity and linearity of the triangular membership function, involving only three parameters, (2) the permission from TFNs in relatively simple implementation of the fuzzy arithmetical operations (Calabrese et al., in press), and (3) it can be readily used to represent and handle linguistic variables (Dubois and Prade, 1980; Hanss, 2005). In applications, fuzzy solutions using TFNs are proven to be very effective for solving decision-making problems where the available information is imprecise (Krohling and Campanharo, 2011). However, the fuzzy AHP proposed by Chang (1996) is only useful to compare TFNs by expressing the highest intersection point of membership functions (Wang et al., 2008). It may derive zero weights for the elements, possibly leading to the incorrect prioritization of these elements (Wang et al., 2008; Calabrese et al., 2013, 2016). This approach is inappropriate because it indicates that these zero-weight elements are unnecessary in the sustainability hierarchy. In order to overcome this problem, Calabrese et al. (2013) developed Chang's fuzzy AHP evaluations based on the means of fuzzy comparison matrices. The means of the positive lower value, positive middle value and positive upper value of each converted fuzzy judgment are positive values, apparently.

2.2. *The proposed iSAF*

The proposed assessment framework of iSAF includes nine methodological steps with the details of specific purposes and activities in each step which are shown in Fig. 1.

Step 1- determination of ultimate goal and objectives: In this study, the final goal is to reach sustainability of the mining sector at national and global scales; the objective is to find out the actions which should/ shouldn't been taken to effectively improve the sustainability.

Step 2, Step 3, Step 4, Step 5 are to select the appropriate and significant criteria and indicators in each criterion for constructing the sustainability hierarchy, which appropriately describing not only the sustainability concept but also the actual situation of the mining sector in the target area. Selection of the appropriate criteria and indicators describing the actual issues are essential, because the mining sector has highly conflicting characteristics with the concept of sustainability (Kirsch, 2009). Details of those steps are as following.

Step 2-Explore the actual situation: is to have better understandings of the main issues in the mining sector via intensively reviewing a series of previous studies, which are related to the actual impacts from mining activities on human well-being in the target areas.

Step 3-Constructing a primary sustainability hierarchy: is to construct a primary sustainability hierarchy including sustainability goal, criteria and indicators based on the results of the previous steps. The characteristics and levels of each component (criteria and indicators) are regulated by MCDM and AHP concepts.

Step 4- Consultation: is to consult the relevant stakeholder's opinions of generally rating the relative importance of the criteria and indicators into the final sustainability goal. In this step, face-to-face discussions and/or questionnaire-based surveys can be used to consult the opinions.

Step 5- Final sustainability hierarchy: Based on the results of *Step*

4, we select the suitable criteria and the number of significant indicators to construct the final sustainability hierarchy. Because time-consuming, costly and useless assessment processes may result from the selection of irrelevant indicators and more than the necessary number of significant indicators (Graymore et al., 2008; Moles et al., 2008). How many significant indicators are considered as an appropriately manageable number? Interestingly, Moles et al. (2008) suggested that using twenty significant indicators in an assessment is reasonable because it is not too few causing significant information exclusion problems and not too many leading to time and available data difficulties. To this end, iSAF takes 20 significant indicators as the appropriately minimum number of substantial indicators to build up the final sustainability hierarchy.

Step 6-Expert's pairwise judgments: is to consult the experts in making the series of pairwise comparisons among criteria with respect to the final sustainability goal and among indicators with respect to the corresponding criterion, based on the linguistic variables of fuzzy AHP concept. The appraisal is carried out in the form of a questionnaire-based interview.

The triangular fuzzy conversion scale proposed by Chang (1996) with 6 linguistic variables and the corresponding triangular fuzzy reciprocal scales are shown in Table 2a. However, Chang's scale may make decision makers difficult to distinguish two variable terms of "*just equal*" and "*equally important*". That is the reason why iSAF modified this scale in a more suitable way. iSAF uses only one variable of "*equal*" to express that two attributes are equally important. Table 2b in this study shows the modified triangular fuzzy conversion scale with 5 distinguished linguistic variables and the corresponding triangular fuzzy reciprocal scales. The *equal* rating indicates that two attributes are equally important. The *weak* rating indicates that one attribute is slightly more important than the other. The *fairly strong* rating indicates that one attribute is fairly more important than the other. The *very strong* rating indicates that one attribute is strongly more important than the other. The *absolutely strong* rating indicates that one attribute is absolutely more important than the other. Each of the linguistic ratings is given a corresponding fuzzy performance and the corresponding reciprocal fuzzy performances based on the following rule:

If the triplet (l, m, u) is the fuzzy performance, the corresponding reciprocal one is $(1/u, 1/m, 1/l)$. In this case, the middle value, m, is selected as the arithmetic mean of the lower value, l, and the upper one, u. The fuzzy performance thus can be expressed by the interval of (l, u).

From the beginning, iSAF uses a fuzzy-oriented questionnaire to consult relevant stakeholder's opinions. To answer the questionnaire, the respondents simply use the following linguistic variables: "*equal*", "*weak*", "*fairly strong*", "*very strong*", and "*absolutely strong*" to express their preferences.

Step 7- Consistency analysis: After getting the series of comparisons from the stakeholders, the linguistic variables are converted into their corresponding conversion and reciprocal fuzzy scales, generating to a series of interval reciprocal comparison matrices (IRCM). We can consider fuzzy AHP evaluation as a black box, the input for this box is the IRCM and the output is the relative weights of criteria and local weights of indicators in each criterion. The sensitivities of iSAF are (1) the appropriate list of criteria and indicators and (2) the consistent IRCM from the survey. Checking whether these IRCMs are acceptably consistent is essential, because the more these IRCMs are acceptably consistent, the more the fuzzy AHP derived weights are reliable. Adapted from Saaty (2000) and Fang (2009), the method to check whether IRCM consistent is described as follows:

It is assumed that n is number of indicators to be compared and a decision-maker provides an IRCM as named as matrix A:

$$A = \begin{bmatrix} 1 & \cdots & [l_{1n}, u_{1n}] \\ \vdots & \ddots & \vdots \\ [l_{n1}, u_{n1}] & \cdots & 1 \end{bmatrix} \tag{1}$$

where l_{ij} and u_{ij} are the lower and upper values of a fuzzy performance when the indicator i is compared to the indicator j; $l_{ij} \le u_{ij}$, $l_{ij} = 1/u_{ji}$ and $u_{ij} = 1/l_{ji}$ are the features of A. $i,j = 1, ..., n$.

A is considered as an acceptably consistent matrix if its two crisp reciprocal comparison matrices, B, and C given by (2) are both acceptably consistent.

Let $B = (b_{ij})_{n\times n}$ and $C = (c_{ij})_{n\times n}$ where

$$b_{ij} = \begin{cases} u_{ij} & \text{if } i < j \\ 1 & \text{if } i = j \\ l_{ij} & \text{if } i > j \end{cases}, \text{ and } c_{ij} = \begin{cases} l_{ij} & \text{if } i < j \\ 1 & \text{if } i = j \\ u_{ij} & \text{if } i > j \end{cases} \tag{2}$$

Considering one crisp reciprocal comparison matrix, B: $RI(B)$ is a random index depended on the size of the reciprocal matrix B as presented in Table 3.

$$CI(B) = (\lambda_{max}^{B} - n)/(n-1) \tag{3}$$

$$CR(B) = CI(B)/RI(B) \tag{4}$$

where λ_{max}^{B} is the largest eigenvalue of the matrix B. According to Saaty (2000), Cheng and Li (2001a), and Kannan et al. (2008), the reciprocal matrix B is acceptably consistent if its consistency ratio, $CR(B)$, is in the

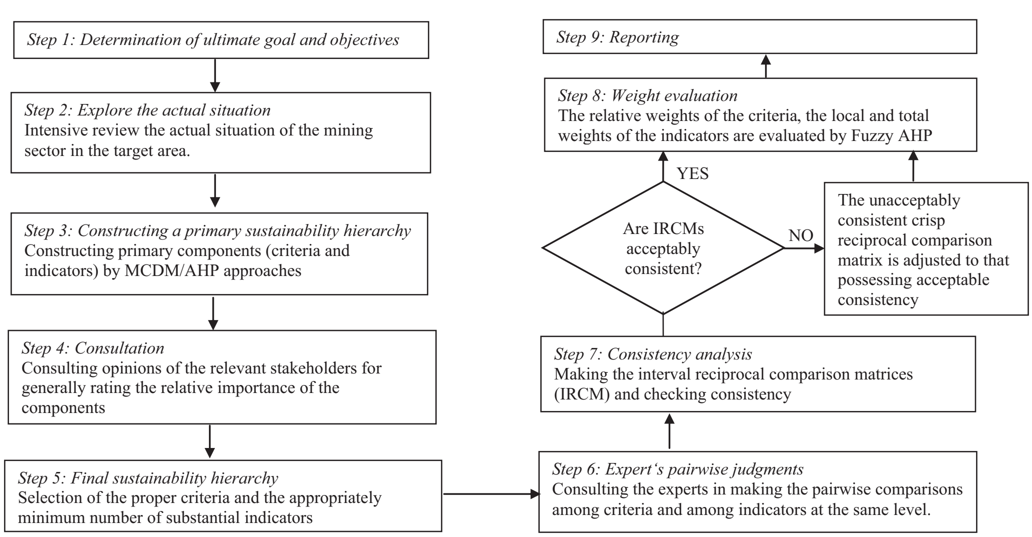

Fig. 1. The nine steps in iSAF for the mining sector at national and global scales.

Table 2
(a) Triangular fuzzy conversion scale (Chang, 1996).

No.	Linguistic variable	Triangular fuzzy conversion scale	Triangular fuzzy reciprocal scale
1	Just equal	(1, 1, 1)	(1, 1, 1)
2	Equally important	(2/3, 1, 3/2)	(2/3, 1, 3/2)
3	Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
4	Fairly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
5	Strongly more important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
6	Extremely more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

(b) Modified triangular fuzzy conversion scale in this study.

No.	Linguistic variable	Triangular fuzzy conversion scale	Triangular fuzzy reciprocal scale
1	Equal	(1, 1, 1)	(1, 1, 1)
2	Weak	(1, 3/2, 2)	(1/2, 2/3, 1)
3	Fairly strong	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
4	Very strong	(2, 5/2, 3)	(1/3, 2/5, 1/2)
5	Absolutely strong	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

range of values corresponding to the order of the matrix as shown in Table 4. Similarly, C is acceptably consistent of $CR(C)$ are in the acceptable consistent range.

In the conventional AHP approach and its applications, in order to deal with unacceptably consistent comparison matrices, the methods normally used were to repeatedly conduct the judgments until the acceptably consistent ones were obtained (Saaty, 2000; Shen et al., 2015); or another method was to consider the equal weights (Yazdi, 2014). However, the former is unfeasible and the latter is likely to make the survey's results useless. Therefore, if there is any unacceptable consistent crisp reciprocal comparison matrix, B or/and C, making A unacceptably consistent, it is necessary to adjust to that possessing acceptable consistency, in which the initial information from the inconsistent IRCM is kept as much as possible (Fang, 2009). The method of this appropriate adjustment is described by Zeshui and Cuiping (1999).

Step 8-Weight evaluations: the relative weights of the criteria and the indicators are derived by the fuzzy AHP evaluations. In order to avoid zero weight situation, iSAF uses the fuzzy AHP evaluation developed by Calabrese et al. (2013) with the suitably modified triangular fuzzy conversion scale presented in *Step 6* previously. The relative weights of the indicators in each criterion are referred as local weights. The product of the local weights and the relative weights of the corresponding criteria are referred as the total weights, presenting how much important the indicators are with respect to the sustainability goal.

Finally, *Step 9-reporting* is to interpret the results and to give recommendations for improving the sustainability of the mining sector.

3. iSAF application for the mining sector of APEC economies

3.1. APEC's mining sector and its sustainable development issues

APEC has twenty-two members, which includes both the developed and developing economies. The concept of sustainable development has become an important objective of policy makers in the mining sector in APEC since the meeting in July 1996 in the Philippines. Throughout the history of human development, there have been numerous studies regarding the mining situation of the APEC region. Among these, the important ones are those by R.H. Chen et al. (2015a), J.F. Chain et al. (2015b), Costa and Scoble (2006), Franks et al. (2011), Giurco and Cooper (2012), Laurence (2011), Luthra et al. (2015), Milanez and de Oliveira (2013), Mudd, (2007, 2010), Shen et al. (2015), Su et al. (2010) and Onn and Woodley (2014). These studies focus mainly on general sustainable development issues as well as some specific mining industries, such as coal or steel. Even though most developing countries already have environmental standards and guidelines for management of hazardous and toxic wastes, the mining sector does not comply with these standards due to a lack of strict law enforcement, monitoring capability and skilled human resources (United Nations, 2016). Therefore, exchanging and harmonizing information among APEC economies regarding improving sustainability for the mining sector could be an effective alternative (United Nations, 2016).

Table 3
The mean consistency index of randomly generated matrices.
Source: Adapted from Saaty (2000).

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54

3.2. A sustainability assessment framework for the mining sector of APEC economies

In order to deal with the sustainability assessment framework at national and global scales for the mining sector regarding all mining products, a list of criteria and important indicators should be carefully selected. Employing the AHP concept and sustainability indicators in sustainable development issues and specifically for the mining sector from the previous related researches (Azapagic, 2004; Boggia and Cortina, 2010; Krajnc and Glavic, 2005; Si et al., 2010; Singh et al., 2007; Worrall et al., 2009), the primary sustainability hierarchy has the first level of sustainable development for mining sector as the final goal. The second level consists of four basic sustainability criteria, three of which are economic development, environmental protection, and social performance. Technological development has been added as the fourth criterion as a trial. The economic development criterion includes 19 indicators; the environment protection criterion is expanded into 24 indicators; the social performance criterion is composed of 8 indicators, and the technological development criterion comprises 6 indicators. Totally, the primary hierarchy consists of 4 criteria and 57 sustainability indicators, as shown in Table A.1 in Appendix A.

In this study, there were two surveys conducted for the duration of the APEC 2010 Project.

3.2.1. The first survey

The objective of the first survey was to ask the respondents to provide the relevant information of the indicators and to rate the relative importance of the criteria and indicators in the primary hierarchy to the sustainability goal using scores. As the results of the first survey, we have collected supportive responses from the representatives of eight APEC economies including the developed economies (Australia, Japan, and Korea) and the developing ones (Thailand, the Philippines, Vietnam, Malaysia, and Indonesia). Among the results

Table 4
Acceptable range of consistency ratio (CR) values.
Source: Adapted from Cheng and Li (2001a), Kannan et al. (2008) and Saaty (2000).

The order of matrix	3	4	Higher than 4
Acceptable range of *CR* values	(0.0–0.05)	(0–0.08)	(0–0.1)

from this primary selection, the technological criterion was removed, since data regarding most of the indicators in this criterion are unavailable, especially in the cases of developing economies. With the target of twenty significant indicators, thirty-seven less important indicators of the primary hierarchy were taken out. Consequently, the three main criteria including economic, environmental, and social performance with 9, 8, and 3 indicators, respectively, were selected to construct the final sustainability hierarchy.

3.2.2. The second survey

The second survey was conducted at the Workshop of "*Balancing competing demands of mining community and environment to achieve sustainable development in mining sector*" in September 2010 in Seoul, Republic of Korea. This second fuzzy-oriented questionnaire survey was to ask the experts to make a series of pairwise comparison judgments among criteria and indicators. There were 24 experts from various APEC members such as Australia, Japan, China, Peru, Vietnam, Thailand, Malaysia, the Philippines, Taiwan, Chile, and Mexico. These experts have many years' experience working in mining companies, mine reclamation and rehabilitation, mine closure, and mining government policies. Regarding the sampling size, Cheng and Li (2001b) mentioned that it is not necessary to consider a large number of experts to participate in the judgment process of AHP approach. The judgments from a small group of key decision-makers of an industry could be considered sufficient to make the results reliable. So that the judgments made by the 24 highly experienced experts in the mining sector of APEC are adequate to make these results appropriately reliable. The majorities of the 24 results from the second survey are selected to create the final reciprocal comparison matrices. A.cri, A.eco, A.envi, and A.soci are these IRCMs among the three criteria, among the nine economic indicators, among the eight environmental indicators and among the three social indicators, respectively, shown in Table B.1, Table B.2, Table B.3, and Table B.4 in Appendix B.

4. Results and discussion

Combined concepts of MCDM/AHP and fuzzy logic with an indicator basis, which were deemed suitable to deal with the multi-faceted and unstructured problems were identified in this study. This finding is similar to the ones in Govindan (2015) and Govindan et al. (2015). In the indicator basis, the unstructured sustainability problem can be structured by a number of significant criteria and a manageable number of significant indicators with their own importance contributed to the sustainability goal. Using this combined concept, the complex sustainability situation can be analyzed on the whole and/or individually via analyzing those criteria and indicators independently.

4.1. A suitable sustainability hierarchy for the mining sector of APEC

4.1.1. Economic performance criterion (S_1)

The purpose of the economic criterion is to assess the significance levels of the mining sector, deciding those aspects that best reflect the economic contribution and the indicators for best assessing its economic performance. In this category, 9 significant sustainability indicators were selected. As shown in Table 5, these selected indicators mainly address the mining import and export situation, the budget allocation for the mining sector, the investment for training, community resettlement and mine closure. These 9 indicators appropriately cover the economic contribution from the mining sector.

4.1.2. Environmental performance criterion (S_2)

The goal of the environment criterion is to assess the significance levels of the mining sector, deciding those aspects that best reflect the sector's environmental impacts and the indicators for best assessing its environmental sustainability performance. In this category, 8 significant sustainability indicators were selected. As shown in Table 5, these selected indicators mainly address the energy consumption as the main input sources for mining operations and the discharges into the environment including waste disposal, particle emission, greenhouse and acid gas emission, noise pollution, and the actual mine closure and rehabilitation situation. These 8 indicators appropriately cover the main environmental impacts from the mining sector.

4.1.3. Social performance criterion (S_3)

The goal of the social criterion is to assess the significance levels of the mining sector, deciding those aspects that best reflect the social impacts and the indicators for best assessing its social sustainability performance. In this category, 3 important indicators including the number of mining employees per year (S_{31}), the number of fatalities at mining sites (S_{32}) and the number of compensated occupational problems caused by mining activities (S_{33}), were indispensably considered and selected to evaluate the social performance. These three indicators appropriately cover the main social situation.

Consequently, the final sustainability hierarchy including the three selected criteria and twenty sustainability indicators for the mining sector of APEC are presented in Table 5.

4.2. Consistency verification

The consistency ratios of all the IRCMs after getting the responses from the second survey are shown in Table 6. Compared to the acceptable level provided in Table 4, a pair of consistency ratios (*CRs)* of 0.000 and 0.003 indicates that the judgment among the three criteria is acceptably consistent because these *CR*s were in the range of acceptable values. The similar results were shown in the comparison judgments among the indicators in each criterion. A pair of *CR*s of 0.043 and 0.043 indicates that judgment among the economic indicators was acceptably consistent; a pair of *CR*s of 0.067 and 0.022 indicates that the judgment among the environmental indicators was acceptably consistent; and lastly, a pair of *CR*s of 0.036 and 0.019 indicates that the judgment among the social indicators was acceptably consistent. The results suggest that the fuzzy logic and fuzzy AHP approach with a suitably modified conversion scales support decision-makers in making the pairwise comparisons with confidence. It was apparent that fuzzy AHP provided support to the decision-makers for assigning more confident pairwise comparison judgments. This finding is important because the more these judgments were acceptably consistent, the more the weights derived by fuzzy AHP evaluation were reliable. Especially, this finding is economically meaningful because successfully obtaining acceptably consistent judgments is the most practically-time-consuming and complicated (Bui et al., 2016). The consistency verification would be even more interesting if there were some unacceptably consistent IRCMs, which should have been treated by appropriately adjusting the unacceptable consistent crisp reciprocal comparison matrix to the acceptable consistent one. To this end, iSAF could be a suitable framework for preventing the uncertainty and vagueness of decision-making judgments in AHP applications.

4.3. Identification of the significant indicators for sustainability improvement

The weights of the indicators in each criterion and the weights of three criteria are shown in Table 7. The sustainability significance in percentage of the indicators in the corresponding criterion and in total is also presented.

In terms of economic performance, Fig. 2 shows that four indicators (S_{12}, S_{14}, S_{17} and S_{18}) have slightly higher significance percentages than others. S_{18} has the highest percentage of 13%. This suggests that the funds for mine closure and rehabilitation of the whole site are vital for any mining project to make sure that all mine wastes are controlled in a manner that produces safe and non-polluting landforms. This finding provides useful advice for developing economies in their limited legal frameworks, because serious

Table 5
Final sustainability indicator set for mining sector of APEC economies.

Criterion	Indicator	Short explanation	Explanation (Unit)
Economic performance (S_1)	S_{11}	Total import payments	Total payment for importing mining products/year (Million USD/year)
	S_{12}	Total export earnings	Total earning from exporting mining products per year (Million USD/year)
	S_{13}	Allocation of Fiscal Year Budget	Allocation of Fiscal Year Budget to mining sector (Million USD/year)
	S_{14}	GDP Contribution	Contribution of mining industry to GDP per year (at constant price) (%)
	S_{15}	Total investment	Total investment per year for mining industry (Million USD/year)
	S_{16}	The training investment	The amount of training investment per year for mining workers (Million USD/year)
	S_{17}	Community resettlement investments	Investments per year for resettlement communities (Million USD/year)
	S_{18}	Mine closure/rehabilitation fund	Total fund for mine closure and mine rehabilitation (Million USD/year)
	S_{19}	Foreign direct investment	Total foreign direct investment per year for mining sector (Million USD/year)
Environment performance (S_2)	S_{21}	Total energy consumption	Total amount of energy consumption for mining sector per year (TOE/year)
	S_{22}	Total waste disposal	Total waste disposal per year (Tones/year)
	S_{23}	Greenhouse gas emission	The amount of greenhouse gas emission from mining operation per year (Mt CO_2/year)
	S_{24}	Acid gas emissions (NO_x, SO_2, etc)	The amount of acid gas emissions (NO_x, SO_2, etc) from mining operation per year
	S_{25}	Particle emissions	Emissions of particles from mining operation per year (%)
	S_{26}	Noise pollution	Percent of noise pollution exceeding national standard from mining activities (%)
	S_{27}	Total closed/ rehabilitated mining sites	Total number of mining sites closed and/or habilitated per year
	S_{28}	Complaints	Total number of complaints related to living condition form residents per year
Social performance (S_3)	S_{31}	Mining employees	Number of mining employees per year
	S_{32}	Mining fatalities	Number of fatalities at work in mining industry per year
	S_{33}	Compensated occupational problems	Number of compensated occupational problems caused by mining activities per year

environmental problems may occur due to inappropriate mine closure and rehabilitation. Similarly, in terms of environmental performance, Fig. 3 shows that one of the significant factors with the highest percentage of 14% is S_{21}, followed S_{22} and S_{24} with the comparable percentages of 13%. This suggests that it is important not only to control energy consumption as a key input source, but also to minimize the disposal of waste to the surroundings as much as possible to effectively improve the environmental sustainability. Interestingly, Figs. 2 and 3 show that all of the percentages of the economic and environmental indicators were higher than 10% and there were only small differences (4% as the maximum) among these sustainability significances in the corresponding criteria. This indicates that all the economic and environmental indicators were the significant factors that needed improvement to effectively enhance the economic and environmental sustainability performances.

In contrast, there were substantial differences among the significance levels of the social indicators displayed in Fig. 4. There were considerable differences among the weights of the social indicators, entirely differed from both the economic and environmental indicators. The most significant factor is the number of fatalities at work in mining industry per year (S_{32}) with the highest percentage of 51.2%; followed by S_{33} with the smaller percentage of 28.5% and S_{31} with the smallest percentage of 20.3%. The social sustainability predominantly depends on reducing the number of fatalities at work and relatively depends on the compensation for occupational accidents and the mining employee contribution. This result is similar to one of the Choi (2015)'s findings that revealed the accidents at mining sites are the most important factor to improve the social sustainability. In order to improve social sustainability, stakeholders need to focus on safety issues by the integrated consideration of safe working conditions, raising public awareness of safety, and corporate social responsibility.

The sustainability significances of all the indicators in a global view are presented in Fig. 5. The economic, environmental, and social indicators are displayed in red, blue and yellow, respectively. In order to improve sustainability of the mining sector, safe working conditions and reducing the number of fatalities at work are given the highest priority, followed by S_{33}, S_{31}, S_{18}, S_{17} and S_{14} (Table 5) which have significance percentages higher than the average value of 5.0% of all the

Table 6
Consistency analysis.

	Matrix A.cri (3×3)	Matrix A.eco (9×9)	Matrix A.envi (8×8)	Matrix A.soci (3×3)
λ_{max}^{B}	3.000	9.508	8.658	3.037
λ_{max}^{C}	3.003	9.507	8.217	3.020
CR(B)	0.000	0.043	0.067	0.036
CR(C)	0.003	0.043	0.022	0.019
Consistency	Acceptable	Acceptable	Acceptable	Acceptable

Table 7
The weights of the criteria and indicators based on fuzzy AHP evaluations.

Weights of Criteria	Indicators	Local weights	Total weights	Sustainability significance (%)	
				In each criteria	In total
Economic performance (S_1)	S_{11}	0.095	0.040	10%	4.0%
	S_{12}	0.116	0.049	12%	4.9%
	S_{13}	0.101	0.042	10%	4.2%
	S_{14}	0.120	0.050	12%	5.0%
0.42	S_{15}	0.100	0.042	10%	4.2%
	S_{16}	0.107	0.045	11%	4.5%
	S_{17}	0.119	0.050	12%	5.0%
	S_{18}	0.128	0.054	13%	5.4%
	S_{19}	0.112	0.047	11%	4.7%
Environmental performance (S_2)	S_{21}	0.143	0.042	14%	4.2%
	S_{22}	0.133	0.039	13%	3.9%
	S_{23}	0.124	0.036	12%	3.6%
	S_{24}	0.132	0.038	13%	3.8%
0.29	S_{25}	0.113	0.033	11%	3.3%
	S_{26}	0.117	0.034	12%	3.4%
	S_{27}	0.120	0.035	12%	3.5%
	S_{28}	0.119	0.034	12%	3.4%
Social performance (S_3)	S_{31}	0.203	0.059	20.3%	5.9%
0.29	S_{32}	0.512	0.148	51.2%	14.8%
	S_{33}	0.285	0.083	28.5%	8.3%

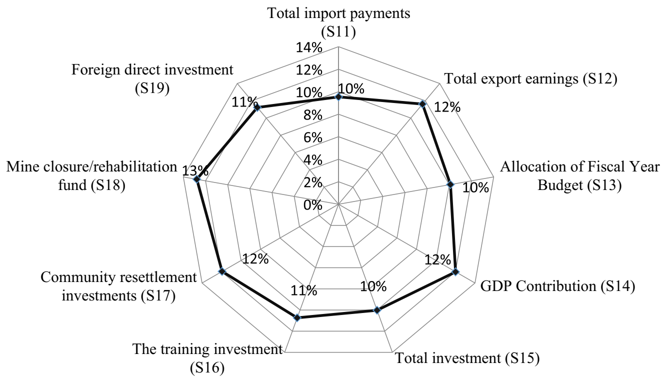

Fig. 2. Significance levels of the indicators under the economic criterion.

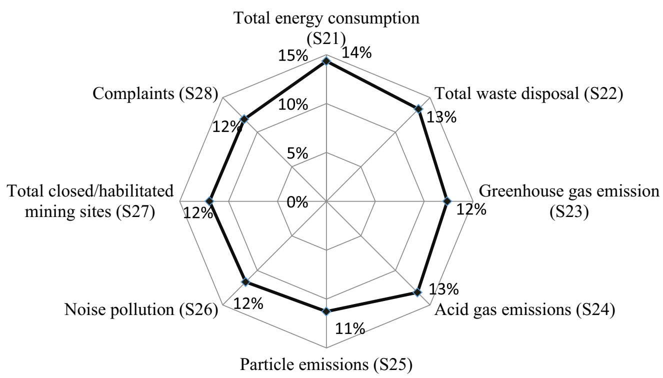

Fig. 3. Significance levels of the indicators under the environment criterion.

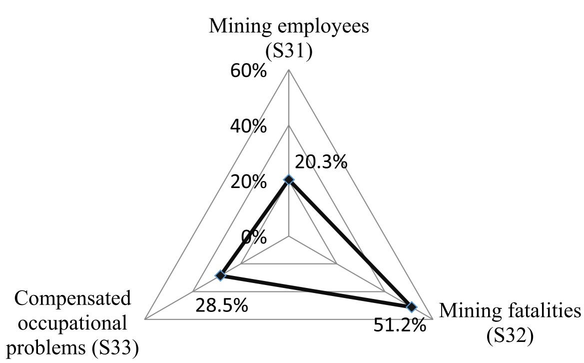

Fig. 4. Significance levels of the indicators under the social criterion.

indicators. The other indicators, which have significance percentages less than 5.0% are also important factors to some degree since their significance percentages are bigger than 3.0%.

However, it is apparent that the dominant weight proportions are mainly seen in the social indicators, resulted from the big differences among the number of indicators in three criteria. The social criterion has only three indicators while the economic and environment criteria have nine and eight indicators, respectively. Therefore, in this study, it is suggested that there is a need to ensure the number of indicators from criterion to criterion to remain consistent.

5. Conclusion

In order to assess the sustainability of the mining sector of APEC economies, in this study, an indicator-based sustainability assessment framework at global and national scales is proposed. In this framework, fuzzy logic was utilized to adequately deal with the uncertainty and vagueness of human expressions. The conventional fuzzy scales were suitably modified in the proposed framework to facilitate confident decision-making. Furthermore, in order to avoid repeatedly conducting the judgment until the acceptably consistent one is obtained, iSAF implemented an innovative theory to deal with unacceptably consistencies in judgments.

In iSAF application for the mining sector of APEC economies, two expert-opinion surveys were conducted during the APEC 2010 Project. In the primary survey, three significant criteria including economic, environmental and social criteria and twenty important indicators were selected. In the second survey, a series of pairwise comparison judgments among the criteria and indicators at the same level of the hierarchy were made by the experts to decide the weights of all the components. It was apparent that fuzzy AHP with the suitably modified conversion scales provided a key support to the decision-makers in making judgments with confidence, because all the judgments were acceptably consistent. iSAF was also capable of dealing with unacceptably consistent IRCMs. To this end, iSAF could be a suitable framework for coping with the uncertainty and vagueness of decision-making judgments in AHP applications and effectively prioritize the significant sustainability components.

From the application, fuzzy AHP approach with the suitably modified conversion scale is appropriate not only for handling the uncertainty in human preferences but also for highlighting the more important factors that should be invested to improve sustainability. Among the criteria, the indicators of the social criterion have the dominant weight proportions, resulting from the large differences among the number of indicators in the three criteria. The most significant factor in the social performance is reducing the number of

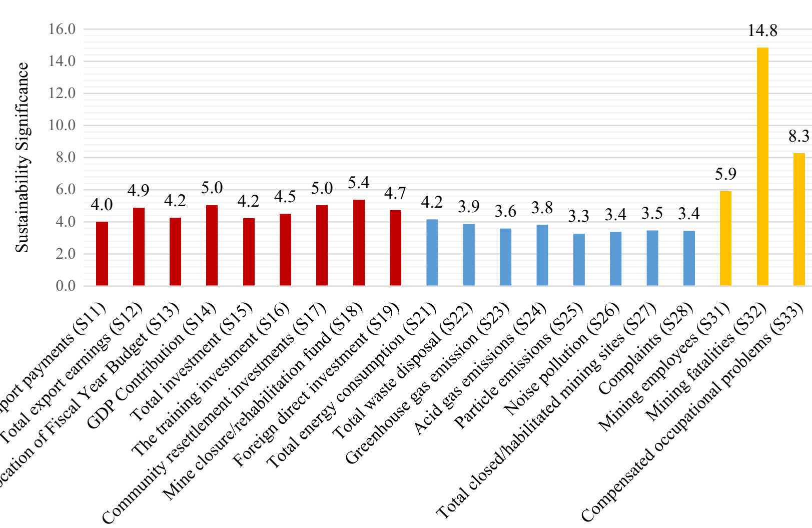

Fig. 5. Significance levels of the sustainability indicators in total.

fatalities at work. In the economic and environment criteria, all the indicators have significance percentages larger than 10% and there are just small differences among the indicators. This indicates that all the economic and environment indicators are almost equally important. Specifically, funds for mine closure and rehabilitation indicator was the most important factor in the economic criterion, suggesting that the investment for mine rehabilitation and closure is vital for any mining project. In the environment criterion, the most significant factor is the total energy consumption. From the global point of view, in order to improve sustainability for the mining sector, the safety issues and reducing the number of fatalities at work are given the highest priority, followed by the compensation of the occupational problems with smaller priority, and the other indicators are relatively important factors. The results obtained from this study are fundamental and useful for further researches on sustainability assessments of the mining sector at national and global scales.

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Appendix A

See Table A.1.

Table A.1
Four-primary criterion and fifty seven-primary indicator set.
Source: Adopted from Azapagic (2004), Krajnc and Glavic (2005), Singh et al. (2007), Boggia and Cortina (2010) and Si et al. (2010).

No.		No.	
	Economic development (19 indicators)		
1	The amount of domestic mineral consumption/ year	11	The amount of investment in employee training and education program/year
2	Number of type of mining products/ year	12	The amount of mining employment costs/year
3	Total amount of mining products /year	13	Total amount of foreign direct investment (FDI) /year for mining/ year
4	Income from mining/year	14	Total investment for mining business/year
5	Total earning(without tax and interest) of mining business/year	15	Total investments into resettlement communities
6	Total amount of mining products imported /year	16	Total taxes and royalties paid
7	Total amount of mineral export earning/ year	17	Fines paid for non-compliance (economic, environmental and social)
8	The amount of Fiscal Year Budget allocated into mining sector/year	18	Total investment for environmental protection program/year
9	Number of countries for selling mining products/year	19	Total fund for mine closure and rehabilitation/year
10	Mining contribution to GDP/year		
	Environment protection (24 indicators)		
1	Amounts of primary mineral resources that need to be extracted	13	Total amount emissions of greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6)
2	Total waste discharged (non-saleable material) /year	14	Total amount emissions of acid gases (NO_x, SO_2…)
3	Total amount of products' yield per year	15	Percentage amount emissions of particles exceeding national standard/ year
4	Total amount of chemicals used for mining business/ year	16	Total amount toxic emissions (heavy metals, dioxins, crystalline, silica…)/year
5	Total amount of water used for mining business/ year	17	Total volume of water discharged into waterways/ year
6	Total amount of energy consumption during mining operation/year	18	Total volume of tailings/ year
7	Ratio of total number of mines closed and mine abandoned	19	Total discharges of substances with liquid effluents enables
8	Ratio of total number of mining sites rehabilitated and total number of mines closed	20	The amount of solid waste generated in the extraction and production activities
9	Total area of land rehabilitated/ Total land area occupied by mining operation	21	Total number of prosecutions for environmental non- compliance
10	Number of awards for rehabilitation	22	Total number of sites certified to an EMS (e.g. ISO14001/EMAS…)
11	Number of sites officially designated for biological recreational or other interest as a result of rehabilitation	23	Total number of external complaints related to noise, road
12	Total number of species under a threat of extinction in areas affected by operation	24	Percentage amount of noise pollutants exceeding national standard/year
	Social performance (8 indicators)		
1	Number of mining Employees per year	5	Percentage of women employed in mining companies
2	Labor/management: Number of complaints from employee to employers	6	Total number of health and safety complaints from local communities
3	Number of fatalities at work	7	Having the regulation to require resettlement of communities
4	Number of compensated occupational diseases	8	Number and type of instances of non-compliance with regulations concerning customer health and safety, the fines assessed for these breaches
	Technological development (6 indicators)		
1	Ratio between the amount earning from mining export and total earning from mining business.	4	No. of complaints regarding to quality of mining products from customers
2	Number of special grades productions from mining	5	Advanced Equipment availability (%)
3	Market performance (% increase in domestic share with previous year)	6	% of budget Government invested for technology development per year

Appendix B

See Tables B.1–B.4.

Table B.1
Interval reciprocal comparison matrix (A.cri) for three criteria.

	S_1	S_2	S_3
S_1	(1, 1)	(3/2,5/2)	(3/2, 5/2)
S_2	(2/5, 2/3)	(1, 1)	(1, 1)
S_3	(2/5, 2/3)	(1, 1)	(1, 1)

Table B.2
Interval reciprocal comparison matrix (A.eco) for the indicators in the economic performance.

	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}
S_{11}	(1, 1)	(1, 1)	(1/2, 1)	(2/5, 2/3)	(1, 1)	(1, 1)	(1, 1)	(2/5, 2/3)	(1/3, 1/2)
S_{12}	(1, 1)	(1, 1)	(3/2, 5/2)	(1, 1)	(3/2, 5/2)	(1/2, 1)	(1, 1)	(2/5, 2/3)	(3/2, 5/2)
S_{13}	(1, 2)	(2/5, 2/3)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(2/5, 2/3)	(1, 1)
S_{14}	(3/2, 5/2)	(1, 1)	(1, 1)	(1, 1)	(3/2, 5/2)	(1, 1)	(1/2, 1)	(1/2, 1)	(1, 1)
S_{15}	(1, 1)	(2/5, 2/3)	(1, 1)	(2/5, 2/3)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 1)
S_{16}	(1, 1)	(1, 2)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 1)
S_{17}	(1, 1)	(1, 1)	(1, 1)	(1, 2)	(1, 1)	(1, 1)	(1, 1)	(3/2, 5/2)	(3/2, 5/2)
S_{18}	(3/2, 5/2)	(3/2, 5/2)	(3/2, 5/2)	(1, 2)	(1, 1)	(1, 1)	(2/5, 2/3)	(1, 1)	(3/2, 5/2)
S_{19}	(2, 3)	(2/5, 2/3)	(1,1)	(1,1)	(1,1)	(1,1)	(2/5, 2/3)	(2/5, 2/3)	(1, 1)

Table B.3
Interval reciprocal comparison matrix (A.envi) for the indicators in the environmental performance.

	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	S_{26}	S_{27}	S_{28}
S_{21}	(1, 1)	(3/2, 5/2)	(1, 1)	(3/2, 5/2)	(3/2, 5/2)	(1, 1)	(1, 1)	(1/2, 1)
S_{22}	(2/5, 2/3)	(1, 1)	(1, 2)	(1, 2)	(3/2, 5/2)	(1, 1)	(1, 2)	(3/2, 5/2)
S_{23}	(1, 1)	(1/2, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 2)	(1, 2)	(1, 2)
S_{24}	(2/5, 2/3)	(1/2, 1)	(1, 1)	(1, 1)	(1, 1)	(3/2, 5/2)	(3/2, 5/2)	(1, 1)
S_{25}	(2/5, 2/3)	(2/5, 2/3)	(1, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 2)	(1, 1)
S_{26}	(1, 1)	(1, 1)	(1/2, 1)	(2/5, 2/3)	(1, 1)	(1, 1)	(1, 1)	(1, 1)
S_{27}	(1, 1)	(1/2, 1)	(1/2, 1)	(2/5, 2/3)	(1/2, 1)	(1, 1)	(1, 1)	(1/2, 1)
S_{28}	(1, 2)	(2/5, 2/3)	(1/2, 1)	(1, 1)	(1, 1)	(1, 1)	(1, 2)	(1, 1)

Table B.4
Interval reciprocal comparison matrix (A.soci) for the indicators in the social performance.

	S_{31}	S_{32}	S_{33}
S_{31}	(1, 1)	(2/7, 2/5)	(2/5, 2/3)
S_{32}	(5/2, 7/2)	(1, 1)	(2, 3)
S_{33}	(3/2, 5/2)	(1/3, 1/2)	(1, 1)

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